Artificial Intelligence for Logistic Program Conference: May 17th - 18th 2023, Ottawa, Canada: abstract booklet / Conférence du Programme « L'Intelligence artificielle au service de la logistique » : 17 – 18 mai 2023, Ottawa, Canada: livret de résumés

https://doi.org/10.4224/40003097

NRC·CNRC

Artificial Intelligence for Logistic Program Conference

May 17th -18th 2023 – Ottawa, Canada

Abstract booklet

Conférence du Programme « L'Intelligence Artificielle au Service de la Logistique »

17 – 18 mai 2023– Ottawa, Canada

Livret de résumés

National Research Council Canada
Conseil national de recherches Canada

Canada

The National Research Council of Canada (NRC) is committed to supporting the scale ai cluster's goals through its Artificial Intelligence for Logistics program, which includes convener support in supply chain and logistics. The program also provides R&D expertise focused on next-generation technology issues to ensure Canadian excellence in logistics for the longer term. Using its national reach, the NRC program is creating linkages between stakeholders, and enabling the advancement of the technologies and firms that will make supply chain and logistics excellence a competitive advantage for Canada.

https://nrc.canada.ca/en/research-development/research-collaboration/programs/artificial-intelligence-logistics-program

Le Conseil national de recherches du Canada (CNRC) s'est engagé à appuyer les objectifs de la grappe scale ai par l'entremise de son programme Intelligence artificielle au service de la logistique, reliant des organisations dans les domaines de la chaine d'approvisionnement et de la logistique. Le programme tire parti d'une expertise en R-D axée sur les enjeux technologiques de la prochaine génération afin d'assurer l'excellence de la logistique canadienne à long terme. Fort de sa portée nationale, le programme crée des liens entre les intervenants et permet l'avancement des technologies et des entreprises qui fera de l'excellence dans la gestion de la chaîne d'approvisionnement et de la logistique un avantage concurrentiel pour le Canada.

https://nrc.canada.ca/fr/recherche-developpement/recherche-collaboration/programmes/programme-intelligence-artificielle-au-service-logistique

Table of contents/ Table des matières

Transportation & Warehousing

Biologically-Inspired Neural Representations Improve Reliability in Reinforcement Learning

Kathryn Simone †*, Madeleine Bartlett†, Nicole Dumont†, Jeff Orchard†, Terrence C. Stewart‡

† Cheriton School of Computer Science, University of Waterloo

‡ National Research Council of Canada, University of Waterloo Collaboration Centre

Waterloo, ON, N2L 3G1

Abstract

Reinforcement learning (RL) has become ubiquitous for logistics, such as for industrial process control and autonomous navigation applications [1]. Here, deep neural networks have become popular due to their ability to approximate complex dynamics as well as to learn to extract useful features of the input for learning. However, these models tend to suffer from performance instability, necessitating workarounds such as introducing early stopping [2], or learning rate decay or increasing the training batch size [3]. These characteristics are unacceptable for applications where unreliable performance can, for example, undermine a production schedule or threaten a human rescue mission. We hypothesize that the instability of deep networks is in part due to their capacity to continually refine their input features with additional training data when it may no longer be advantageous to do so. By this logic, constraining the feature representation would confer temporal stability in performance, as it would be impossible in such an architecture to undermine this fundamental function with increased training. To test this prediction, we leveraged biologically-inspired representations of the state using hexagonally-structured grid pattern features (which we call HexSSPs, previously demonstrated by our group on RL tasks [4]) in a single hidden-layer Advantage Actor-Critic (A2C) network and compared performance to a standard deep A2C benchmark implementation [5]. We observed comparable learning speed between the two models on both a dynamic control task and a navigation task when averaged over many independent model runs, but found much lower variability in terminal performance with the HexSSP implementation. This work is related to reports from others that hexagonally-structured representations applied to a deep network can improve learning in standard RL tasks [6], which we extend by demonstrating that comparable performance to a deep network can be achieved in a single-layer network using HexSSPs. These findings illustrate the advantages of feature engineering in neural network design, and pursuing biologically-inspired feature engineering in particular, for RL applications where reliability is mission critical.

Keywords: Reinforcement learning, grid cells, spatial semantic pointers

References

[1] Yan, Y., Chow, A. H., Ho, C. P., Kuo, Y. H., Wu, Q., & Ying, C. (2022). Reinforcement learning for logistics and supply chain management: Methodologies, state of the art, and future opportunities. Transportation Research Part E: Logistics and Transportation Review, 162, 102712.

[2] Prechelt, L. (2012). Early stopping—but when?. Neural networks: tricks of the trade: second edition, 53-67.

[3] Smith, S. L., Kindermans, P. J., Ying, C., & Le, Q. V. (2017). Don't decay the learning rate, increase the batch size. arXiv preprint arXiv:1711.00489.

[4] Bartlett, M. E., Stewart, T. C., & Orchard, J. (2022a). Biologically-based neural representations enable fast online shallow reinforcement learning. In Proceedings of the annual meeting of the cognitive science society (Vol. 44).

[5] Raffin, A., Hill, A., Gleave, A., Kanervisto, A., Ernestus, M., & Dormann, N. (2021). Stable-baselines3: Reliable reinforcement learning implementations. Journal of Machine Learning Research, 22 (268), 1-8

[6] Yu, C., Behrens, T. E., & Burgess, N. (2020). Prediction and generalisation over directed actions by grid cells. arXiv preprint arXiv:2006.03355.

Reinforcement Learning in Continuous Time and Space

Madeleine Bartlett†, Kathryn Simone†, Jeff Orchard†, Terrence C Stewart‡

† Cheriton School of Computer Science, University of Waterloo, Waterloo, ON, N2L 3G1, Canada
‡ National Research Council of Canada, University of Waterloo Collaboration Centre, Waterloo, ON, N2L 3G1, Canada

Abstract

Reinforcement Learning (RL) is a branch of machine learning which involves training neural networks to make decisions through a process of trial and error. RL can be particularly useful for solving problems in logistics. Logistics refers to the delivery of goods and services and can involve large state spaces. For example, in the case of transporting goods, the state space can consist of vehicle and customer locations, and information about traffic and weather conditions. Choosing an appropriate method for encoding state information is therefore an important consideration that can have a significant impact on whether the RL algorithm is able to efficiently learn a high-quality solution. This can potentially be overcome by representing continuous state spaces, rather than relying on finding the optimal resolution for discretizing the state. Similarly, identifying a discretized resolution for representing time can be difficult when dealing with dynamic and complex real-world environments. Therefore, having an RL network that operates in continuous time would have similar advantages. This project has involved developing methods for representing continuous space and time and evaluating them in terms of any advantages gained in the performance of RL algorithms. Our results showed that continuous space representations facilitate faster learning over discrete state representation methods [1,2]. Additionally, continuous state representations were found to be more robust to perturbations on the task [3]. Finally, we demonstrated the viability of a novel continuous-time variant on Temporal Difference (TD) learning [4]. Both of the methods developed for representing continuous space and time were biologically motivated. To represent continuous state variables, we adopted a model of grid cells for representing spatial information. Grid cells found in the medial entorhinal cortex (MEC) encode an agent's location in space, firing at regular intervals as the agent moves around its environment [5]. We created a model of these grid cells using Spatial Semantic Pointers (SSPs), a type of vector symbolic architecture that can represent continuous state information [6]. A specific type of SSP, Hexagonal SSPs (HexSSPs), employs an encoding matrix that is structured to model the activity of MEC grid cells [7]. These grid cells facilitated faster learning and were more robust to changes in the task compared to discrete tabular representations [1,2,3]. To address the problem of learning in continuous time we employed a recently developed, novel learning rule TD(θ). This rule employs Legendre Delay Networks (LDNs) [8] to encode the history of events. LDNs can store continuous-time input signals over fixed windows of time. TD(θ) involves integrating this input signal in order to obtain the event histories needed to update the learned values and policy. This rule was implemented and compared with a standard, discrete time learning rule (TD(n)) and shown to be effective in learning a policy on a task defined in discrete time [4].

Keywords: Reinforcement Learning, Continuous State Representations, HexSSPs, Spatial Semantic Pointers

References

[1] Bartlett, M., Stewart, T. C., & Orchard, J. (2022). Biologically-based neural representations enable fast online shallow reinforcement learning. In Proceedings of the Annual Meeting of the Cognitive Science Society (Vol. 44, No. 44).

[2] Bartlett M. E., Stewart T. C., and Orchard J. Fast Online Reinforcement Learning with Biologically-Based State Representations. In: Proceedings of the 20th International Conference on Cognitive Modeling (ICCM 2022). (2022)

[3] Bartlett M. E., Simone K., Dumont N., Furlong P. M., Eliasmith C., Orchard J., and Stewart T. C., Improving Reinforcement Learning with Biologically Motivated Continuous State Representations. Under review

[4] Bartlett M. E., Dumont N., Furlong P. M., and Stewart T. C. "Biologically-Plausible Memory for Continuous-Time Reinforcement Learning". In: Proceedings of the 20th International Conference on Cognitive Modeling (ICCM 2022). (2022)

[5] Hafting, T., Fyhn, M., Molden, S., Moser, M. B., & Moser, E. I. (2005). Microstructure of a spatial map in the entorhinal cortex. Nature, 436(7052), 801-806.

[6] Komer, B.; Stewart, T.C.; Voelker, A.R.; Eliasmith, C. A neural representation of continuous space using fractional binding. In Proceedings of the 41st Annual Meeting of the Cognitive Science Society; Cognitive Science Society: Montreal, QC, Canada, 2019

[7] Dumont, N., & Eliasmith, C. (2020). Accurate representation for spatial cognition using grid cells. In CogSci.

[8] Voelker, A., Kajić, I., & Eliasmith, C. (2019). Legendre memory units: Continuous-time representation in recurrent neural networks. Advances in neural information processing systems, 32.

Novelty Detection, Insect Olfaction, Mismatch Negativity, and the Representation of Probability in the Brain

P. Michael Furlong 1* , Kathryn Simone1, Jeff Orchard1, Terry Stewart2

1 Centre for Theoretical Neuroscience, University of Waterloo
2 National Research Council of Canada

Abstract

It is critically important for any cognitive agent to recognize their sensory stimuli as novel or unexpected. Different strategies may be applicable, depending on whether one is in a familiar situation (in which case one can safely rely on previously learned knowledge), or in a novel situation (in which case a more careful and exploratory strategy may be appropriate). In mammals, an example of this is seen in the Mismatch Negativity signal, a strong EEG signal that appears approximately 200ms after a surprising stimulus [1]. This seems to be an automatic process, occurring regardless of whether the participant is paying attention to the stimulus or not. This automaticity and the speed of the response suggests that this novelty detection is a simple and basic process that may be understood without involving the entire brain.

Furthermore, a specific neural circuit for novelty detection has also been identified in the insect brain. The MBON (Mushroom Body Output Neuron) α'3 neuron is consistently active in the presence of novel odours, and is silent for odours that have been previously encountered. The inputs to this neuron come from Kenyon Cells, which form a very sparse representation of the current odour, so each odour corresponds to a different (sparse) pattern of activity in these neurons. In [2], this system is compared to the computer-science idea of a Bloom Filter, a type of hashtable where input data is converted into a sparse representation, and then individual elements of that representation (i.e. the activity of the Kenyon Cells) are used to quickly determine whether the current input is likely to be novel or not. The core idea is to do this without requiring a complete database of every odour that has been previously observed; instead, use the overlap in the sparse representation as a fast estimate as for the input's novelty.

In this paper, we present a simple model of this novelty detection system that is compatible with the above idea, but interprets the computation being performed by the neurons in a slightly different way. Building on the work of [3], we suggest that the neurons (and the connection weights between them) are in fact representing a probability distribution (Fig. 1, A&B), and ``novelty'' is detected if the current input is highly unlikely according to that distribution. We show that a very simple learning rule, combined with a particular method for encoding information in neurons, results in a network that accurately estimates the observed probability distribution of different inputs, and that a single neuron (such as the MBON α'3 neuron) can use this distribution to signal novelty (Fig. 1, C).

Given this insect-based model, we then expand the system to encode information over time, and show that the very same model is capable of detecting the sort of temporal novelty that is the hallmark of the Mismatch Negativity signal in mammals (Fig. 1, D). This expanded system makes use of Legendre Memory Units (LMUs), a recurrent neural structure that has been mapped to Time Cells [4], temporal patterns in the cerebellum [5], and has been shown to improve performance on Machine Learning tasks over LSTMs [4] and Transformers [6].

Keywords: novelty detection; insect olfaction; mismatch negativity; neural representation; hyperdimensional computing; fractional binding; spatial semantic pointers; Bayesian inference

References

[1] Pazo-Alvarez, P., Cadaveira, F., & Amenedo, E. (2003). MMN in the visual modality: A review. Biological Psychology, 63(3), 199–236.

[2] Dasgupta, S., Sheehan, T., Stevens, C., & Navlakha, S. (2018). A neural data structure for novelty detection. Proceedings of the National Academy of Sciences, 115, 201814448.

[3] Furlong, P. M., & Eliasmith, C. (2022). Fractional binding in vector symbolic architectures as quasi-probability statements. In Proceedings of the Annual Meeting of the Cognitive Science Society (Vol. 44, No. 44).

[4] Voelker, A. R., Kaji´c, I., & Eliasmith, C. (2019). Legendre memory units: Continuous-time representation in recurrent neural networks. Advances in Neural Information Processing Systems, 15544–15553.

[5] Stöckel, A., Stewart, T. C., & Eliasmith, C. (2021). Connecting biological detail with neural computation: Application to the cerebellar granule-golgi microcircuit. Topics in Cognitive Science, 13(3), 515–533.

[6] Chilkuri, N., Hunsberger, E., Voelker, A., Malik, G., & Eliasmith, C. (2021). Language modeling using lmus: 10x better data efficiency or improved scaling compared to transformers. arXiv preprint.

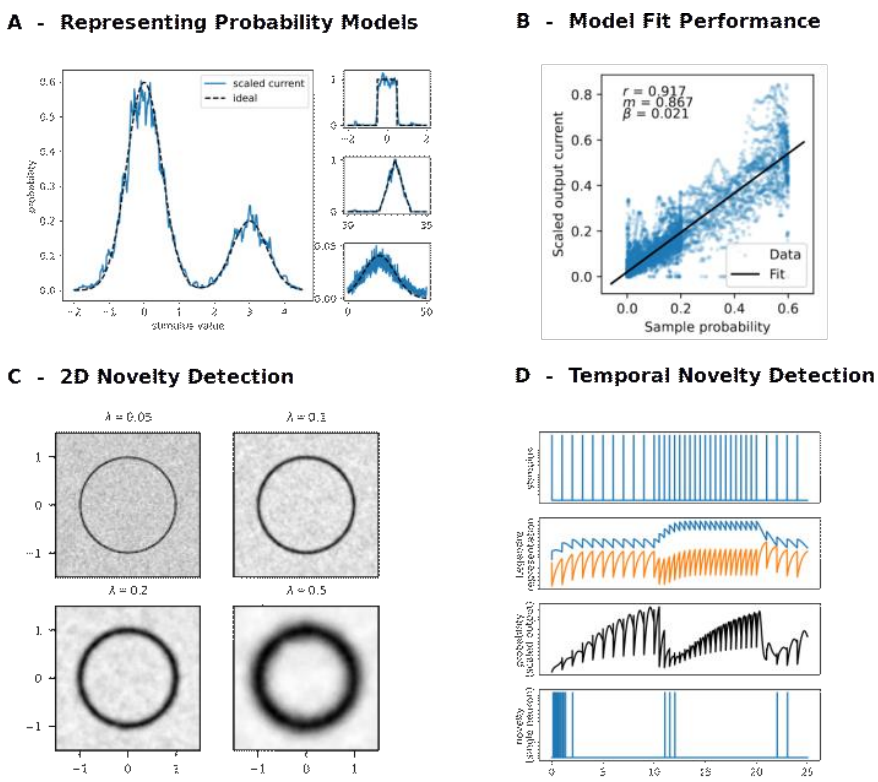


Figure 1. Panel **A** demonstrates representing different probability distributions using a single neuron. Panel **B** illustrates that the relationship between the neural representation and the represented probabilities is approximately linear (regression line shown in black). Panel **C** illustrates the representing a 2D circular distribution with a single neuron. Black indicates less novel stimuli. Panel **D** shows that by combining this representation with the Legendre Memory Unit, we can detect temporal novelty.

Aerial Visual-Inertial-LiDAR Dataset for Autonomous Navigation and Mapping Algorithm Development

Ravindu G. Thalagala*, Oscar De Silva, Awantha Jayasiri, George K.I. Mann, Arthur Gubbels, and Raymond G. Gosine

†Intelligence Systems Lab, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL, Canada.

Abstract

In recent years, the last-mile delivery of goods has been a topic of investigation due to the increasing demand and the development of autonomous navigation technology [1]– [3]. To address this issue, large corporations such as Amazon, Google, and FedEx [4] are already testing autonomous systems. For safety reasons and higher payload carrying capacity, full-scale aerial platforms have been explored for this purpose [5]. This work presents datasets captured from a unique sensing suite designed for aiding research on outdoor autonomous navigation on full-scale and small-scale aerial platforms. The sensing suite developed as an interchangeable payload unit that can attach on a Bell412 aircraft and a DJI M600 drone, equipped with a 360-degree field of view 3D LiDAR, two monocular global shutter cameras, an IMU, a real-time kinematic (RTK) enabled GNSS module, and an Nvidia Jetson Xavier AGX GPU as the processing unit. The datasets contain front and nadir facing monocular images, IMU measurements, 3D LiDAR point clouds, and high-precision RTK-GNSS-based ground truth. The areas covered by the datasets are not typically available in public aerial datasets, such as urban towns, highways, airports, hillsides, waterfronts, and prairies. Delete this paragraph and replace it with your abstract - The Artificial Intelligence for Logistic Program Conference will take place physically in Ottawa, from May 17 to 18, 2023. This event will bring together numerous leaders in research and government, as well as Canada's most accomplished students. They showcase Canada's ingenuity, innovation and leadership in intelligent systems and advanced information and communications technology.

Fig. 1 - The developed multi-sensor payload unit attached to a fixed turret under the nose of Bell 412 Advanced Systems Research Helicopter (ASRA) in NRC-FRL facility is shown in the top-left and top-right shows payload unit attached to a DJI M600 Drone.

The datasets captured provide a resource for the development of autonomous navigation and mapping algorithms, leveraging state-of-the-art AI techniques. The fusion of visual, LiDAR, and inertial data enables the development of accurate navigation solutions [6]– [8], which can be enhanced using AI-based aiding modules. For instance, system model learning algorithms can be used to learn the dynamics of the platform and improve its prediction accuracy [9], while measurement noise parameter learning algorithms can be used to estimate and compensate for measurement errors [10]. Unmodeled system dynamics learning algorithms can be used to detect and compensate for any discrepancies between the model and the actual system behavior [11]. In addition to navigation and mapping, the dataset can also be used to develop safety-critical features of full-scale aerial platforms, such as object detection, obstacle avoidance, segmentation, and classification algorithms [12], [13]. These features can be developed using deep learning algorithms, which have shown success in the field of computer vision. For instance, object detection algorithms based on convolutional neural networks (CNNs) can be used to detect and track objects of interest in the environment [14], while segmentation algorithms based on fully convolutional networks (FCNs) can be used to segment the environment into different classes (e.g., ground, buildings, vegetation, water bodies) [15].

Therefore, the datasets presented in this work provide a resource for the development of autonomous navigation and mapping algorithms, leveraging the advances in AI and machine learning. They can help accelerate research in this field and enable the development of reliable autonomous systems for a wide range of applications, including last-mile delivery, search and rescue, and environmental monitoring.

Keywords: Dataset, Aerial Autonomy, Full-scale Aircraft, Drones, Visual Inertial LiDAR Odometry and Mapping

References

[1] V. R. Miranda, A. M. Rezende, T. L. Rocha, H. Azp´urua, L. C. Pimenta, and G. M. Freitas, "Autonomous Navigation System for a Delivery Drone," Journal of Control, Automation and Electrical Systems, vol. 33, no. 1, pp. 141–155, 2 2022.

[2] Z. Pei, T. Fang, K. Weng, and W. Yi, "Urban On-Demand Delivery via Autonomous Aerial Mobility: Formulation and Exact Algorithm," IEEE Transactions on Automation Science and Engineering, pp. 1–15, 6 2022.

[3] J. P. Aurambout, K. Gkoumas, and B. Ciuffo, "Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities," European Transport Research Review, vol. 11, no. 1, pp. 1–21, 12 2019.

[4] N. Boysen, S. Fedtke, and S. Schwerdfeger, "Last-mile delivery concepts: a survey from an operational research perspective," OR Spectrum 2020 43:1, vol. 43, no. 1, pp. 1–58, 9 2020.

[5] "How Xwing Is Bringing End-To-End Autonomous Flight." [Online]. Available: https://simpleflying.com/how-xwing-isbringing-end-to-end-autonomous-flight/

[6] T. Shan, B. Englot, C. Ratti, and D. Rus, "LVI-SAM: Tightly-coupled Lidar-Visual-Inertial Odometry via Smoothing and Mapping," 4 2021.

[7] T. Shan, B. Englot, D. Meyers, W. Wang, C. Ratti, and D. Rus, "LIO-SAM: Tightly-coupled Lidar Inertial Odometry via Smoothing and Mapping," IEEE International Conference on Intelligent Robots and Systems, pp. 5135–5142, 7 2020.

[8] T. M. Nguyen, S. Yuan, M. Cao, Y. Lyu, T. H. Nguyen, and L. Xie, "NTU VIRAL: A visual-inertial-ranging-lidar dataset, from an aerial vehicle viewpoint:," https://doi.org/10.1177/02783649211052312, vol. 0, no. 0, pp. 1–11, 11 2021.

[9] A. Saviolo, G. Li, and G. Loianno, "Physics-Inspired Temporal Learning of Quadrotor Dynamics for Accurate Model Predictive Trajectory Tracking," IEEE Robotics and Automation Letters, vol. 7, no. 4, pp. 10 256–10 263, 10 2022.

[10] B. Or and I. Klein, "A Hybrid Model and Learning-Based Adaptive Navigation Filter," IEEE Transactions on Instrumentation and Measurement, vol. 71, 2022.

[11] A. Lederer, Z. Yang, J. Jiao, and S. Hirche, "Cooperative Control of Uncertain Multi-Agent Systems Via Distributed Gaussian Processes," IEEE Transactions on Automatic Control, 2022.

[12] X. Yang and P. Wei, "Autonomous Free Flight Operations in Urban Air Mobility with Computational Guidance and Collision Avoidance," IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 9, pp. 5962–5975, 9 2021.

[13] A. P. Cohen, S. A. Shaheen, and E. M. Farrar, "Urban Air Mobility: History, Ecosystem, Market Potential, and Challenges," IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 9, pp. 6074–6087, 9 2021.

[14] A. Mauri, R. Khemmar, B. Decoux, M. Haddad, and R. Boutteau, "Lightweight convolutional neural network for realtime 3D object detection in road and railway environments," Journal of Real-Time Image Processing, vol. 19, no. 3, pp. 499–516, 6 2022.

[15] Z. Yang, H. Yu, Y. He, W. Sun, Z. H. Mao, and A. Mian, "Fully Convolutional Network-Based Self-Supervised Learning for Semantic Segmentation," IEEE Transactions on Neural Networks and Learning Systems, 2022.

AI powered Visual Loop Closure and Place Recognition System for VLOAM

Kusal B. Tennakoon[a] , Oscar De Silva[b] , Awantha Jayasiri[c] , George K. I. Mann[d] , Raymond G. Gosine[e]

a , b , d , e Intelligent Systems Lab , Memorial University of Newfoundland, St.John's, NL, Canada.
c Aerospace Research Centre ,National Research Council Canada, Ottawa, ON, Canada

Abstract

The autonomy of Vertical Take-off and Lift (VTOL) vehicles can significantly enhance the safety and operational efficiency of future logistical and personal transport operations. While most current autonomous navigation systems primarily rely on the Global Positioning System (GPS), it proves unreliable in areas such as densely-packed urban environments or zones with GPS dropout, dilution of precision, or potential GPS spoofing. Visual Lidar Odometry and Mapping (VLOAM) offers a robust, multi-sensory navigation solution that localizes a moving platform in an environment while simultaneously creating a map of the traversed area. VLOAM combines inertial, Lidar, and visual sensor information to deliver highly accurate odometry estimation without GPS assistance.Project AI4L-112-1 aims to develop an AI-powered VLOAM navigation system that can further improve the GPS-denied navigation capabilities of a VTOL aircraft.

Visual information proves advantageous for navigation due to its ability to recognize visually distinct features and locations in an environment. Place recognition, loosely defined as the identification of an environment within a specific map using captured sensory information, helps reduce the overall drift of the VLOAM system. It involves determining whether the vehicle is at a known or previously visited map location and updating the navigation solution accordingly. For real-time implementation, the place recognition system must be fast, memory-efficient, and accurate.

Using pre-existing geo-referenced maps like Google Maps for VTOL visual place recognition offers several advantages, including high accuracy, increased efficiency, wide availability, reduced computational requirements, and easy integration with other systems through standard APIs. Recently, CNN-based approaches have gained preference over conventional feature-based methods for visual place recognition of VTOL aircraft due to their numerous benefits. CNNs automatically learn and extract relevant features from input images, adapt to various environments and conditions, demonstrate superior performance in image recognition and localization tasks, can be fine-tuned and optimized using large amounts of labeled data, and are more robust in handling environmental changes.

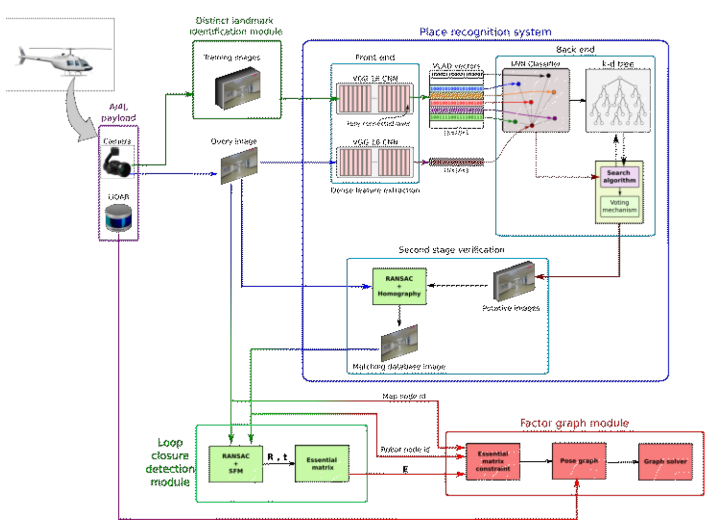


Figure 1 : Key stages of the MUN NRC VLOAM place recognition module

Figure 1 illustrates the key stages and modules of the MUN NRC VLOAM place recognition system. It extracts the output of the last fully connected layer of an off-the-shelf VGG-16 network, transforming it into a dense feature extractor for the place recognition system. This feature extractor forms the system's front end. The extracted features are converted into VLAD (Vector of Locally Aggregated Descriptors) and normalized, training a Nearest Neighbor (NN) classifier using a k-d tree data structure. The system processes a query image by extracting features, converting them into VLAD vectors, and normalizing them. These VLAD vectors are then matched against reference images based on distance through NN classification. The matching process includes a searching and voting routine that selects the best matching reference image based on votes. The place recognition system also features a second-stage verification module, a distinct landmark identification module, and a loop closure detection module, all of which contribute to its overall performance.

This study evaluates the performance, execution speed, and disk space requirements of the MUN NRC VLOAM place recognition system using online benchmarks, DJI M600, and Bell 412 flight data.

Keywords: Place recognition, Loop closure, geo-localization, VTOL, CNN

Improving Feature Tracking using Semantic Segmentation and Object Detection

Salaheldin Bilila *, Oscar De Silva, George Mann, & Ray Gosine

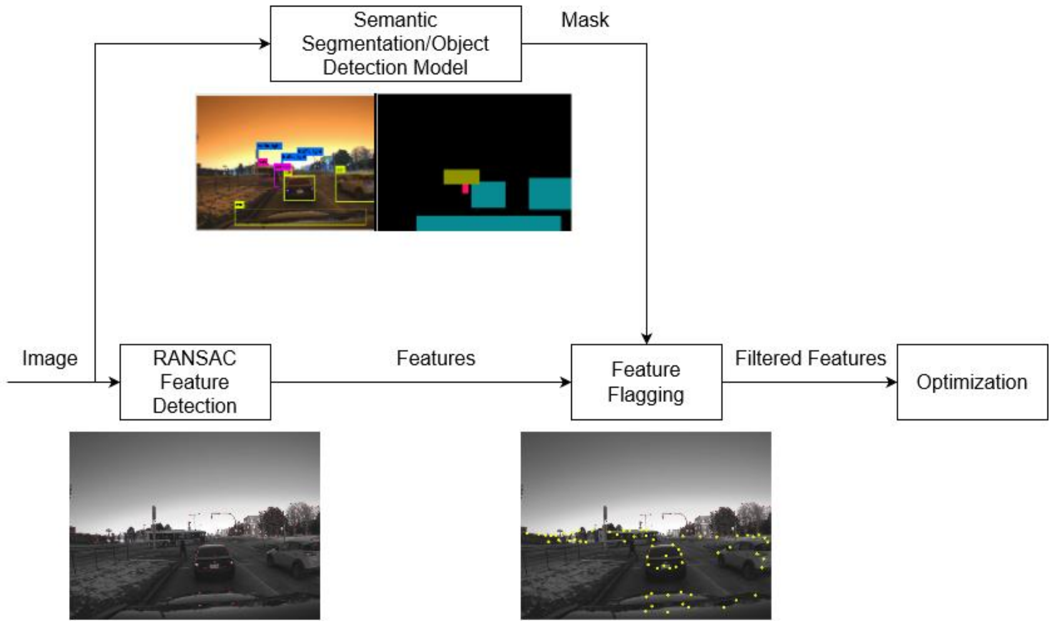
Intelligent Systems Lab, Memorial University of Newfoundland, St. John's, Canada

Abstract

In recent years, autonomous drone navigation algorithms have achieved great results in terms of accuracy and robustness. This allowed for applications in various fields such as delivery, surveillance, aerial photography, mapping, surveying, etc. Visual Inertial Odometry (VIO) and Visual Lidar Odometry and Mapping (VILOAM) algorithms helped solve some of the challenges in this field by combining information from cameras, inertial measurement units (IMU) and LiDARs. However, they suffer in performance in some cases since the visual component operates on the assumption that the observed environment is static. The robustness of these algorithms is affected by moving objects such as vehicles and waves on water. This takes place due to the use of random sample consistency (RANSAC) which extracts distinct feature points from images. However, if the view is largely obstructed by a moving object or a moving surface, such as when flying over water or driving in traffic, these features degrade the performance of the RANSAC algorithm and lead to errors. Advances in computer vision and deep learning, especially in semantic segmentation and object detection, helped in developing models that would detect different objects and surfaces in the scene for identification and tracking purposes. This is crucial for safety critical ground targets in cases of landing and low altitude maneuvering.

In this paper, an AI-powered solution is presented that combines semantic segmentation and object detection models with the already integrated visual feature tracker in VIO systems. The semantic segmentation model is used to detect surfaces such as water, grass, paved area, etc. and the object detection model is used to detect moving objects such as cars, buses, pedestrians, etc. A mask is generated from the segmentation mask and the objects bounding boxes and the features are checked if they are in the detected mask. The unwanted features of moving objects are flagged after classifying them into different classes using the models as moving and they are then omitted from the factor graph optimization solution. Our contribution is to reduce the overhead of running a deep learning moving object tracker separately from the VIO system and instead making use of general object detection and semantic segmentation models with the VINS-Fusion[1] feature tracker. That allows flexibility of using the deep learning models in other tasks such as landing zone detection or obstacle avoidance as well as enhancing the robustness of the system. It also enables the usage of any object detection or semantic segmentation model with the system as long as they output a greyscale mask to identify the different classes. Experimental work was conducted on the MUN-FRL dataset with GPS ground truth.

Keywords: Unmanned aerial vehicle (UAV), semantic segmentation, object detection, visual inertial navigation systems (VINS), feature tracking.



References

[1] T. Qin, P. Li, and S. Shen, "Vins-mono: A robust and versatile monocular visual-inertial state estimator," IEEE Transactions on Robotics, vol. 34, pp. 1004–1020, 8 2018.

Unsupervised Domain Adaptation for Aerial Semantic Segmentation using Adversarial Domain Adaptation: Analysis with AI4L NRC-MUN Project Data

Bennett Newhook *

† Memorial University of Newfoundland

Abstract

Adversarial domain adaptation (ADA) is a technique used to address domain shift problems in computer vision tasks. Domain shift occurs when there are significant differences in appearance and context between images from different domains. This can be due to changes in lighting conditions, sensor characteristics, or environmental factors. ADA techniques aim to mitigate these differences by learning a transformation that maps images from the source domain to the target domain in a way that preserves their semantic content.

Aerial semantic segmentation is a challenging computer vision task due to the significant differences in appearance and context between images from different domains; especially for real-world applications. In this work, we focus on applying ADA to aerial semantic segmentation and performing analysis using the real-world data captured during the AI4L NRC-MUN project.

The Semantic-Drone benchmark dataset consists of images captured by unmanned aerial vehicles (UAVs) in urban environments. The dataset contains four sub-datasets with varying degrees of difficulty, including variations in weather conditions, terrain types, and object types. The Holyrood dataset was captured during the AI4L NRC-MUN project. The dataset consists of aerial images of the Holyrood coastline captured by a DJI Mavic Pro drone.

The method consists of three training phases:

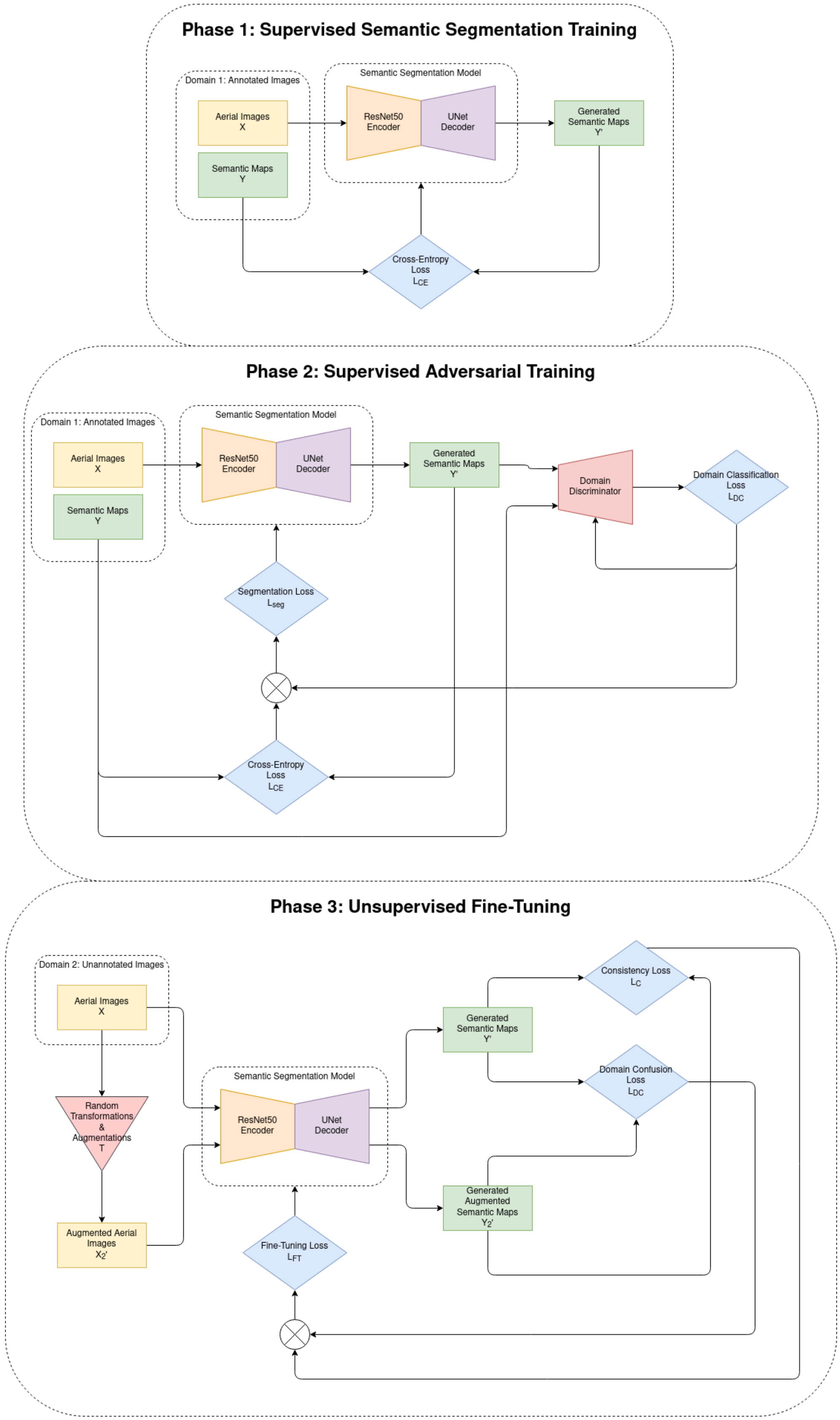
- Phase 1 - Supervised Semantic Segmentation Training: a semantic segmentation network is trained, built from a ResNet50 encoder pre-trained on the ImageNet dataset, and a UNet decoder. The semantic segmentation network is trained on the Semantic-Drone benchmark dataset to learn the features of aerial semantic segmentation.

- Phase 2 - Supervised Adversarial Training: an adversarial domain discriminator model is introduced, a separate network that guesses whether the output of the semantic segmentation network is real or fake. The domain discriminator's classification is used as a shared loss function for both models, forcing the semantic segmentation model to make better segmentation maps. The training is performed on the Semantic-Drone benchmark dataset.

- Phase 3 - Unsupervised Fine-Tuning: the adversarial domain discriminator is removed, and the semantic segmentation network is fine-tuned on the unlabeled Holyrood dataset from the AI4L NRC-MUN project. Random augmentations and transformations are applied to the aerial images and passed through the semantic segmentation network. The outputs of the semantic segmentation network are compared using consistency and domain confusion losses to enforce consistency of the outputs from the semantic segmentation network.

A comparative analysis between ADA and standard semantic segmentation models is performed on the Semantic-Drone and Holyrood datasets to demonstrate the value of ADA techniques for aerial semantic segmentation tasks. The performance of the ADA methods indicates the usefulness of learning domain-invariant features for tasks with high situational variance, such as aerial semantic segmentation. The implications of these findings can be utilized in other computer vision tasks with significant variance between domains and limited or unavailable training data.

Keywords: Computer vision, aerial semantic segmentation, unsupervised adversarial domain adaptation, Generative Adversarial Networks (GANs),


Phase 1: Supervised Semantic Segmentation Training
Domain 1: Annotated Images
Aerial Images X
Semantic Maps Y
Semantic Segmentation Model
ResNet50 Encoder
UNet Decoder
Generated Semantic Maps Y'
Cross-Entropy Loss LCE
Phase 2: Supervised Adversarial Training
Domain 1: Annotated Images
Aerial Images X
Semantic Maps Y
Semantic Segmentation Model
ResNet50 Encoder
UNet Decoder
Generated Semantic Maps Y'
Domain Discriminator
Domain Classification Loss LDC
Segmentation Loss Lseg
Cross-Entropy Loss LCE
Phase 3: Unsupervised Fine-Tuning
Domain 2: Unannotated Images
Aerial Images X
Random Transformations & Augmentations T
Augmented Aerial Images X2'
Semantic Segmentation Model
ResNet50 Encoder
UNet Decoder
Generated Semantic Maps Y'
Generated Augmented Semantic Maps Y2'
Consistency Loss LC
Domain Confusion Loss LDC
Fine-Tuning Loss LFT

AI Based Method for Landing Zone Detection

Nirasha Herath, Oscar De Silva, George K.I. Mann

Memorial University of Newfoundland

Abstract

Unmanned aerial vehicles, especially multi-rotor Vertical Take-Off and Landing (VTOL) vehicles, are becoming increasingly popular across various industries due to their ability to operate autonomously in complex and challenging environments. However, ensuring a safe landing without jeopardizing personnel or infrastructure remains a critical challenge. Although commercial drones can take off and land without operator input, selecting a suitable Landing Zone (LZ) is typically left to the operator. By automating the process of detecting a suitable LZ with a low gradient, obstacle-free, open support surface, and sufficient area for VTOL vehicles [1], the autonomous landing capabilities of drones can be enhanced, providing pilots with visual aids, and improving safety.

Autonomous detection of safe LZs by a VTOL presents a challenging problem, which has been addressed using various sensor data and approaches over the years. Initially, the classical mathematical modeling approaches were used [2], [3]. However, it was unsuccessful due to their rule-based nature and inability to learn and adapt to new data. With the technology advancement, researchers have employed CNN-based techniques for detecting safe LZs for VTOL vehicles [4], [5]. Even though CNN-based object identification and classification are well known, vision data lacks the exact depth information needed to detect LZs.

Recent studies on CNN-based Point Cloud Semantic Segmentation (PCSS) using aerial LiDAR have succeeded in classifying terrains and detecting safe LZs by eliminating the drawbacks of previous works [6]. PCSS could be performed using two approaches, namely, projection-based, and point-based.

The projection-based method is the process of projecting the 3D point cloud onto a 2D image using different intermediate representations like depth or intensity maps and applying 2D CNNs to classify the pixels into semantic categories. On the other hand, point-based methods operate directly on irregular, non-uniform 3D point clouds. According to the literature, point-based methods are more accurate which is a critical requirement in solving autonomous LZ detection problems. However, it is computationally expensive, memory intensive, and requires extensive optimization, making real-time implementation challenging. On the other hand, projection-based methods are faster, but their accuracy can be lower, especially when the resolution of the projection is low.

Thus, to address these limitations, this study proposes a novel method to improve the runtime of projection based PCSS for detecting safe LZs as in Fig. 01. The proposed method involves generating a point cloud map from the 3D point clouds obtained by the LiDAR sensor. After the map is generated, the points in it will be reprojected to a 2D image. As a result, the resolution of the projected image will be increased. This resultant 2D image will then be used for projection based PCSS, resulting in more accurate detection of safe LZs. This reprojection step will reduce the distance between the points in the projected image and improve the segmentation results.

By leveraging the outcome with VLOAM, the proposed method aims to provide a more effective and accurate approach in detecting safe LZs and develop a reliable localization and mapping method.

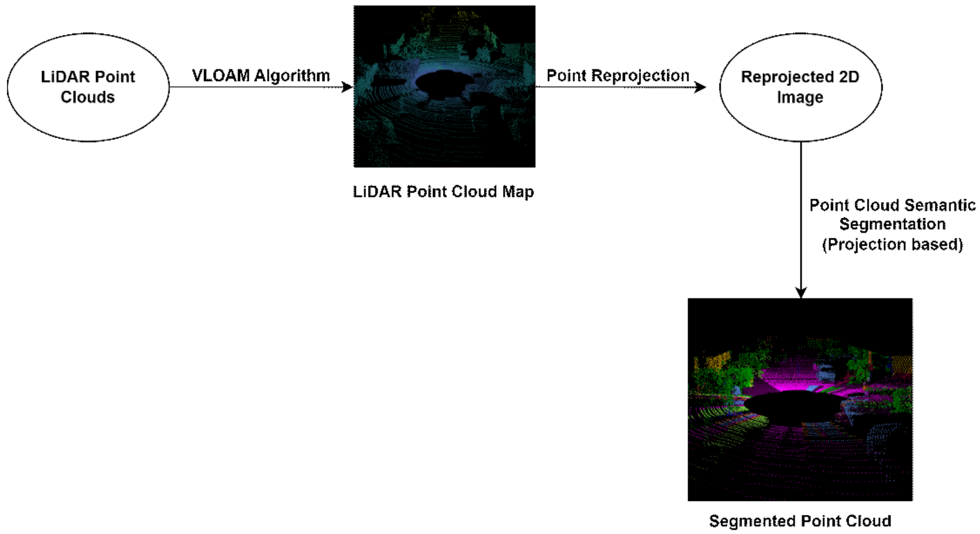


Figure 01: Proposed Landing Zone Detection Method

Keywords: Landing Zone Detection, Point Cloud Semantic Segmentation, Vertical Take-Off and Landing vehicles

References

[1] S. Scherer, L. Chamberlain, and S. Singh, “Autonomous landing at unprepared sites by a full-scale helicopter,” Rob. Auton. Syst., vol. 60, no. 12, pp. 1545–1562, 2012, doi: 10.1016/j.robot.2012.09.004.

[2] B. Bhanu, S. Lee, C. C. Ho, and T. Henderson, “Range Data Processing: Representation of Surfaces By Edges.,” Proc. - Int. Conf. Pattern Recognit., pp. 236–238, 1986.

[3] X. Y. Jiang, U. Meier, and H. Bunke, “Fast range image segmentation using high-level segmentation primitives,” IEEE Work. Appl. Comput. Vis. - Proc., pp. 83–88, 1996, doi: 10.1109/acv.1996.572006.

[4] R. Polvara, S. Sharma, J. Wan, A. Manning, and R. Sutton, “Autonomous Vehicular Landings on the Deck of an Unmanned Surface Vehicle using Deep Reinforcement Learning,” Robotica, vol. 37, no. 11, pp. 1867–1882, 2019, doi: 10.1017/S0263574719000316.

[5] S. Lee and Y. Kwon, “Safe Landing of Drone Using AI-based Obstacle Avoidance,” Int. J. Mech. Eng. Robot. Res., vol. 9, no. 11, pp. 1495–1501, 2020, doi: 10.18178/ijmerr.9.11.1495-1501.

[6] S. Atapattu, N. M. Balasooriya, O. de Silva, A. Jayasiri, G. Mann, and R. Gosine, “Landing zone identification using a hardware-accelerated deep learning module,” 77th Annu. Vert. Flight Soc. Forum Technol. Display, FORUM 2021 Futur. Vert. Flight, no. May 2022, 2021.

AI based method for Lidar Assisted Radar Super Resolution and Segmentation

Thakshila Thilakanayake, Oscar De Silva, Thumeera R. Wanasinghe, George K.I. Mann, and Raymond, G. Gosine

Memorial University of Newfoundland

Abstract

The recent developments in navigation sensors, Artificial Intelligence (AI) powered navigation payloads and GPS enable Vertical takeoff and landing (VTOL) vehicles to operate remotely and autonomously. Radar, LiDAR, and cameras are the primary sensor types used to gather information about the surroundings of the VTOL. LiDAR sensors provide accurate distance measurements with high-resolution point clouds. Additionally, LiDAR data can be used to detect and classify ground targets. However, LiDAR sensors are not robust to adverse weather conditions. The output of LiDAR is significantly affected, and the detection range is drastically reduced in rain, snow, mist, and fog conditions, potentially leading to misclassification of ground targets.

Previous studies [1]-[3] have focused on using classical filters, such as Kalman filters, and AI-based filters to reduce the effects of adverse weather conditions on LiDAR point cloud data. While these methods can reduce the adverse weather effects, they are unable to reconstruct the affected LiDAR point clouds. Other studies [4] have focused on using LiDAR and camera fusion sensor setups incorporated with deep learning-based methods to improve detection and classification performance. However, these methods are still not entirely robust to adverse weather conditions. Most of the currently used radar sensors have robustness against adverse weather conditions. Therefore, many studies [5] have employed radar sensors for ground target detection and classification. However, low-resolution 2D point clouds provided by radar systems in VTOLs are insufficient for accurate detection and classification of critical ground targets.

This study proposes a Generative Adversarial Network (GAN)-based method to super-resolve radar output using LiDAR. High-resolution LiDAR data collected under good weather conditions is used to train a GAN model that generates high-resolution output using the radar input. The dataset used for the training consisted of data collected in a variety of weather conditions using an automobile. Using this method, high-resolution data can be generated using radar when LiDAR is affected by adverse weather conditions.

The results of this study demonstrate that this method can effectively super-resolve radar output and is robust even under adverse weather conditions, such as snow, rain, and fog. Therefore, the super-resolved radar output can be employed in object detection, classification, and trajectory planning modules for obstacle-avoidance purposes when the LiDAR system in a vehicle is affected by adverse weather conditions. As future work, it is expected to extend the proposed method to generate high-resolution segmented output from the radar. See Figure 01. Additionally, it is expected to evaluate this model using data collected from VTOL vehicles.

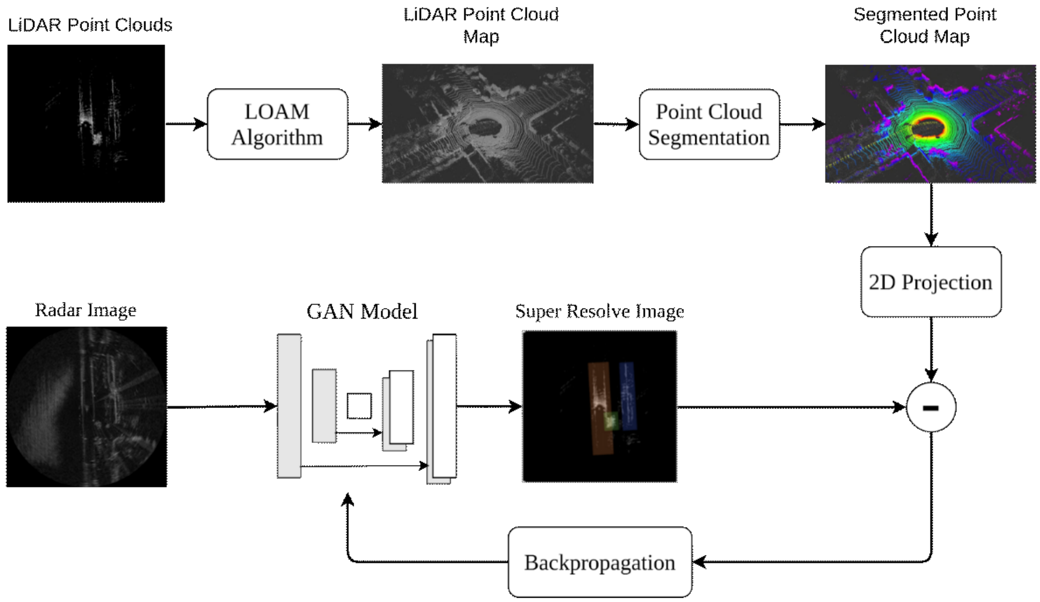


Figure 01: Proposed AI based method for Lidar Assisted Radar Super Resolution and Segmentation

Keywords: Radar Super Resolution, LiDAR segmentation

References

[1] Lin SL, Wu BH. Application of kalman filter to improve 3d lidar signals of autonomous vehicles in adverse weather. Applied Sciences. 2021 Mar 28;11(7):3018.

[2] Heinzler R, Piewak F, Schindler P, Stork W. Cnn-based lidar point cloud de-noising in adverse weather. IEEE Robotics and Automation Letters. 2020 Feb 10;5(2):2514-21.

[3] Heinzler R, Schindler P, Seekircher J, Ritter W, Stork W. Weather influence and classification with automotive lidar sensors. In2019 IEEE intelligent vehicles symposium (IV) 2019 Jun 9 (pp. 1527-1534). IEEE.

[4] Kim T, Ghosh J. Robust detection of non-motorized road users using deep learning on optical and lidar data. In2016 IEEE 19th international conference on intelligent transportation systems (ITSC) 2016 Nov 1 (pp. 271-276). IEEE.

[5] Hong Z, Petillot Y, Wallace A, Wang S. Radar SLAM: A robust slam system for all weather conditions. arXiv preprint arXiv:2104.05347. 2021 Apr 12.

Contact Simulation and Control of a Quadrotor Drone using a 3-DOF Haptic Device

Michael Farquharson*, Chantal Hutchison, Siamak Arbatani, József Kövecses,
† McGill University, Centre for Intelligent Machines
Bruno Chapdelaine, Michel Lambert
National Research Council

Abstract

The goal of this project is to create a semi-autonomous teleoperated drone for use in outside novel environments, performing maintenance on remote / hard-to-reach structures. The drone is to be controlled via a haptic device and support autonomous vertical surface landing. To accomplish this goal we are using a model predictive control (MPC) algorithm for controlling a quadrotor drone, utilizing a haptic device and force feedback. The MPC is made up of 5 main parts, the haptic device that the user interacts with, the bubble method navigation algorithm used with the haptic device, the reduced order model simulation of the drone, the full simulation of the drone, and the delay handling algorithm. The rest of the work presented here focuses on producing the expanded bubble method navigation algorithm, and the full drone simulation, then combining all the previous work to perform some experiments.

The internal dynamic modelling of a quadrotor drone is well established as shown by [1] and more. Although these methods can accurately represent the internal behaviour of the drone, they don't account for external stimuli. In this work, additional elements were added to the typical model, including a drag component, a crosswind component, and the ability for the drone to experience contact with both stationary planes and moving obstacles. This was accomplished using the Newton-Euler equations as explained here [2], allowing for the implicit inclusion of contact, reducing instabilities. Additionally, the drone simulation was also connected to the Haply, Inverse 3 device allowing a user to control the drone via position commands, and get force feedback from the system. To connect the infinite exploration space of the drone to the finite workspace of the Inverse 3, the bubble method navigation scheme was used [3]. However, this also had to be adjusted to allow continuous contact between the drone and obstacles. Finally, the previous system was connected to a hardware drone, the Bitcraze CrazyFlies 2.1. Experiments were completed testing different delays in information transfer between the three simulation components, testing for instability and edge points where the model breaks down. This first experiment had the Haply Inverse 3 connected to the simulation sending position commands and receiving force feedback. The simulation was connected to the hardware drone, sending desired position commands and receiving the drone's actual position. Later, a type of reduced-order model (ROM), a reduced interface model (RIM) component was added, allowing for a faster simulation for the haptic device to interact with, further reducing instabilities. [4] The final setup had the haptic device interacting with the RIM at 1-2kHz, sending position commands and receiving force feedback. The RIM then exchanged information, including the effective mass matrix, and the constraint Jacobian with the full simulation, which ran at 100-500Hz. Finally, position commands and actual positions were then sent and received with the hardware drone every 20ms.

Keywords: Drone, Quadrotor, Simulation, Haptic, Contact, RIM

References

[1] Luukkonen, Teppo. "Modelling and control of quadcopter." *Independent research project in applied mathematics, Espoo* 22.22 (2011).

[2] Peiret Gimenez, Albert. "Modelling and simulation of multibody systems with unilateral contact." (2019).

[3] Gallacher, Colin, James Harrison, and József Kövecses. "Characterizing device dynamics for haptic manipulation and navigation." *2015 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2015.

[4] Kerr, Liam, and József Kövecses. "Reduced Interface Models for Haptic Interfacing With Virtual Environments." *IEEE Robotics and Automation Letters* 7.4 (2022): 8683-8690.

Interactions between Systems with Different Operating Frequencies

Siamak Arbatani†, Chantal Hutchison†, Michael Farquharson†, József Kövecses†, Jason Michel Lambert* and Bruno Chapdelaine*

†Department of Mechanical Engineering, Centre for Intelligent Machines, McGill University, 817 Sherbrooke St. West, Montréal, QC, H3A 0C3, Canada

*Centre de technologies de fabrication en aérospatiale, Conseil National de Recherches du Canada, 2107 chemin de la Polytechnique, Montréal, QC, H3T-1J4, Canada

Abstract

In this study, we primarily investigate interactions between systems with critically different operating frequencies, focusing on the contact interaction between haptic feedback devices and virtual environments that include highly flexible systems. This is particularly relevant in the context of aerial robots for remote manipulation, where accurate and stable force feedback is essential for precise control and interaction with the environment. Haptic feedback devices typically function at relatively high frequencies, making real-time simulation of virtual environments, including flexible systems, a significant challenge. To address this challenge, we propose to use a method based on the reduced interface model (RIM) concept, which has been proven highly successful in various applications, such as its integration with a haptic feedback device for steering wheel control [1], and in other complex contact modeling scenarios [2]. The RIM concept has generally been demonstrated as efficient for enhancing the explicit co-simulation of multibody systems in complex multirate simulation environments. It approximates the responses of the subsystems with representative reduced models during a micro time step, reducing instability and inaccuracies in the results. At its core, the RIM represents the dynamics of the mechanical system in the contact subspace. In this work, we first present a method for computing the RIM for flexible mechanical systems represented based on the Absolute Nodal Coordinate Formulation (ANCF). We will employ this method to obtain stable contact interaction between the haptic feedback device and 3-dimensional ANCF elements modeling highly flexible virtual environments. This approach is particularly relevant for aerial robots involved in remote manipulation tasks, where accurate force feedback and stable interaction with the environment are crucial for successful operations. Results demonstrate stable haptic contact force rendering of the interactions with simulations running at 30-60 Hz and haptic device operating at frequencies higher than 4 KHz. This provides a solid foundation for improving the effectiveness of aerial robotic systems for remote manipulation tasks, enhancing their capabilities in various applications such as inspection, maintenance, and disaster response.

Keywords: Aerial robots for remote manipulation, Haptic feedback devices, Reduced Interface Models (RIM)

References

[1] Kerr L., K¨ovecses J. Reduced Interface Models for Haptic Interfacing With Virtual Environments. IEEE Robotics and Automation Letters, Vol. 7 (4), pp. 8683-8690, 2022.

[2] Peiret A., Gonz´alez F., K¨ovecses J., Teichmann M. Multibody System Dynamics Interface Modelling for Stable Multirate Co-Simulation of Multiphysics Systems. Mech. Mach. Theory, Vol. 127, pp. 52-72, 2018.

Time Delay and Stability in Haptics for Remote Robotic Operations

Chantal Hutchison *1, Siamak Arbatani1, Michael Farquharson1, Jozsef Kövecses1, Michel Lambert2 and Bruno Chapdelaine2

1Department of Mechanical Engineering, Centre for Intelligent Machines, McGill University, 817 Sherbrooke St. West, Montréal, PC, H3A 0C3, Canada

2Centre de technologies de fabrication en aérospatiale, Conseil National de Recherches du Canada, 2107 chemin de la Polytechnique, Montréal, PC, H3T 1J4, Canada

Abstract

Haptic systems are sampled-data systems which impart force feedback to users when interacting with a remote or simulated environment. The applications of such systems are many, including training simulators and teleoperation of remotely controlled robots. Haptic devices need to sample the virtual environment at a high frequency, typically on the order of 1000Hz, and with a low latency to render realistic interactions between the user and the environment. However, often the virtual environment outputs samples at much lower frequency (~30-60Hz), and depending on the communication network, possibly at a high latency. These systems are prone to instability, which usually manifests as unwanted vibrations of the haptic device. This is especially relevant for using haptic devices for remotely operated aerial robots, as both different sampling frequencies and high latency can be unavoidable.

Early detection of the onset of instability in a haptic system may consequently be desired, and there has been some effort in the literature to develop algorithms to monitor instability. Some stability observers already exist to indicate the onset of instability, including passivity conditions, frequency-domain stability monitoring algorithms, and machine learning. We investigate stability monitoring via a different approach with the aim of faster and more efficient instability detection; namely, we treat the haptic system as a dynamical system [1]. We show that haptic systems are capable of exhibiting types of bifurcations, or can approach a critical threshold in their dynamics, which are related to the phenomenon of critical slowing down (CDS). Our results show that indicators of CSD can be used to detect instability in a 1DoF haptic device coupled to a virtual environment ~0.14s before detection of instability in existing haptic stability observers. Moreover, computation of CSD indicators can be done, on average, 2 times faster than existing metrics.

Another approach to handling the unstable nature of haptic systems is to develop methods to mitigate the inherent sampling and latency issues with these systems. Our goal is to use a 3DoF haptic device to teleoperate a drone over a 5G network, high latency being a key issue in achieving this operation. Model-based methods for achieving stable multi-rate haptic interfacing such as hold methods, multi-rate sampling, and recently reduced interface modelling or RIM [2], have been investigated. We propose a RIM-based method to better estimate the current state of the virtual environment (i.e. without latency). The approach involves using the RIM model, based on the delayed state of the virtual environment, and the recent history of the haptic device, to estimate the force that the haptic device renders if the device had access to the state of the virtual environment with no latency. Our preliminary results suggest that for high latency in a 3DoF haptic device interfacing with a simulated articulated rigid body system, the state estimation error can be improved by a factor of 3 or more. Our work so far provides strong grounds for using a "delayed RIM" model for applications with high latency, in particular teleoperation of aerial robots.

Keywords: haptic systems, instability, virtual environment, teleoperation, latency, reduced order modelling

References

[1] L. Kerr, C. Hutchison, and J. Kövecses, "Identifying Critical Transitions and Instability in Haptic Systems" in Nonlinear Dynamics (accepted for publication).

[2] L. Kerr and J. Kövecses, "Reduced Interface Models for Haptic Interfacing With Virtual Environments," in IEEE Robotics and Automation Letters, vol. 7, no. 4, pp. 8683-8690, Oct. 2022, doi: 10.1109/LRA.2022.3189190.

Cost-effective UAV-based LTE Signal Surveying and Path Optimization

Jeremy Bittick *

Toronto Metropolitan University's Robotics, Mechatronics and Automation Laboratory (RMAL)

Abstract

A cost-effective method for surveying and optimizing LTE signal data using unmanned aerial vehicles (UAVs) has been developed, with potential applications in the project Artificial Intelligence for Logistics (AI4L). The method utilizes open-source, freely available software and affordable hardware, making it widely accessible. The system consists of a UAV equipped with a 500g payload capacity, GPS, a Raspberry Pi or NVIDIA Jetson Nano with a Sixfab LTE hat, and a ground station computer for data collection. The UAV is controlled using QGroundControl to fly survey patterns at regular altitudes across specified locations. During flights, LTE signal data is collected and saved on board or to a cloud database for later analysis using ROS. Gaussian smoothing, Haversine formula transformation, outlier removal, and MatPlotLib visualization is applied to the data once in the database. This process enables the examination of how LTE signals are affected by various factors including altitude, weather conditions, obstructions, terrain, and distance. In the context of AI4L, this method offers significant benefits for LTE path optimization research. By gathering and analyzing data over time, it can predict LTE connection quality based on weather conditions and establish correlations between weather patterns and signal metric fluctuations. The non-invasive nature of the technique allows for the assessment of LTE signal quality in remote or challenging locations where traditional surveying methods may not be feasible. The collected data can inform network planning and optimization, ultimately enhancing the quality of service for LTE users. The method is adaptable to other communication technologies, such as 4G, and 5G. Integrating this UAV-based LTE signal surveying and optimization method into AI4L applications will prove valuable for acquiring approvals from Transport Canada for BVLOS (Beyond Visual Line of Sight) applications.

Keywords: Path Optimization, LTE, Surveying, UAV

References

[1] "Messages (common)," *Messages (common) · MAVLink Developer Guide*. [Online]. Available: https://mavlink.io/en/messages/common.html. [Accessed: 09-Apr-2023].

[2] "QGC - Qgroundcontrol - drone control," *QGroundControl*, 25-Feb-2020. [Online]. Available: http://qgroundcontrol.com/. [Accessed: 09-Apr-2023].

[3] "Wiki," *ros.org*. [Online]. Available: http://wiki.ros.org/mavros. [Accessed: 09-Apr-2023].

Adaptive Sliding Mode Control for Coupled Aerial Manipulation Systems: Dynamics, Design, and Simulation Analysis

Shayan Sepahvand *

† Toronto Metropolitan University

Abstract

Extensive research has been carried out on Aerial Manipulation Systems (AMS) over the past decade. However, the majority of recent research has focused on studying decoupled AMS, where the system is treated as two separate subsystems. Control techniques are then developed separately for each subsystem, namely the unmanned aerial vehicle (UAV) and the robotic manipulator. Consequently, this separation may lead to unsatisfactory or even unstable results in achieving desired control tasks. This is due to the characteristics of the AMS and the task space, which include nonlinearities and parametric uncertainties in the dynamics of the platform, the manipulator, and their interaction. Moreover, depending on the environment, undesirable effects such as wind, obstacles, and external forces can lead to the possible complexity of the plant. In order to fill the existing gap for the coupled AMS, this study first examines the dynamics of the coupled AMS. Next, an adaptive sliding mode controller (ASMC) is offered for the position control of the UAV and the configuration of the arm. Consequently, the increased redundancy in the degree of freedom of the system will be an advantage in many practical applications. By applying Lyapunov synthesis, the stability of the system will be proved to be globally asymptotically stable. Eventually, the simulation findings confirm the performance and effectiveness of the proposed control for several various scenarios where the initial condition or tracking commands differ, or parametric uncertainty exists. The suggested method will also be compared to some recent control strategies to verify the superiority in terms of tracking performance.

Keywords: Aerial Manipulation Systems, Coupled Dynamics, Controller Design, Lyapunov Synthesis, Adaptive Sliding Mode

References

[1] Samadikhoshkho, Z.; Lipsett, M. Decoupled Control Design of Aerial Manipulation Systems for Vegetation Sampling Application. Drones 2023, 7, 110. https://doi.org/10.3390/drones7020110

Dynamic Behavior of an Aerial Manipulation System: Coupling the UAV and Robotic Arm

Niloufar Amiri *

† PhD Student, Toronto Metropolitan University

Abstract

This study focuses on the modeling of a combined aerial manipulation system consisting of an unmanned aerial vehicle (UAV) with four degrees of freedom and a robotic arm, OpenManipulator, with five degrees of freedom. With a total of nine degrees of freedom, this system can reach any desired location. The OpenManipulator has two perpendicular axes of orientation in the task space, allowing for a wider reach point compared to other aerial manipulation systems where the robotic arm has parallel axes of rotation and moves in a planar surface. Moreover, the robot's flexibility is enhanced by four consecutive links, thereby making it better suited for operating in confined environments.

To derive kinematic model, the Jacobian is calculated through forward kinematics to derive the angular and translational velocities of both the UAV and the arm. To formulate the dynamic equations of the coupled system, the LaGrange-D'Alembert method is utilized, considering potential and kinetic energies. The impact of external and gravitational forces is also included to create a more realistic model [1].

This work involves creating an effective MATLAB/Simulink simulation that solves the coupled kinematic and dynamic equations for generalized coordinates. The Coriolis and gravity matrices are symbolically solved using the MATLAB symbolic toolbox. By implementing realistic inputs such as thrust and various impact forces, the simulation can determine the position, velocity, and acceleration of the entire system.

In conclusion, the coupled modeling approach in this study is superior to the existing decoupled models when it comes to real-time control because it considers the effects of the arm and the UAV on each other in the system's dynamics. This allows for a more accurate and comprehensive representation of the behavior of the combined aerial manipulation system, making it more suitable for real-world applications where precise control is required. One novel aspect of this study is to examine how the coupled system responds to external disturbances by analyzing how impact force on both the UAV and arm affects the dynamic behavior of the entire system. By investigating the impact force, it is possible to gain a better understanding of how the system functions in response to sudden changes in momentum or acceleration.

Keywords: Unmanned Aerial Vehicle, Aerial Manipulation System, Coupled Dynamics, OpenManipulator-X

References

[1] Kim S, Choi S, Kim HJ. Aerial manipulation using a quadrotor with a two dof robotic arm. In2013 IEEE/RSJ International Conference on Intelligent Robots and Systems 2013 Nov 3 (pp. 4990-4995). IEEE.

Control-oriented Dynamic Modelling of Aerial Continuum Manipulation Systems

Amir Jalali* and Farrokh Janabi-Sharifi *

* Robotics, Mechatronics, and Automation Laboratory (RMAL), Toronto Metropolitan University, Toronto, ON, CA

Abstract

Due to the diverse application of Aerial Manipulation Systems (AMSs), they have recently attracted significant attention. An AMS is usually composed of an aerial platform, such as an Unmanned Aerial Vehicle (UAV), equipped with a robotic manipulator. Regarding the manipulator, it is traditionally composed of multi degrees of freedom (MDOF) rigid manipulator(s). Recently, we have proposed a new framework of aerial continuum manipulation systems (ACMSs) in which rigid-link arms are substituted with continuum robots [1], providing numerous advantages such as small size, safe interaction with human/environment, and the ability to operate in unknown unstructured environments. However, it suffers from the complex dynamics of the coupled aerial-manipulator system. Furthermore, the nonlinear dynamics of the continuum manipulator(s) make the development of model-based control algorithms challenging. In this study, we aim to propose a control-oriented dynamic model for the ACMS without scarifying the accuracy of the dynamic model. For this purpose, we introduce a hybrid dynamic model in which the conventional MDOF model of aerial platforms are combined with the continuum model of the robotic manipulator while the outcoming equations are formulated in classical control form. In this regard, the continuum robots are modeled as Cosserat rods and discretized based on constant/variable strain assumption. The model is adapted for large deformations of the manipulator under distributed/concentrated external loads. The proposed hybrid model is extendable for complex structural configurations of robotic manipulators such as cooperative continuum manipulation systems, providing a novel framework for the dynamic modeling and model-based controlling of advanced ACMSs.

Keywords: Aerial manipulation, continuum arm, coupled dynamic, Cosserat rod.

References

[1] A. Jalali and F. Janabi-Sharifi, “Aerial Continuum Manipulation: A New Platform for Compliant Aerial Manipulation,” Front Robot AI, 2022 Aug 5;9:903877. doi: 10.3389/frobt.2022.903877.

Ant Colony Optimization Approaches for a Multi-Trip Vehicle Routing Problem with Heterogeneous Fleet and Time Windows: An Industrial Case Study

Beom Sae Shawn Kim[a], Jihee Han[a], Arash Mozhdehi [a], Xin Wang [a]*, Yunli Wang [b], Sun Sun[b]
a Department of Geomatics Engineering, Schulich School of Engineering, University of Calgary,
b National Research Council Canada

Abstract

The Vehicle Routing Problem (VRP) is regarded as one of the most well-known combinatorial optimization problems. The primary objective of the VRP is to determine optimal routes for a fleet of vehicles within operational constraints. There are several variants of VRP in terms of constraints, such as route length, resources, time windows, heterogeneous vehicles, and multiple trips [1]. In recent years, the Vehicle Routing Problem (VRP) has become a more popular and important research topic due to the rapid increase in delivery volumes during and after the COVID-19 pandemic. Especially in the transportation, distribution, and logistics industries, the VRP is a critical problem because identifying and optimizing the problem reduces operational costs and enhances delivery service quality.

In this paper, we focus on optimizing a practical variant of VRP, namely multi-trip VRP with heterogeneous fleet and time windows (MTVRPHFTW) for a Canadian logistics company. In MTVRPHFTW, each customer is associated with a time interval under time windows, and each vehicle can make multiple trips within a single working day [1]. In addition, the MTVRPHFTW allows heterogeneous fleets to operate with varying capacities (weight and skid), as opposed to general VRP. A simplified version of MTVRPHFTW can be seen in Figure 1 below. The figure shows that three heterogeneous fleets perform multiple trips, and customers are serviced while meeting the time windows.

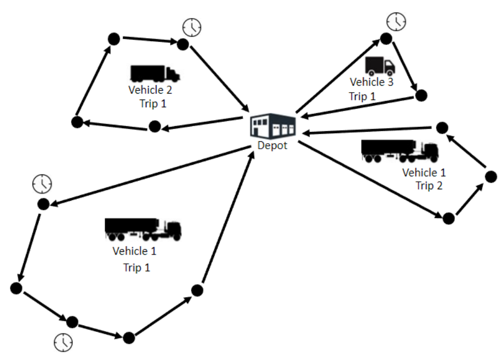


Figure 1. An illustration of simplified MTVRPHFTW

In order to solve the industrial problem, one of our main contributions is to improve the ant colony optimization (ACO) method. This improved ACO can be an efficient solution approach to MTVRPHFTW as ACO is considered as a constructive-based algorithm which is easy to handle multiple constraints. For example, multi-trip constraints are addressed by tracking the vehicle index along with trips and vehicle change decisions [2]. Moreover, heterogeneous fleet and time window constraints are managed by filtering out non-feasible customers [2].

To find out how the IACO method improves the quality of solutions, comparative experiments are conducted between the ACO, the Sweep algorithm as one of the traditional VRP algorithms [3], and the industry solution obtained from the company. According to the comparison results, the proposed IACO reduced the total distance from the ACO by approximately 3.75%. Further, the IACO resulted in fewer number of trips per vehicle, fewer total number of trips, and a more balanced load for drivers than the ACO method. The industry solutions showed 18.79% and 24.04% increases in total distance and the number of vehicles compared to IACO solutions. The sweep method had the 24.14% and 4.83% increases in the total distance and the number of vehicles from the IACO method. Among all algorithms, sweep had the largest total distance.

This work aims to understand and solve MTVRPHFTW as the realistic VRP for industrial applications. In light of the fact that the proposed method was developed with actual industrial data and the results indicated that the proposed method enhanced the overall solution more than the existing methods, this project can be helpful to last-mile logistics providers.

Keywords: meta-heuristic, vehicle routing problem (VRP), heterogeneous fleet, time windows, multi-trip, ant colony optimization

References

[1] P. Toth and D. Vigo, “1. An Overview of Vehicle Routing Problems,” in The Vehicle Routing Problem, in Discrete Mathematics and Applications. Society for Industrial and Applied Mathematics, 2002, pp. 1–26. doi: 10.1137/1.9780898718515.ch1.

[2] J. Han, A. Mozhdehi, Y. Wang, S. Sun, and X. Wang, “Solving a multi-trip VRP with real heterogeneous fleet and time windows based on ant colony optimization: an industrial case study,” in Proceedings of the 15th ACM SIGSPATIAL International Workshop on Computational Transportation Science, in IWCTS ’22. New York, NY, USA: Association for Computing Machinery, Nov. 2022, pp. 1–4. doi: 10.1145/3557991.3567776.

[3] B. E. Gillett and L. R. Miller, “A Heuristic Algorithm for the Vehicle-Dispatch Problem,” Operations Research, Apr. 1974, doi: 10.1287/opre.22.2.340.

Solving Multi-Trip Time-Dependent Vehicle Routing Problem using Deep Reinforcement Learning

Arash Mozhdehi†, Yunli Wang‡, Sun Sun‡, Xin Wang† *

† University of Calgary

‡ National Research Council Canada

Abstract

In recent years, due to rapid urbanization and the exponential increase in demand for goods transport, improving the city logistics operations has gained tremendous importance. Multi-trip time-dependent vehicle routing problem (MTTDVRP) is one of the important variants of vehicle routing problem (VRP) in city logistics [1]. VRPs in general, as NP-Hard problems, were conventionally solved using the exact solvers and heuristics methods. While exact methods are guaranteed to find the optimal solution, given their exponential computation complexity consume prohibit long time to find the solution for the routing problem of large-scale. Heuristics methods, on the other hand, can provide solution with much shorter computational time for large-scale problems by utilizing handcrafted searching rules. However, these methods suffer from lack of generalizability a slight change in the problem setting, such a coordinate of a customer, may require solving it from scratch to find a near-optimal solution [2]. With the recent success of applying deep learning and deep reinforcement learning (DRL) for solving combinatorial optimizations, studies investigated proposing learning-based algorithms for solving VRPs for decision making in more principled manner [3]. However, none of these researches investigated solving the MTTDVRP which is more generalized variant of the routing problem with more realistic assumption. In fact, these methods fail to take the dynamic of traveling time into account, which is of great importance for city logistics where traveling speed manifest considerable change over time based on the traffic conditions. Besides, despite the advantages of allowing the vehicle to perform multiple trips within a planning horizon for cutting the transportation costs, these studies do not take this constraint into consideration.

To rectify the shortcomings of the current learning-based methods with regards to their unrealistic assumptions, we proposed a novel DRL-based method that solve the MTTDVRP by automatically learning search heuristics.

Our experimental results demonstrate the superior routing performance of our method compared to the conventional heuristic methods and the state-of-the-art DRL-based ones.

Keywords: Vehicle Routing Problem, Multi-Trip Time-Dependent Vehicle Routing Problem, Combinatorial Optimization, Mixed-Integer Linear Programming, Deep Reinforcement Learning

References

[1] Cattaruzza, Diego, et al. "Vehicle routing problems for city logistics." *EURO Journal on Transportation and Logistics* 6.1 (2017): 51-79.

[2] Zhang, Zizhen, et al. "Meta-learning-based deep reinforcement learning for multiobjective optimization problems." *IEEE Transactions on Neural Networks and Learning Systems* (2022).

[3] Bengio, Yoshua, Andrea Lodi, and Antoine Prouvost. "Machine learning for combinatorial optimization: a methodological tour d'horizon." *European Journal of Operational Research* 290.2 (2021): 405-421.

Truck Route Recommendation System

Mahdi Mohammadizadeh†, Yunli Wang‡, Sun Sun‡, Xin Wang*†

† Department of Geomatics Engineering, University of Calgary, Canada

‡ National Research Council, Canada

Abstract

The truck industry is constantly looking for ways to optimize its operational costs by minimizing the total traveling time and fuel consumption of trucks. Route optimization for trucks is an avenue of study that has a far-reaching impact on supply chain efficiency, fuel consumption costs, and environmental sustainability. To minimize the operational costs, traveling time and the fuel consumed by the truck should be considered simultaneously considering user preferences. These objectives are influenced by various factors such as travel distance, traffic congestion, road conditions, and weather conditions. The importance of route optimization for trucks, taxis, and buses considering various factors such as travel time, fuel consumption, emissions, travel safety, environmental factors, and road conditions has been widely recognized in the literature. Several solutions based on exact methods, heuristics, and recently state-of-the-art deep reinforcement learning methods have been proposed for routing problems [1-6].

In our research, we focus on presenting a route recommendation system for trucks that utilize the integration of deep reinforcement learning (DRL) with graph neural networks to recommend the best possible route for a given source and destination considering several factors including the road networks, current weather conditions, and user preferences to minimize the total travel time and fuel consumption. This leads to minimizing the overall transportation costs and has a positive impact on the environment as well. Our DRL-based method leverages historical travel data for trucks to create a predictor model to calculate the traveling time and fuel consumption of each edge in road network graphs as the cost functions. Then we deep Q-Networks (DQN) to train an agent based on the reward function to find the best route considering the initial user preferences for traveling time and fuel consumption. Considering these criteria in our objective function, this research greatly benefits logistics operations and environmental studies in the truck industry.

Keywords: Route Recommendation System, Deep Reinforcement Learning, Deep Q-Networks, Graph Neural Network, Travel Time, Fuel Consumption

References

[1] Ankur Sarker, Haiying Shen, and Kamran Kowsari. A data-driven reinforcement learning based multi-objective route recommendation system. In 2020 IEEE 17th international conference on mobile ad hoc and sensor systems (mass), pages 103–111. IEEE, 2020.

[2] *Ekram Hossain, Md Rezaul Karim, Mir Hasan, Syeed Abrar Zaoad, Tauhid Tanjim, and Md Mosad- dek Khan. Spafe: A crowdsourcing and multimodal recommender system to ensure travel safety in a city. IEEE Access, 10:71221–71232, 2022.*

[3] *Qiang Xing, Yan Xu, Zhong Chen, Ziqi Zhang, and Zhao Shi. A graph reinforcement learning- based decision-making platform for real-time charging navigation of urban electric vehicles. IEEE Transactions on Industrial Informatics, 2022.*

[4] *Yining Ma, Jingwen Li, Zhiguang Cao, Wen Song, Le Zhang, Zhenghua Chen, and Jing Tang. Learning to iteratively solve routing problems with dual-aspect collaborative transformer. Advances in Neural Information Processing Systems, 34:11096–11107, 2021.*

[5] *Shenggong Ji, Zhaoyuan Wang, Tianrui Li, and Yu Zheng. Spatio-temporal feature fusion for dynamic taxi route recommendation via deep reinforcement learning. Knowledge-Based Systems, 205:106302, 2020.*

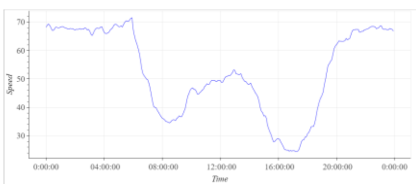
[6] *Chung Park, Jungpyo Lee, and So Young Sohn. Recommendation of feeder bus routes using neural network embedding-based optimization. Transportation Research Part A: Policy and Practice, 126:329–341, 2019.*

Deep Learning Based Truck Traffic Prediction Under Extreme Weather Conditions Using Truck Probe GPS Data

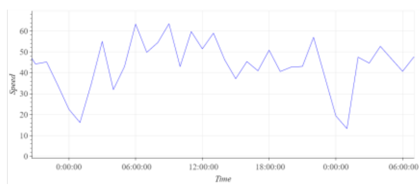
Reza Safarzadeh1, Arash Mozhdehi1, Saeid Kalantari1, Yunli Wang2, Sun Sun2, Xin Wang1*
1 University of Calgary, Calgary, Alberta, Canada
2 National Research Council Canada, Ottawa, Ontario, Canada

Abstract

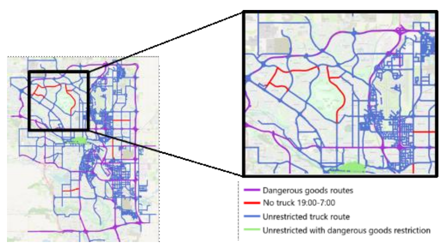
Reliable truck freight transport is essential for the sustainable operation of modern supply chains and the resulting economic development [1]. Truck speed prediction plays a key role in truck transportation management. Existing traffic prediction models primarily focus on passenger car data [2-5], overlooking the distinct characteristics and speed patterns of trucks. As can be seen in Figure 1, unlike passenger cars, truck traffic does not necessarily follow the same patterns of morning and evening peaks, and operational policies in many countries restrict truck operations at specific times, making nights busier for trucks. Moreover, extreme weather conditions such as snowstorms, ice, fog, and floods can significantly disrupt truck driving conditions and lead to road closures [6].



(a) Passenger cars speed changes during the day



(b) Truck speed changes during the day



(c) Operational policies to restrict truck operation on specific road sections

Figure 1. Truck traffic characteristics are different than passenger cars

In recent years, there has been a surge in the number of trucks equipped with GPS devices, generating a vast volume of truck trajectory data. This data can be leveraged to develop highly effective traffic information services for analyzing truck traffic operation status [7]. However, several questions regarding truck speed prediction under extreme weather conditions remain unanswered, such as how to incorporate spatial-temporal and contextual information with historical truck trajectories, how to improve accuracy by utilizing other relevant truck traffic information (e.g., truck flow), and how to address under-represented truck traffic data under extreme weather conditions.

This project proposes a novel Multi-Task Context Based Gated Recurrent Unit Graph Convolutional Network (MT-C2G) for truck speed prediction under extreme weather conditions. It is the first study to apply Multi-Task Learning (MTL) for describing the correlation between truck speed and flow while using an oversampling technique on truck GPS data under extreme weather conditions. The contributions of this project are as follows:

MT-C2G takes contextual features into account when predicting truck speed, employing a layer of GRU units to capture the temporal dependence in multivariate time series of external factors, including historical truck traffic and contextual factors. As weather is a time-varying factor that directly affects road conditions and traffic states, capturing the temporal dependencies of this factor is crucial for speed prediction tasks.

MT-C2G utilizes an MTL model to obtain reasonable speed predictions based on real-world truck speed and flow historical data. By considering truck speed and flow simultaneously, MT-C2G makes full use of the interactions between these two variables, reduces the impact of noise and sparseness in the data, focuses on relevant features, decreases the likelihood of overfitting, and learns a more general representation of the data.

To address under-represented truck speed and flow samples synchronized with extreme weather conditions, MT-C2G utilizes the Synthetic Minority Oversampling Technique (SMOTE) to over-sample the data under extreme weather conditions, improving truck speed prediction accuracy for such conditions.

In summary, the MT-C2G model provides a comprehensive solution to truck speed prediction under extreme weather conditions by incorporating contextual features, utilizing MTL to describe the correlation between truck speed and flow, and addressing under-represented truck traffic data during extreme weather events. The project conducts extensive experiments on real-world datasets to evaluate the performance of the proposed model. The results demonstrate that the proposed approach achieves significant improvement over state-of-the-art baseline methods, highlighting the effectiveness of the MT-C2G model for truck speed prediction under extreme weather conditions [8].

Keywords: truck speed prediction, multitask learning, spatiotemporal models, extreme weather, truck traffic forecasting

References

[1] Wang, Zun, Anne V. Goodchild, and Edward McCormack. "Freeway truck travel time prediction for freight planning using truck probe GPS data." European journal of transport and infrastructure research 16.1 (2016).

[2] Guo, Shengnan, et al. "Attention based spatial-temporal graph convolutional networks for traffic flow forecasting." Proceedings of the AAAI conference on artificial intelligence. Vol. 33. No. 01. 2019.

[3] Zhao, Ling, et al. "T-gcn: A temporal graph convolutional network for traffic prediction." IEEE transactions on intelligent transportation systems 21.9 (2019): 3848-3858.

[4] Li, Yaguang, et al. "Diffusion convolutional recurrent neural network: Data-driven traffic forecasting." arXiv preprint arXiv:1707.01926 (2017).

[5] Wu, Zonghan, et al. "Graph wavenet for deep spatial-temporal graph modeling." arXiv preprint arXiv:1906.00121 (2019).

[6] Akter, Taslima, et al. "A spatial panel regression model to measure the effect of weather events on freight truck traffic." Transportmetrica A: transport science 16.3 (2020): 910-929.

[7] Wang, Shengyou, et al. "Truck traffic flow prediction based on LSTM and GRU methods with sampled GPS data." IEEE Access 8 (2020): 208158-208169.

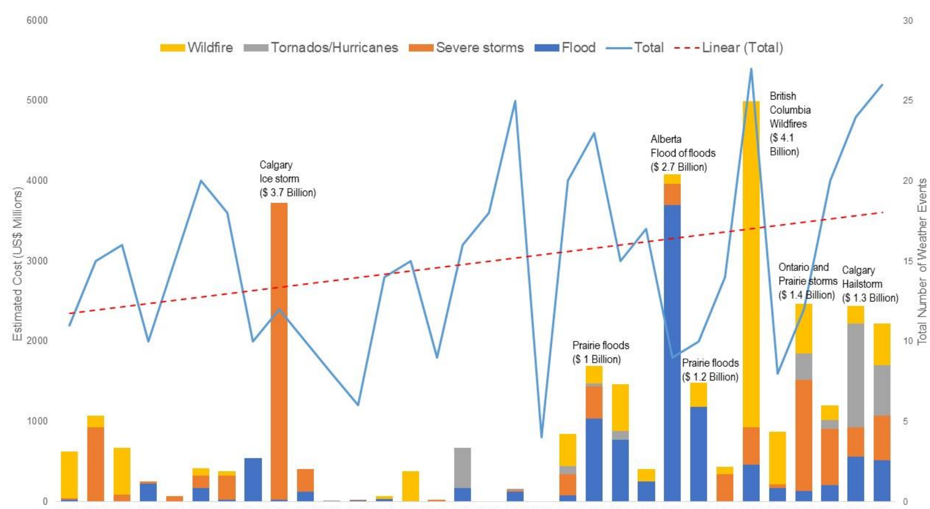
[8] Safarzadeh, Reza, et al. "Multi-task graph neural network for truck speed prediction under extreme weather conditions." Proceedings of the 30th International Conference on Advances in Geographic Information Systems. (2022).

Road Freight Transport Network Resilience to Extreme Weather Events: Concepts and Open Challenges

Phani Kumar Patnala, Ph.D. *, a
Jonathan D. Regehr, Ph.D., P.Eng. a
Babak Mehran, Ph.D., P.Eng. a
[a] University of Manitoba
Chaouki Regoui, Ph.D., P.Eng. b
[b] National Research Council Canada

Abstract

As road freight transportation systems (FTSs) are drivers of modern economies, operational interruptions in freight movements due to road network disruptions have received heightened attention from all levels of government. When extreme weather events such as hurricanes, flooding, or winter storms impose road network disruptions, trucking companies may choose to delay, reschedule, or reroute freight shipments. The resulting delays have considerable economic impact on road network operations (see figure). Rising demand for FTSs coupled with an increase in the frequency and intensity of weather-related disruptive events have motivated governments of all levels to shift from risk-based to resilience-based approaches for assessing system performance [1]. Resilience is a complex, multidisciplinary concept that deals with rapid response and recovery of a system experiencing a disruption [2]. Despite this motivation and extensive research, there is a need to clarify resilience concepts in the context of the multi-dimensional nature of FTSs (physical infrastructure, users, and managing organizations) and to identify persistent knowledge gaps concerning the characterization and measurement of FTS resilience vis-à-vis disruptive events. This study addresses these shortcomings through a systematic review of 122 research studies. The synthesis of findings clarifies inconsistencies associated with the characteristics of FTS resilience and in so doing, establishes a unified framework for measuring FTS resilience through the life cycle of disruptive events. By focusing on weather-related disruptions, this study posits a novel way to categorize such events and advances resilience theory by demonstrating how they may be considered using resilience triangles. Critical knowledge gaps concerning FTS resilience to long-term, climatic events remain. Addressing those gaps requires robust analytical approaches supported by comprehensive, multidisciplinary, time-series data.



Economic Impact of Extreme Weather Events in Canada, 1990-2021

Keywords: resilience; road freight transportation systems; infrastructure; users; organizations; disruptive events; extreme weather

References

[1] Ta, C., Goodchild, A. V., & Ivanov, B. (2010). Building resilience into FTS: Actions for state departments of transportation. Transportation research record, 2168(1), 129-135.

[2] Markolf, S. A., Hoehne, C., Fraser, A., Chester, M. V., & Underwood, B. S. (2019). Transportation resilience to climate change and extreme weather events–Beyond risk and robustness. Transport policy, 74, 174-186.

Design and Deployment of an Integrated, Portable Road-Weather and Traffic Information System

Phani Kumar Patnala, Ph.D. †
Musharraf Khan, Ph.D. †
Kerry Lynch †
Charleen Choboter †
Jonathan D. Regehr, Ph.D., P.Eng. *, †
Babak Mehran, Ph.D., P.Eng. †
† University of Manitoba

Abstract

The effects of weather and road conditions on driver behaviour, traffic patterns, and traffic safety are generally acknowledged, but a lack of micro-scale data often precludes evidence-based decisions. In November 2022, the Urban Mobility and Transportation Informatics Group (UMTIG) at the University of Manitoba, in partnership with the National Research Council of Canada (Artificial Intelligence for Logistics Program), International Road Dynamics (IRD), and Manitoba Transportation and Infrastructure (MTI), deployed a portable road-weather information system (RWIS) and integrated video classification cameras at an existing WIM installation. The integrated equipment is capable of recording time-synched data, including road surface condition, surface temperature, surface grip and ice/snow/water layer thickness, air temperature, rain state, humidity, wind speed and direction, visibility, and precipitation details. Simultaneously, the system records live video, counts and classifies vehicles (by lane), and retains the individual vehicle records generated by the WIM system.

In preparation for the first deployment, the research team worked closely with technicians from IRD and MTI to select a suitable sampling location with access to power and to complete initial calibration and equipment setup. The system's initial deployment was on a four-lane divided highway near the city of Winnipeg that serves as a major regional trucking route. Since its deployment, the system has generated an initial data set which will undergo validation as a next step.

In March 2023, the system was moved and re-deployed at a four-leg signalized intersection of a four-lane divided highway and a two-lane undivided urban arterial. For this deployment, additional cameras and a non-intrusive radar-based traffic sensor were added to monitor vehicle behaviours at the intersection as a function of traffic signal changes.

Ultimately, the data will support investigations about the impact of adverse road-weather conditions on truck operations and safety, the contribution of weather-related parameters to network resilience, and the effect of weather conditions on traffic data collection.

Initial deployment of a portable road-weather and traffic information system in Manitoba

Keywords: road-weather information system, portable, traffic data collection

Evaluating Network Elements using Random Walk for Resilient Route Planning

Musharraf Ahmad Khan, Ph.D. *, †
Giuseppe Grande, Ph.D. †
Babak Mehran, Ph.D. P.Eng. †
Jonathan D. Regehr, Ph.D. P.Eng. †
† University of Manitoba

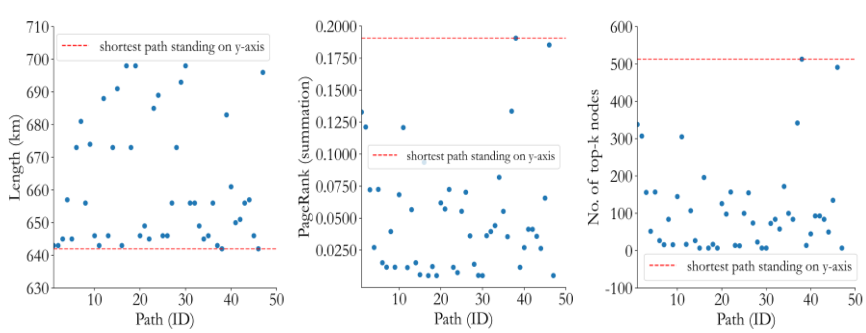
Abstract

Accessibility- and serviceability-based vulnerability analyses highlight the accessibility and operational consequences of network degradation, respectively, and are primarily governed by failure probabilities. However, they fail to capture the network's resilience or its ability to perform in a complete failure of critical nodes irrespective of their failure probabilities. This research uses topological-based vulnerability and proposes a PageRank variant algorithm to determine these critical nodes for a road freight network (modelled as a weighted directed graph). The topological-based vulnerability here refers to the identification of vulnerable locations within the network.

The application is demonstrated on a real network, namely the provincial road network of Saskatchewan, Canada. The application demonstrates how a more resilient network of optimized routes can be established by exploiting the top-k critical nodes' location and vulnerability information in the routing optimization process. The shortest path may not always be the best path in terms of vulnerability (see figure). With a compromise on the length, better routes can be chosen which may exhibit lesser vulnerability in terms of the value of the criticality and the number of most critical nodes on the route. By avoiding these potentially critical nodes, a potential cost can be saved in case of network elements' breakdown (naturally or by a malicious attack) or in case of traffic congestion. The results show that PageRank is effective in highlighting busy network elements and can be personalized based on the origins of the freight trips. Since PageRank accumulates node criticality from the nodes and its neighbors, the relationship among the nodes is a vital outcome. These relationships can be personalized based on the choice of the source(s) of the random walk which can be deemed as the freight origin(s).

The proposed model is potentially dynamic in the sense that it can update the results based on the new information on freight traffic, which may evolve over time. In future work, the implication of the 'supervised random walk' in the proposed method would be investigated. An estimation of the Origin-Destination pairs based on the link flows would be explored by i) improving the proposed PageRank model with supervised random walk, and ii) integrating supervised random walk with the deep learning framework.

Keywords: critical nodes, PageRank, route planning, resilient network design, topological network vulnerability



Standing of the shortest OD path in terms of vulnerability within a sample of optimized paths

References

[1] Page, L. et al. (1998) 'The PageRank Citation Ranking: Bringing Order to the Web', World Wide Web Internet And Web Information Systems, 54(1999–66), pp. 1–17. Available at: http://ilpubs.stanford.edu:8090/422.

[2] Lalou, M., Tahraoui, M. A. and Kheddouci, H. (2018) 'The Critical Node Detection Problem in networks: A survey', Computer Science Review. Elsevier Inc., 28, pp. 92–117. doi: 10.1016/j.cosrev.2018.02.002.

Using Reliability Models for Crash Frequency Analysis on the Saskatchewan Highway Network

Nasim Deljouyi †
Phani Kumar Patnala, Ph.D. †
Babak Mehran, Ph.D., P.Eng. *, †
Jonathan D. Regehr, Ph.D., P.Eng. †
† University of Manitoba

Abstract

The present study demonstrated the potential applications of reliability models for crash analysis of a large highway network. Specifically, three major outcomes of reliability models were investigated: temporal distributions of crashes, reliability score, and expected number of crashes. These parameters were derived using 20 years of crash data (2001-2020) recorded on the Saskatchewan highway network, although time sensitivity analysis is addressed for 5, 10, 15, and 20 years of crash data. A series of reliability models were developed for crashes by crash severity, vehicle involvement, and highway type at both the segment and highway levels. First, the temporal distributions of crashes on each segment were fit to a statistical distribution. Second, the reliability scores were used to rank the high crash-risk segments and visualize the weekly reliability of each segment on the map of the Saskatchewan highway network using ArcGIS software. Third, the mean expected crash frequency was used to develop network-wide safety performance functions for total and fatal crashes in urban and rural highway segments using Poisson-Tweedie (PTw) regression models. The developed PTw models showed that the presence of trucks in the traffic composition has a significant effect on crash frequency, especially for urban highway segments. Moreover, the use of reliability-based safety performance functions (SPFs) will allow safety analysts to rely on probabilistic rather than deterministic network screening approaches. The findings from this study push highway authorities to introduce reliability models in the decision-making of safety investment plans. Also, the framework of reliability modeling is transferable and can be developed for the highway networks of other provinces or different weather conditions.

Keywords: crash frequency analysis, reliability theory, temporal aspects, prediction models

Using GIS to Harness the Power of Twitter for resilience analysis of Alberta's rural highways

Sina Abolhoseini †
Phani Kumar Patnala †
Babak Mehran †
Jonathan D. Regehr *,†
† University of Manitoba

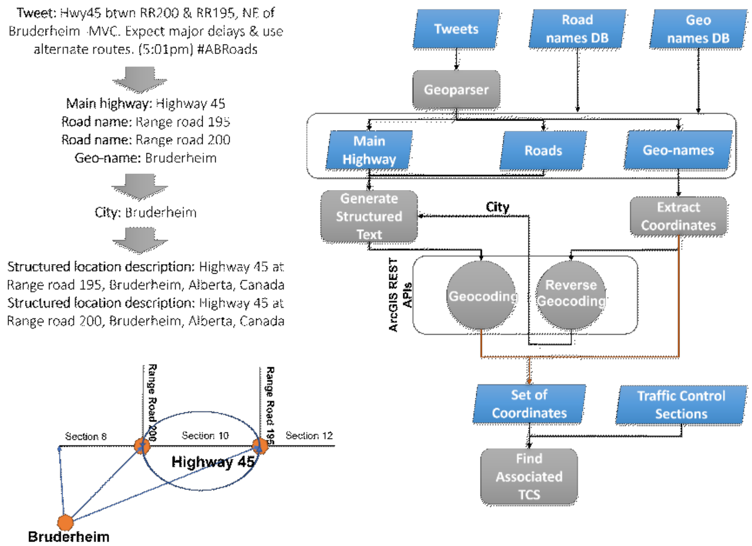
Abstract

Social networks, such as Twitter, are becoming valuable sources of historical and real-time traffic data [1]. For example, in 2022, approximately 410 million tweets were posted by 290 million users each day [2]. Many agencies operate Twitter accounts dedicated to reporting traffic-related incidents. One such account, the Alberta 511 account, has been tweeting since 2016. A shortcoming with this data is that only 1-2% of all tweets on Twitter have geographical coordinates [3]. Instead, traffic-related tweets describe locations of incidents briefly in a semi-structured text format. Moreover, the Alberta 511 account only reports confirmed incidents and updates the event status when the incidents are cleared. Therefore, this account has potential for providing data for resilience analysis of the Alberta highway network. However, a methodology is needed to extract geographical information from its tweets. In this research, GIS techniques are used to develop a methodology for extracting information regarding motor vehicle collisions (MVCs) from the Alberta 511 account to be used for resilience analysis.

The figure below presents the methodology as a flowchart. The proposed methodology requires four resources: the Tweets archive was fetched from Twitter API [4]; geo-names were obtained from Canada Open Data portal [5]; road names were extracted from the Shapefile layer of National Road Network from Alberta Open Data portal [6]; and the Traffic Control Sections Shapefile layer were created from Alberta Traffic Data Mapping website [7]. After obtaining the required resources, tweets were parsed into road-names and geo-names. The first road-name mentioned in each tweet was assumed to be the highway that the collision happened on and was called the main highway. This resulted from investigating the structure of 511 tweets. After that, the coordinates of geo-names were entered into ArcGIS reverse geocoding API [8] to get the city of the geo-names. Then, structured location descriptions were generated based on the main highway, mentioned road names, and geo-named cities. City names were added to deal with uncertainties. This structure is compatible with the ArcGIS geocoding API [9]. Coordinates were extracted for each description by entering them into the ArcGIS geocoding API. At this stage, for each tweet we had a set of points. After converting points into a Shapefile layer, GIS was used to find the main highway's TCS that had the minimum cumulative distance to each set of points. This TCS was considered as the location of a tweet.

To investigate the performance of the methodology, it was deployed on Alberta 511 tweets in September 2022. Results were compared with manual geo-tagging. From the overall 112 tweets, we were able to manually geo-tag 106 tweets with certainty. From the 106 MVC tweets, 71% (75 tweets) were geocoded correctly, 17% (18 tweets) were geocoded on an adjacent TCS, and the rest of the tweets were geocoded incorrectly.

This methodology is neither limited to MVCs nor to the Alberta 511 Twitter account. Different provinces use a similar structure to post tweets across Canada, and we can use this methodology to get nationwide data coverage for resilience analysis.



Flowchart of the proposed methodology for extracting geographical information from contextual content of the Alberta 511 Twitter account (with an example on the left side)

Keywords: social media, motor vehicle collision, text mining, natural language processing, geographical information system, geocoding

References

[1] Y. Gu, Z. S. Qian and F. Chen, "From Twitter to detector: Real-time traffic incident detection using social media data," Transportation research part C: emerging technologies, vol. 67, pp. 321-342, 2016.

[2] "Visualizing A Decade Of Twitter's Evolution: Jan 2012 – Nov 2022 & Musk's Purchase," 17 11 2022. [Online]. Available: https://blog.gdeltproject.org/visualizing-a-decade-of-twitters-evolution-jan-2012-nov-2022-musks-purchase/.

[3] "Advanced filtering with geo data," Twitter, [Online]. Available: https://developer.twitter.com/en/docs/tutorials/advanced-filtering-for-geo-data. [Accessed 27 03 2023].

[4] "Download Geographical Names Data," Government of Canada, [Online]. Available: https://natural-resources.canada.ca/earth-sciences/geography/download-geographical-names-data/9245. [Accessed 27 3 2023].

[5] "National Road Network (NRN) - AB, Alberta," Government of Alberta, 6 6 2016. [Online]. Available: https://open.alberta.ca/opendata/gda-6aa3584c-e1c1-4d9e-879c-082686587608. [Accessed 27 3 2023].

[6] "Traffic Data Mapping," Government of Alberta, [Online]. Available: https://www.transportation.alberta.ca/mapping/. [Accessed 27 3 2023].

[7] "Traffic Data Mapping," Government of Alberta, [Online]. Available: https://www.transportation.alberta.ca/mapping/. [Accessed 27 3 2023].

[8] "Reverse Geocode," Esri, [Online]. Available: https://developers.arcgis.com/rest/geocode/api-reference/geocoding-reverse-geocode.htm. [Accessed 27 3 2023].

[9] "Geocode Addresses," Esri, [Online]. Available: https://developers.arcgis.com/rest/geocode/api-reference/geocoding-geocode-addresses.htm. [Accessed 27 3 2023].

Estimation of Origin-Destination Trip Exchange Rate based on Observed link flows: Implications for Manitoba's Road Freight Transport Network

Nasim Deljouyi †
Babak Mehran, Ph.D., P.Eng. *,†
Jonathan D. Regehr, Ph.D., P.Eng. †
† University of Manitoba

Abstract

Over the past few years, finding the trip exchange rates between origins and destinations (ODs) has attracted significant attention for traffic and transportation planning purposes, particularly in the context of freight transportation where commercial vehicles transport different commodities between freight generation centers. The availability of information regarding the exchange rates of different commodities between major centers is essential for freight network vulnerability and resilience analysis. However, other than some spatially aggregated information (e.g., between provinces and major urban centers), trip exchange rates are unavailable to inform freight demand models in the Canadian context. Rather, many transportation agencies develop and maintain estimates of truck traffic volume at the link level.

This study aims to infer the magnitude of trip exchange rate between origins and destinations based on the link flows observed across the road network of Manitoba. In the first attempt, we investigated the applicability of Standard Artificial Neural Networks (ANN) to this problem for a sample toy network and compared the results for three proposed ANN models. This is an ongoing research effort, and in the next step, we plan to investigate the application of Convolution Neural Networks (CNN) to the OD trip estimation and compare the result with the model already developed. Next, we plan to apply the models to an actual network (e.g., the Manitoba highway network) and expand the models using additional features as inputs that include spatial network characteristics and socio-economic characteristics of freight generation zones in the region. Applying the model to specific industries (e.g., agriculture, forestry) may facilitate further methodological refinements.

Keywords: origin-destination trip estimation, link flow, artificial neural network, convolutional neural network, freight transportation

Modelling the Impacts of Transportation Hazards on Truck-Involved Crash Frequency on Cold Region Rural Highways

Rillagoda G.N. Yasanthi, Ph.D. †
Babak Mehran, Ph.D., P.Eng. *, †
Phani Kumar Patnala, Ph.D. †
Jonathan D. Regehr, Ph.D., P.Eng. †
† University of Manitoba

Abstract

The highway safety manual [1] provides guidance on predicting crash frequency (CF) based on safety performance functions (SPFs) — multiple linear regression models predicting CFs under a set of driving conditions — and crash modification factors (CMFs) — multiplicative factors applied to SPFs. The goal of this research is to mitigate crash risk to freight transport trucks travelling on rural highways located in cold regions such as the Canadian Prairies. The research objectives are twofold. First, this research attempts to develop (i) truck SPFs that predict truck-involved CFs, and (ii) hazard-specific CMFs reflecting the change in truck CFs due to transportation hazards for cold region rural highways. Second, this research intends to identify transportation hazards (hereinafter hazards) with significant crash risks.

The research methodology consists of three steps. First, police-reported truck-involved crash data on rural highway segments of Alberta, Canada, from 2015 to 2017 were used to develop truck SPFs for (i) four crash severity levels: total, fatal, personal injury (PI), and property damage only (PDO), and (ii) two highway segment types: rural two-lane two-way highways (R-TL-TWH) and rural multilane highways (RMH). In this research, each trucks SPF was developed as a negative binomial regression model — a multiple linear regression model in which the dependent variable is assumed to follow the negative binomial distribution. The dependent variable of all truck SPFs developed in this research represents the annual truck-involved CF on a rural highway segment in Alberta. The independent variables include (i) $AADT$: annual average daily traffic, (ii) Trp: percentage of trucks, (iii) N: number of lanes (for RMHs), (iv) L: highway segment length, (v) highway horizontal alignment, (vi) highway vertical alignment, and (vii) transportation hazard(s) present, for each highway segment considered. Second, the exponents of regression model coefficients of truck SPFs were used to estimate hazard-specific CMFs for each hazard for a specific highway type and a collision severity type. Third, hazards with significant crash risks were identified based on the (i) numerical value of each hazard-specific CMF, and (ii) statistical significance of regression model coefficients used to estimate hazard-specific CMFs.

According to the study results, most hazard-specific CMFs (e.g., snow, fog) were deemed statistically insignificant implying the absence of a statistically significant relationship between truck-involved CF and the presence of hazards. Of the statistically significant CMFs, the CMF for poor visibility (CMF=1.5) suggests that poor visibility increases PI type truck-involved crashes on R-TL-TW segments by 50% as compared to the frequency of such crashes attributed to crash causes other than transportation hazards. The impact of wildlife on truck-involved CF was also deemed statistically significant. Current research on this topic includes evaluating the effectiveness of Provincial Wildlife Sanctuary Corridors, a wildlife-vehicle collision mitigation measure, on reducing truck-involved wildlife-vehicle collisions in Alberta. Road safety researchers and practitioners may adapt the study methodology to effectively rank hazard risks to a highway freight transportation system, thus prioritizing safety countermeasures designed to mitigate truck crashes attributed to transportation hazards that intensify truck vulnerability.

Keywords: truck crash modelling, transportation hazards, safety performance functions, crash modification factors

References

[1] American Association of State Highway and Transportation Officials (AASHTO), Highway Safety Manual (1st Edition) with Supplement, 2010

Applying a Hierarchical Approach to Develop a Regional Truck Traffic Volume Model

Giuseppe Grande, Ph.D. †
Jonathan D. Regehr, Ph.D., P.Eng. *, †
Babak Mehran, Ph.D., P.Eng. †
† University of Manitoba

Abstract

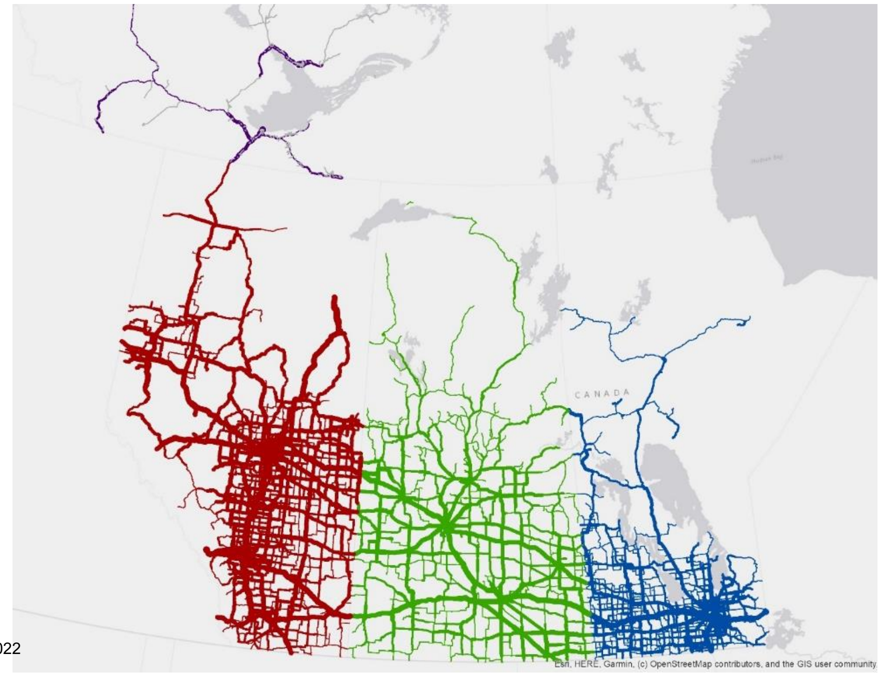
Assessing the resilience and safety of road freight transport requires reliable estimates of network-wide truck traffic volumes. However, in many Canadian provinces, a lack of data and inconsistent practice have led to a persistent gap in the availability of these estimates. To address this gap, this research constructs a regional truck traffic volume model for the Canadian Prairie and Northern Region (i.e., Alberta, Saskatchewan, Manitoba, and Northwest Territories). Extending earlier work by Regehr and Reimer (2013), the research focuses on the application of a hierarchical approach for developing network-wide truck traffic volume estimates in Manitoba.

The hierarchical approach categorizes traffic data sites into three levels. Level 1 sites continuously classify vehicles. These sites provide a complete data record but are sparsely distributed geographically. Level 2 sites provide short-duration classification data, typically up to about 48 hours. While only providing a short-duration sample, Level 2 sites provide better spatial coverage of the network. Level 3 sites have (total) traffic volume data but do not have any available classification data. Classification distributions are estimated for these sites based on observed roadway and operational characteristics.

Data from Level 1 sites were used to generate truck traffic pattern groups (TTPGs) that represent the variation of single-unit trucks, single-trailer trucks, and multiple-trailer trucks by day-of-week, hour-of-day, and month-of-year. Cluster analysis using Euclidean distance between each data vector was used to group sites with similar temporal trends in these three vehicle classes. Engineering judgment was used to define the TTPGs in terms of identifiable roadway and operational characteristics for the grouped sites. Finally, an assignment algorithm was developed and applied to assign Level 2 sites to the appropriate TTPG, enabling those counts to be factored into representative annual average volumes.

Using a similar process, TTCGs were created using Level 1 site classification data. This began with a cluster analysis using the classification distribution of classes 5, 6, 9, 10, and 13, as well as the total proportion of trucks to all vehicles at each Level 1 site. Each TTCG was defined in terms of identifiable roadway and operational characteristics to enable assignment of Level 3 sites to the appropriate TTCG.

To visualize the results, truck traffic volume—expressed as annual average daily truck traffic—was estimated at all sites by dividing the network into truck traffic segments, based on an assumption of volume homogeneity (Ominski et al., 2021) and applying data attribution rules. The results for Manitoba were combined with truck volume estimates available from other jurisdictions to produce a regional truck traffic volume model (see figure). While methodological differences exist between jurisdictions, the model represents the first known regional-scale estimate of truck volumes.



Truck traffic volume model for the Canadian Prairie and Northern Region, 2019

Keywords: truck volume, traffic monitoring, vehicle classification, hierarchical approach, cluster analysis

References

[1] Regehr, J. D., & Reimer, M. J. (2013). Methodology to estimate the distance traveled by trucks on rural highway systems. Journal of Transportation Engineering, 139(4), 390-398. doi: 10.1061/(ASCE)TE.1943-5436.0000505

[2] Ominski, A., Paramita, P., & Regehr, J. D. (2021). Development and attribution of a linear referencing system for managing and disseminating traffic volume data on rural highway networks. Canadian Geographer. https://doi.org/10.1111/cag.12707

An Integrated Modelling Approach to Estimate Grain Truck Activity in the Canadian Prairie Region

Jenna Duke, E.I.T. †
Jonathan D. Regehr, Ph.D., P.Eng. *, †
Babak Mehran, Ph.D., P.Eng. †
† University of Manitoba

Abstract

Network resiliency is foundational for the economic well-being of the agricultural industry in the Canadian Prairie Region (CPR) due to the agricultural sector relying so heavily on the rural road network. This makes it important to understand the movement of agricultural truck traffic in the region.

Truck traffic monitoring data and methodologies offer one approach to model truck activity. While useful for most engineering applications, these data are not well-suited for planning or forecasting purposes. In contrast, freight demand modelling approaches are designed to forecast future activity and are often tailored to specific industries. However, these approaches tend not to provide the level of detail required for engineering applications, such as road design, asset management, or understanding how road closures impact a sector's supply chain.

The modelling approach developed in this research integrates methodologies from the truck traffic monitoring and freight demand modelling fields to establish sector-specific activity patterns in the CPR. The approach consists of a 3-step commodity model, the Grain Tonnage Demand (GTD) model, which is converted to the Hopper Bottom Truck Demand (HBTD) model using truck body type data. The results of the HBTD are then compared to those obtained using the Hopper Bottom Truck Traffic (HBTT) model, which is independently developed from truck traffic monitoring data.

The comparison of the HBTD and HBTT results considers the truck kilometres travelled (TKT) by hopper bottom trucks normalized by network distance and focusing on activity in southwestern Manitoba. This research found the HBTD model to underestimate the HBTT model by 39 percent (in terms of normalized TKT). Since neither model can be considered as ground truth, the difference should not be interpreted as an error, but rather as a way to assess the relative strengths and limitations of the different modelling approaches. For the HBTD model, these limitations relate to challenges in modelling grain activity in urban areas, the exclusion of dump trucks from the model, an inability to include all segments of the grain supply chain, trip assignment assumptions, and the limited number of commodities considered. Likewise, for the HBTT model, limitations relate to data collection approaches, sampling methods, data processing techniques, the assignment of counts to the network, and the assumption that all hopper bottom trucks carry grain. Further integration of the approaches and resolution of the limitations could yield better agreement in the future.

Keywords: grain trucking, freight demand modelling, truck body type data, commodity-based modelling, truck traffic monitoring

Options for Enhancing Network-Wide Truck Volume Estimates in Manitoba

Cassidy Zrobek, E.I.T. †
Giuseppe Grande, Ph.D. †
Jonathan D. Regehr, Ph.D., P.Eng. *, †
Babak Mehran, Ph.D., P.Eng. †
† University of Manitoba

Abstract

There is a persistent need to enhance the quality of network-wide truck volume estimates through improved traffic monitoring practices. Challenges exist because of uncertainties about sampling approaches that provide sufficient spatial and temporal coverage. This research addresses these challenges: (1) by conducting a class-specific investigation of the temporal variability of short-duration truck classification counts; and (2) by comparing truck volumes obtained from traffic counts with those obtained from probe-based data.

Government agencies rely on short-duration classification counts (SDCCs) to provide information about how trucks use the highway network. With the emergence of non-intrusive classification technologies and increased demand for classification data, questions arise about how to deploy SDCCs and retain disaggregated classification data throughout the volume estimation process. While the practice of estimating volume from an SDCC attempts to compensate for known periodicities, it does not account for the inherent random variability of the sample data. Past studies focused on the impacts of count duration on annual estimates of total traffic; however, little is known about the nature of this relationship for trucks. This research analyzes the inherent temporal variability of vehicle classification data by simulating SDCCs with durations of one to eight days using continuous count data from 55 bi-directional sites in Manitoba. For each count duration, the variability of total traffic, trucks, three aggregate truck classes, and Federal Highway Administration classes 4 to 13 was calculated. The results indicate that the variability decreased as the count period increased from one to seven days for all classes. The variability was more sensitive to count duration for trucks compared to total traffic and for low-volume classes compared to high-volume classes. The analysis revealed that a 7-day count of trucks had less variability than a 1-day count of total traffic for 75% of site-directions.

Beyond SDCCs, commercially-available probe-based data provides an alternative for improving network-wide truck volume estimates by increasing spatial and temporal traffic data coverage. Past research on the traffic volume estimates from a North American company called StreetLight Data (StL) was conducted in the United States and focused primarily on total traffic. However, StL now provides truck activity indices for medium-duty and heavy-duty trucks. This research assesses the accuracy of annual average daily total traffic, medium-duty truck traffic, and heavy-duty truck traffic volumes obtained using StL's traffic activity indices. The analysis was conducted using 2019, 2020, and 2021 continuous count data from 11 sites near Winnipeg, Manitoba. The results showed agreement between the ground truth and probe-based total traffic estimates with mean absolute percent errors (MAPEs) ranging from 8.8% to 22.1% across the study years. The medium-duty truck volume estimates had larger errors up to 37.5%. Despite having higher volumes than medium-duty trucks, heavy-duty truck estimates had the largest errors, likely due to StL's lower sample size. The errors of the truck estimates may preclude certain design applications but may be useful for planning applications on unmonitored roads where truck volume estimates are unavailable or of unknown quality.

Keywords: truck volume, traffic monitoring, vehicle classification, short-duration counts, temporal variation, probe-based data

Addressing Uncertainties and Incorporating Flexibility in the Development of the Slave Geological Province Transportation Corridor

Jianjing Jin1, Moein Sadeghi2*, Amy Kim3

1Ph.D. Student, Department of Civil & Environmental Engineering, University of Alberta
2Ph.D. Student, Department of Civil Engineering, University of British Columbia
3Assosiate Professor, Department of Civil Engineering, University of British Columbia

Abstract

The Tibbitt to Contwoyto Winter Road (TCWR) is the only ground access to mines in the southeastern region of the Northwest Territories. To replace this winter road, the Government of Northwest Territories has plans for the Slave Geological Province Corridor (SGPC) all-weather road. However, uncertainties about climate change impacts and economic outlooks make it challenging to determine the benefits and costs of building such a project. A framework based on real options analysis is proposed to evaluate investment value and determine optimal investment times for such a large project in such conditions of uncertainty. Freight demand and climate change are modelled as Geometric Brownian Motion processes, and the payoffs of constructing each segment are assessed using benefit-cost analysis within a real-options framework. The results indicate that freight demand and project horizon are the two most critical factors influencing the project construction, followed by the impact of climate change. The first segment's value is found to be highest among the three segments assessed, and thus should be constructed immediately, while the second and third segments should follow a “wait and see” approach.

The analysis framework can be extended to support other transportation infrastructure projects in other areas of northern Canada, such as the Inuvik Region. The region’s transportation system consists of gravel and winter roads, aviation, and marine barging, with some communities solely dependent on winter roads for ground access. A decision model will be developed to assess plans for new construction and maintenance projects that consider climate change impacts, community connectivity, budget constraints, and economic opportunities. This analysis can be supposed with data gathered through the project “Building a Multimodal Transportation Network Database and Exploring Data Collection Methods to Support Transportation Operations in the Canadian North.”

Keywords: Climate Change, SGP, Real Option Analysis, Benefit-cost analysis

Trustworthy Decentralized Last-Mile Delivery Framework Using Blockchain

Ala Alqaisi 1, Sherif Saad 1, Mohammad Mamun 2

1 University of Windsor, Windsor, Canada, 2 National Research Council Canada, New Brunswick, Canada

Abstract

The fierce competition in eCommerce is a painful headache for logistics companies. In 2021, Canada Post's parcel volume peaked at 361 million units with a minimum charge of $10 per each. Last-Mile Delivery (LMD) is the final leg of the supply chain that ends with the package at the customer's doorstep. LMD is the most costly process, accounting for more than 50% of the overall supply chain cost [1]. Platforms such as Uber Eats and Amazon Flex help overcome this inefficiency and provide an outstanding delivery experience by enabling crowd-shipping using freelancer drivers willing to deliver packages in exchange for compensation. However, the current generation of LMD platforms that leverage crowd-shipping are centralized platforms and behave as intermediaries that charge commission fees. They lack transparency, and most of them, if not all, are platform monopolies in the making. This paper introduces the design of the next-generation LMD crowd-shipping platforms by leveraging Blockchain and smart contracts. A decentralized crowd shipping platform for LMD that is scalable, reliable, secure, and promotes fairness. The proposed platform connects the primary stakeholders of LMD without intermediaries. The stakeholders could use the platform to manage shipping and delivery, handle disputes, maintain fairness, and mitigate monopoly power. Our approach replaces the need for a centralized intermediator such as Uber by introducing a decentralized reputation model that executes over a cryptocurrency-less blockchain network. Our proof-of-concept implementation of the proposed framework demonstrates the potential of blockchain technology to decentralize the crowd economy. We used informal security analysis to illustrate how the proposed decentralized reputation model discourages misuse and encourages fairness between parties.

Keywords: Last-mile Delivery, Crowd-shipping, Blockchain, Reputation Models

References

[1] Dolan, S. (2023). The challenges of last mile delivery logistics and the tech solutions cutting costs in the final mile. https://www.insiderintelligence.com/insights/last-mile-delivery-shipping-explained.

Decentralized Proof of Delivery System with Blind Signature and Reputation-Based Trust Model for Last Mile Delivery

Vipul Malhotra

† University of Windsor

Abstract

Shipping a product from a warehouse shelf to a customer's doorstep might look simple initially, but it is a complicated and expensive operation in reality. Moving the product from the last distribution hub in the distribution channel to the final destination (residential or business address), also known as Last-Mile Delivery (LMD), is the costliest and time-consuming phase. Studies show that LMD accounts for 53% to 70% of the total cost of transportation. One of the main challenges in the LMD operations is proof-of-delivery (PoD). It is the responsibility of any LMD solution to provide Proof of Delivery (POD) to confirm that the purchased item is delivered to the customer (buyer). It makes both sender and receiver accountable because POD acts as proof that the sender sends the package to the correct destination, and the buyer receives the product in good condition. Most of today, PoD solutions uses paper and pen to collect customers' signatures as PoD and even when handheld devices are used, it is only to collect buyer signatures. Developing a secure and trusted PoD solution will increase logistics accuracy, improve customer experience, enhance packages visibility and tracking and reduce operational cost. Recently, digital signature and new technologies such as blockchain introduced an opportunity to improve logistics and LMD operations. Several works in the literature proposed PoD using blockchain and other cryptographic schemes. In our research, we investigated existing work; we selected the most promising solutions in the literature and implemented those solutions to test them against several scenarios. Based on our analysis, we identified several limitations in the existing work; some of these limitations are related to security, trust, and scalability. Finally, we propose a new PoD scheme using blockchain, blind signatures and a reputation-based trust model to overcome existing limitations in state-of-the-art PoD solutions.

Keywords: last mile, proof of delivery, blind signatures, reputation-based trust model

References

[1] Kirill, G. (2019). Overview of 9 blockchain consensus algorithms.URL: https:// digiforest.io/en/blog/blockchain-consensus-algorithms.

[2] Signatures, B. (2018). Blind Signatures. URL: https://www.sciencedirect.com/topics/computer-science/blind-signature

[3] Hasan H.R., Salah K. (2018) Blockchain-Based Solution for Proof of Delivery of Physical Assets. In: Chen S., Wang H., Zhang LJ. (eds) Blockchain – ICBC 2018. ICBC 2018. Lecture Notes in Computer Science, vol 10974. Springer, Cham. https://doi.org/10.1007/978-3-319-94478-4_10

[4] H. R. Hasan and K. Salah, "Blockchain-Based Proof of Delivery of Physical Assets With Single and Multiple Transporters," in IEEE Access, vol. 6, pp. 46781-46793, 2018, doi: 10.1109/ACCESS.2018.2866512.

[5] AlTawy, R., ElSheikh, M., Youssef, A. M., and Gong, G. (2017). Lelantos: Ablockchain-based anonymous physical delivery system. In2017 15th Annual Con-ference on Privacy, Security and Trust (PST), pages 15–1509.

[6] Malik, S., Dedeoglu, V., Kanhere, S., and Jurdak, R. (2019). Trustchain: Trustmanagement in blockchain and iot supported supply chains.

[7] Tuler de Oliveira, M., Reis, L., Medeiros, D., Carrano, R., Olabarriaga, S.,and Menezes, D. (2020). Blockchain reputation-based consensus: A scalable andresilient mechanism for distributed distrusting applications.Computer Networks,179:107367.

[8] Marti, S. and Garcia-Molina, H. (2006). Taxonomy of trust: Categorizing p2preputation systems.Computer Networks, 50:472–484.

[9] Zhao, Z. and Liu, Y. (2019). A blockchain based identity management systemconsidering reputation. In2019 2nd International Conference on Information Sys-tems and Computer Aided Education (ICISCAE), pages 32–36

[10] URL:https://medium.com/@treasureishere/last-mile-delivery-market-to-2027-global-analysis-and-forecasts-by-technology-ae2c04b6c9b4

[11] 9. Barclays (2014).The Last Mile: Exploring the online purchasing and de-livery journey. URL:https://docplayer.net/1342335-The-last-mile-exploring-the-online-purchasing-and-delivery-journey.html. [Online accessed 23-Feb-2021].

[12] 10. TransUnion (2020). Protecting the Last Mile of Retail E-Commerce: The Prevention of Shipping Fraud. URL:https://www.transunion.com/blog/prevention-of-shipping-fraud

On Statistical Learning of Branch and Bound for Vehicle Routing Optimization

Andrew Naguib†, Waleed A. Yousef†, Issa Traoré†, and Mohammad Mamun2

† University of Victoria
2National Research Council

Abstract

We examine the use of geometric deep neural networks to provide competent solutions, not necessarily incumbent, to the capacitated vehicle routing problem and the bin packing problem---which have non-deterministic polynomial computational complexity. The core idea is based on learning to approximate the decisions made by the branch and bound algorithm using the computationally expensive strong branching strategy. The classifiers - graph convolutional neural network, GraphSAGE, and graph attention network - are trained on six topologically different (to investigate the geographical dispersion effect on optimality) instances and evaluated on eight additional instances. The experiments we conducted show that the proposed approach is able to match the performance of the branch and bound algorithm and improve upon it on two different branching strategies, while requiring significantly less computation time and explored branching nodes.

Keywords: combinatorial optimization, deep learning, vehicle routing problem, bin packing problem

Evaluating Permissioned Blockchain Using Stochastic Modeling and Chaos Engineering

Shiv Sondhi1, Sherif Saad2, Mohammad Mamun3
† University of Windsor
National Research Council of Canada

Abstract

A critical component of any blockchain or distributed ledger technology (DLT) platform is the consensus algorithm. Blockchain consensus algorithms are the primary vehicle for the nodes within a blockchain network to reach an agreement. In recent years, many blockchain consensus algorithms have been proposed mainly for private and permissioned blockchain networks. However, the performance of these algorithms and their reliability in hostile environments or the presence of byzantine and other network failures are not well understood. In addition, the testing and validation of blockchain applications come with many technical challenges. In this paper, we apply chaos engineering and testing to understand the performance of consensus algorithms in the presence of different loads, byzantine failure and other communication failure scenarios. We apply chaos engineering to evaluate the performance of three different consensus algorithms (PBFT, Clique, Raft) and their respective blockchain platforms. We measure the blockchain network's throughput, latency, and success rate while executing chaos and load tests. We develop lightweight blockchain applications to execute our test in a semi-production environment. These experiments help in developing an understanding of blockchain system performance and selecting an appropriate blockchain platform to build our Last Mile Delivery system. Our results show that using chaos engineering helps understand how different consensus algorithms perform in a hostile or unreliable environment and the limitations of blockchain platforms. Thus our work demonstrates the benefits of using chaos engineering in testing complex distributed systems such as blockchain networks.

Keywords: Blockchain, consensus algorithms, chaos engineering

References

[1] M. S. Ferdous, M. J. M. Chowdhury, M. A. Hoque, and A. Colman, "Blockchain consensus algorithms: A survey," 2020.

[2] Y. Hao, Y. Li, X. Dong, L. Fang, and P. Chen, "Performance analysis of consensus algorithm in private blockchain," 06 2018, pp. 280–285.

[3] P.-Y. Piriou and J.-F. Dumas, "Simulation of stochastic blockchain models," 092018, pp. 150–157.

[4] B. Ampel, M. Patton, H. Chen, "Performance modelling of Hyperledger Sawtooth blockchain", 2019 IEEE ISI, pp. 59-61.

[5] D. Wybranietz, D. Haban, "Monitoring and performance measuring distributed systems during operation", 1988 ACM SIGMETRICS Conference on Measurement and Modelling of Computer Systems, NY, USA, p. 197-206.

Development of an AI Driver Intentionality and Action Predictor to Improve Safety in Urban Last Mile Delivery Operation

Mike Bauer *, Taufiq Rahman†

* University of Western Ontario, †National Research Council Canada

Abstract

Complex urban driving environments constitute the last mile of home delivery for online shopping. These environments are characterized by a variety of static and moving objects which can be distracting to drivers or missed while driving. This project aims to build an AI-based driver intentionality predictor that will augment and enhance typical advanced driver assistance systems (ADAS) to improve safety for last mile delivery operation. Since driver gaze directly correlates with driver intentionality and precedes driving action, this project will utilize a driver gaze monitoring system to develop an AI-based tool to predict driver intentionality and action. Such predictive tools can significantly improve the safety associated with last mile delivery in urban environments by broadening the time horizon of ADAS systems. These models provide an opportunity to implement proactive safety features that can help keep drivers aware of their environment in urban situations in order to help avoid dangerous situations. By complementing traditionally reactive advanced driver assistance system (ADAS) functionalities, this project aims to improve the safety of the last mile home delivery by continuously evaluating driver attention and alertness, and by predicting driver action against operating conditions.

The project will use an instrumented vehicle with multiple sensors to collect data about the driving environment as well as collect data on driver gaze. Sensors include stereo cameras for recording the driving environment, LiDAR for creating point clouds of the environment, and thermal camera, as well as vehicular data from CAN-bus. Data from actual drives utilizing a number of different drivers will be collected and used to evaluate and compare different machine learning methods to develop models of driver attentiveness and alertness by predicting and assessing driver maneuvers. In the long term, having models that predict driver intentionality and actions can provide additional information to an ADAS that can be used to alert the driver or take action to ensure the safety of the vehicle and driver or avoid likely accident scenarios.

Keywords: ADAS, Driver gaze, driver intentionality, prediction, driving safety.

Towards Driver-Centric Analysis in Advanced Driver Assistance Systems: Incorporating Multiple Environmental Sensors and Eye Gaze Data

Farhad Dalirani *

† Western University

Abstract

Advanced driver assistance systems (ADAS) have the potential to significantly improve driving safety by providing timely warnings and even taking control of the vehicle in critical situations. However, contemporary ADAS can potentially expand the current capabilities of perceiving and subsequently reacting to the situation at hand to attain a greater level of safety. By analyzing the driver and their interactions with the environment, inside and outside the vehicle, ADAS can integrate proactive safety elements to its current reactive operating mode. To achieve this goal, new technologies and algorithms such as computer vision, scene analysis, and predicting driver intentions and maneuvers must be leveraged. These approaches rely on data from multiple sensors, which must be processed and fused to provide a comprehensive snapshot of the vehicle, environment, and the driver. Additionally, solving spatio-temporal correspondence in multi-modal sensor data is a prerequisite for the implementation of sensor fusion techniques required for analyzing roadway scenes. Our work proposes a practical and scalable vehicular instrumentation approach that utilizes multiple environmental sensors along with driver eye gaze data to characterize and track driver intention and behavior in relation to the dynamic roadway environment. This approach offers a promising path for further research in ADAS incorporating driver-centric analyses. By incorporating driver behaviour and intentions, ADAS can offer a more personalized driving experience while enhancing driving safety. This approach is a valuable step towards the development of safer and more user-friendly ADAS. To this end, a research vehicle was equipped with various sensors and an onboard computer that collected multi-modal sensor data while in motion. The instrumentation includes RGB cameras, an RGB-D camera for eye tracking, a thermal camera, LiDAR, an IMU, a GNSS receiver, and a CAN bus monitor. A mobile high-performance computer is connected to these sensors to support data acquisition. Although temporal correspondence in the multi-modal sensor data was achieved by real-time acquisition under a single timestamp, spatial correspondence was solved by applying multiple cross-calibration techniques. For example, the intrinsic camera parameters for the RGB cameras were obtained by using standard calibration methods. Subsequently, the extrinsic calibration of the LiDAR and the RGB cameras were estimated by utilizing a targetless calibration algorithm. This algorithm leverages naturally occurring environmental features such as edges to determine the relative pose of LiDAR and RGB cameras. In order to estimate the cross-calibration between a LiDAR and a thermal camera, we proposed a novel algorithm that utilizes a calibration target to calibrate thermal and LiDAR sensors. Since the thermal camera operates in the long wave infrared spectrum, externally powered thermal markers were used to solve the feature correspondence in the calibration scene. The algorithm finds line and plane equations of the target's edges and plane in both modalities and then cross-calibrates the sensors using lines and plane correspondences. Major contributions of the presented work include development of an ADAS research platform that includes driver gaze data and cross-calibration of multi-modal sensors to enable robust roadway scene perception.

Keywords: Computer Vision, Sensor Fusion, Calibration, Multi-modal

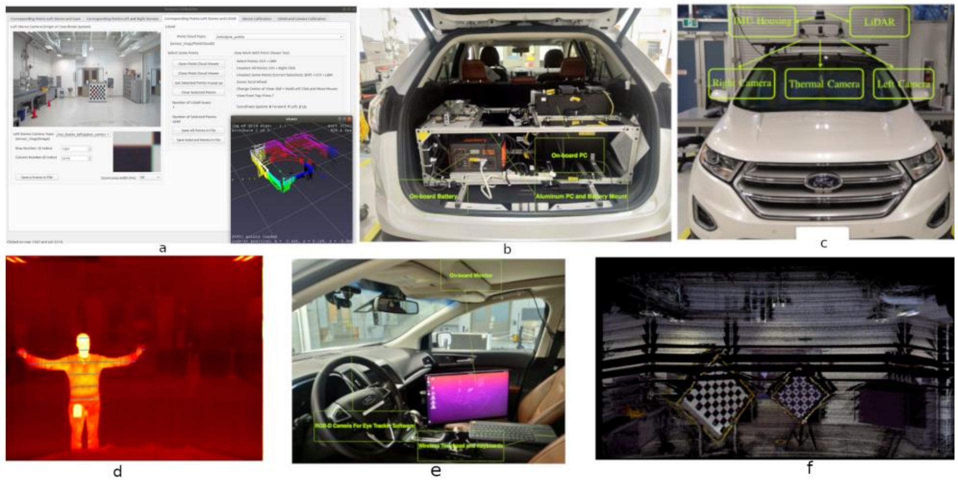


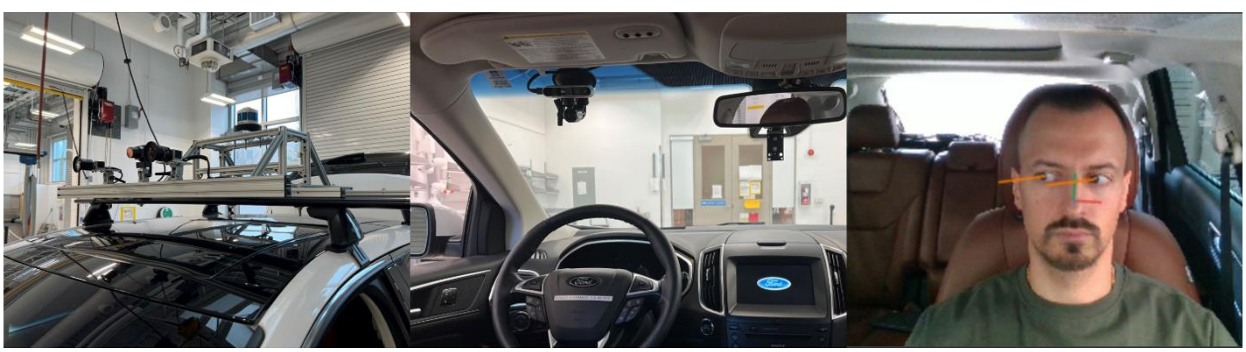
Illustration 1: a) A GUI for selecting points in LiDAR and Camera data. b) Trunk of car that includes PC, battery, etc. c) Front view of the car and mounted sensors. d) Result of thermal camera and LiDAR calibration. e) Inside of the car and gaze sensor. f) Result of LiDAR and RGB camera calibration.

Multi-Depth Cross-Calibration of Gaze Tracker with Stereoscopic and LiDAR Systems

Farzan Heidari*, Farhad Dalirani, Taufiq Rahman, Daniel Singh Cheema, Michael Bauer

Abstract

Driving is an active task that occurs in dynamic and complex environments with many factors. Drivers' actions within these environments and their resulting interactions with elements of these environments can result in dangerous driving situations for all road users. Prior studies show that the majority of all vehicle accidents are caused by human error. This has been the major motivation for advancements in Advanced Driving Assistance Systems (ADAS) that assist human drivers to perform the dynamic driving task (DDT). A driver's gaze can provide valuable information about the focus and intention in relation to DDT. Therefore, determining the degree of driver awareness and scene perception, and predicting driver actions can be valuable in the next generation of ADAS. Although tracking driver gaze can indicate whether a driver is paying attention to the road ahead, determination of where the driver is gazing at (i.e., point of gaze - PoG) creates the potential for not only evaluating the safety of DDT, but also for predicting the next driver action. However, determination of PoG requires that the gaze vector provided by a gaze-tracking system must be mapped to ADAS sensors with spatiotemporal correspondence. By leveraging a data acquisition system that can collect data from multiple sensor streams simultaneously under a common time reference, temporal correspondence can be established in the multimodal data provided by a gaze-tracking system and ADAS sensors such as stereoscopic and LiDAR systems. However, establishing spatial correspondence (i.e., cross-calibration) between a gaze-tracking system and ADAS system requires that the relative positions and orientations (i.e., pose) of the different sensors must be known. Typical cross-calibration approaches that rely on identification of the same markers/features present in the common fields of view (FOV) of different sensors cannot be applied here. Because ADAS sensors such as stereoscopic and LiDAR systems are pointed outward for the purpose of characterizing the roadway environment, their fields of view do not intersect with that of a gaze-tracking system, which is typically focused on a driver's face. In addition, the dissimilar sensing modalities of gaze-tracking systems and ADAS sensors further complicate the problem. In this study, we present an efficient closed-form solution for the cross-calibration problem. Further, we introduce a novel closed-form cross-calibration method to re-project the driver's gaze vector provided by the gaze tracker in its frame of reference to the LiDAR's frame of reference. We also propose a method to estimate the driver's PoG in the sparse LiDAR point cloud. In order to provide more information about the driver's attention, we introduce a technique to calculate the driver's visual attention area in the 3D space. We empirically demonstrate that our proposed cross-calibration of the gaze tracker with the stereoscopic vision systems obtains significantly superior results for estimating PoG when compared with a previously reported iterative approach. We also show that our proposed multi-depth cross-calibration of gaze tracker and LiDAR Systems yields excellent results to find the transformation matrix between the gaze tracker and LiDAR coordinate systems.



Keywords: cross-calibration, gaze tracker, stereoscopic vision system, LiDAR

A) (left): The physical configuration of the stereoscopic vision system and LiDAR mounted on the roof of the vehicle
B) (center): Remote gaze tracking system attached to the windshield
C) (right): Example of the gaze tracker system. The gaze direction appears in orange, and the head pose is a small red-green-blue orientation mark.

Medium Range Sea Ice Presence Forecasting using AI

Zacharie Gousseau*†, K. Andrea Scott†, Philippe Lamontagne††

† Department of Systems Design Engineering, University of Waterloo

†† Ocean, Coastal and River Engineering Research Centre, National Research Council Canada

Abstract

Accurate seasonal forecasts of sea ice in northern waters are critical to ensure the safe passage of ships through ice-infested waters and provide adequate lead time for logistics planning. This study presents a machine learning framework that uses graph convolutional recurrent networks (GCRN) to produce seasonal (90-day) daily ice presence forecasts. The proposed method models ice dynamics on a mesh rather than a two-dimensional grid which allows greater flexibility than approaches based on the convolutional neural network (CNN). Sea ice maps are first transformed into meshes by way of a quadtree decomposition algorithm which maintains high resolution in areas of high spatial variability (e.g., at the ice edge) while reducing the resolution in areas of low variability (e.g., over large swaths of open water). The resulting mesh is interpreted as a graph by placing nodes at the center of each mesh cell, and edges between any two neighboring cells. The decomposition may be performed once over a region to model on a static graph or at each timestep to model over a dynamic graph, though the latter requires considerably greater computation. The GCRN learns spatial patterns over the mesh using the transformer convolution [1] which uses multi-head attention to selectively attend to neighboring nodes, and temporal patterns using a long-short term memory (LSTM) module. The model adopts an encoder-decoder sequence-to-sequence structure, which allows for forecasting longer sequences while avoiding the issue of compounding errors present in autoregressive models.

Keywords: Sea ice forecasting, graph neural networks, attention, spatiotemporal modelling

References

[1] Y. Shi, Z. Huang, S. Feng, H. Zhong, W. Wang, and Y. Sun, “Masked Label Prediction: Unified Message Passing Model for Semi-Supervised Classification,” in Proceedings of the Thirtieth International Joint Conference on Artificial Intelligence, Montreal, Canada: International Joint Conferences on Artificial Intelligence Organization, Aug. 2021, pp. 1548–1554. doi: 10.24963/ijcai.2021/214.

RailTwin: A Digital Twin Framework for Railway

Rahatara Ferdousi*
† University of Ottawa

Abstract

The development of accurate and reliable railway defect detection systems is crucial for ensuring the reliability of railway operations. With the emergence of Digital Twin (DT) , there is an increasing demand for advanced computer vision techniques that can enable Structural Health Monitoring (SHM) of railway infrastructure. However, accurate and efficient defect detection is a key requirement for realizing this SHM. Therefore, there is a need for developing effective defect detection methods that can be integrated into DT models of railway infrastructure. We propose the RailTwin framework [1] as a solution to enable railway systems to achieve the DT beyond traditional structural modeling or information systems. RailTwin combines current state insight, future state foresight, and current and future state oversight for automation and actuation. Artificial Intelligence (AI) technologies such as Deep Learning, Transfer Learning, Reinforcement Learning, and Explainable AI are employed by RailTwin to estimate future states and determine actions beforehand [2]. We demonstrate the potential of RailTwin for health inspection of railway transportation through a use case for SHM. Moreover, the research designed the architecture of a reusable AI model for railway defect detection that uses the RailTwin framework. The AI model ensembles fine-tuned transfer learning models, including VGG-19, MobileNetV3, and ResNet-50, to combine the strengths of multiple deep neural networks for rail defect classification. In addition, the transfer learning mechanism in this model addresses the issues of lower accuracy and overfitting issue due to training a defect classifier with lower samples from scratch. We employed the Canadian Public Railway (CPR) dataset to evaluate the RailTwin Framework and its reusable AI model through empirical analysis. The SHM use case demonstrates RailTwin's potential for automation in railway health inspection using AI. The reusable AI model shows promising results for enhancing the accuracy of the railway defect detection systems. The outcome of our study can be utilized for further research in AI-enabled railway transportation, leading to reliable health inspection for transportation systems.

Keywords: Digital Twin, AI, Structural Health Monitoring, Railway

References

[1] R. Ferdousi, F. Laamarti, C. Yang and A. El Saddik, "RailTwin: A Digital Twin Framework For Railway," 2022 IEEE 18th International Conference on Automation Science and Engineering (CASE), Mexico City, Mexico, 2022, pp. 1767-1772, doi: 10.1109/CASE49997.2022.9926529.

[2] C. Yang, R. Ferdousi, A. El Saddik, Y. Li, Z. Liu and M. Liao, "Lifetime Learning-enabled Modelling Framework for Digital Twin," 2022 IEEE 18th International Conference on Automation Science and Engineering (CASE), Mexico City, Mexico, 2022, pp. 1761-1766, doi: 10.1109/CASE49997.2022.9926693.

Collecting Instructor Feedback to Develop an Adaptive Instructional System for Simulation-Based Lifeboat Training

Jennifer Smith*1, Reza Zeinali-Torbati2, Randy Billard3, Bruno Emond4, and Brian Veitch2

[1] Marine Institute of Memorial University of Newfoundland, St. John's, NL, Canada
[2] Faculty of Engineering, Memorial University of Newfoundland, St. John's, NL, Canada
[3]Virtual Marine, St. John's, NL, Canada
[4]National Research Council of Canada, Ottawa, ON, Canada

Abstract

Lifeboat simulators afford opportunities for seafarers to practice safety critical tasks to keep their skills current in the event of emergencies. The lifeboat simulator technology reproduces credible conditions (i.e., weather and sea states, vessel motions, etc.) for learners to carry out the actions of launching and maneuvering a virtual lifeboat. The instructor plays an equally vital role in the learning process, as they assess and provide qualifying feedback to the learner on their performance. The augmented feature of simulation-based training is the joint effort of the technology and the instructor working together to create opportunities for deliberate practice. These interactions help the student learn how to perform specific tasks and challenge them to think critically on the decisions they make and what information they need to pay attention to in these unpredictable situations.

This presentation at the AI4L mini-conference places particular attention on the lifeboat instructor to understand their collective ways of teaching, assessing, and debriefing students for the purposes of developing an adaptive instructional system (AIS). Integrating an AIS can further enhance simulation-based lifeboat training as it can offer opportunities to reduce instructor workload, automate assessment, and customize feedback. An AIS can be designed to diagnose the learner's needs and recommend deliberate practice exercises in response to the learner's needs. This presentation will outline the lessons learned from a pilot study designed to gather information from instructors to develop the instructional model of an AIS for simulation-based lifeboat training. The goal is to attune the AIS to the teaching and assessment strategies of the instructors.

The pilot study [1] involved semi-structured virtual interviews with three lifeboat instructors. As part of the interviews, the instructors described how they use simulation-based training to not only help trainees practice, but to also build the trainees' confidence and leadership skills as coxswains. The instructors were also asked to watch video examples of lifeboat operations in a simulator. Specifically, the videos showed a trainee launching the lifeboat, clearing away from an offshore installation, and operating the lifeboat in a series of slow speed manoeuvring exercises (e.g., steering by compass, picking up a person in the water, and coming alongside a vessel, etc.). Following each video, the instructor was asked questions on how they would provide instruction, assessment, and feedback to the example students. The insights from the interviews were used to develop a conceptual instructional model for an AIS. Future work will program the AIS and test its functionality for prescribing practice exercises and providing corrective feedback to trainee lifeboat coxswains.

Keywords: Lifeboat Training, Simulation-Based Training, Adaptive Instructional Systems, Instructor Feedback

References

[1] Smith, J., Zeinali-Torbati, R., Billard, R., Emond, B., and Veitch, B. (2023). Developing an adaptive instructional system for simulation-based lifeboat training using instructor feedback. Accepted for presentation at 14th International Conference on Applied Human Factors and Ergonomics (AHFE), San Francisco, CA, USA.

Application of Adaptive Instructional Systems in Simulation-Based Lifeboat Training using Bayesian Networks

Reza Zeinali-Torbati *1, Jennifer Smith 2, Randy Billard 3, Bruno Emond 4, Joshua Barnes 4, Brian Veitch 1
[1] Memorial University of Newfoundland, St. John's, Canada
{r.zeinalitorbati,bveitch}@mun.ca
2 Marine Institute, St. John's, Canada
jennifer.smith@mi.mun.ca
3 Virtual Marine, Paradise, Canada
randy.billard@virtualmarine.ca
4 National Research Council Canada, Ottawa, Canada
{bruno.emond,joshua.barnes}@nrc-cnrc.gc.ca

Abstract

Adaptive instructional systems (AISs) are computer-based learning technologies that utilize artificial intelligence to customize the learning experience according to learners' competence, psychological states, and preferences [1]. The majority of educational systems lack adaptability and provide the same instructional material to all learners. Simulation-based lifeboat training facilitated by human instructors is an instance of this, where seafarers are trained for typical offshore emergency drills through virtual scenarios using identical materials and situations, regardless of their competencies. The objective of this pilot study is to develop an AIS for simulation-based lifeboat training, which aims to enhance learners' performances and automate the role of a human instructor.

This study builds on a previous study [2] that developed a task-based lifeboat coxswain competence model for slow-speed maneuvering (SSM) through Bayesian Networks (BNs) informed by simulator and expert data. Here BNs are used to develop a behavioral competence model to provide a framework for evaluating learners' competencies. The states of BN for learners' behaviors are determined from their performance in simulated scenarios during each task. A typical training scenario includes several launching and SSM tasks. The BN for launching primarily comprises procedural nodes, whereas the BN for SSM is more intricate and includes skill-based behavioral nodes such as speed, approach direction with respect to the wind, stopping time, and proximity. While performing the scenarios, the simulator's log files record evidence of the learners' performance behaviors for various subtasks within the scenarios (e.g., picking up persons in water, retrieving a life raft, and stopping by an offshore supply vessel). Using a pre-defined scoring system, the captured data is converted into BN states and used as input for the BNs to infer the competencies of the learners.

The competence model will be validated by generating and using large representative data sets to confirm that the developed model can 1) be updated based on new data, 2) show sensitivity to anomaly data from high/low performance population, and 3) diagnose high/low performance population with a high predictive accuracy. The successful assessment of the competence model will be followed by collecting large data sets from lifeboat simulators to train/validate the model before it can be integrated with machine learning algorithms and instructor feedback [3] to develop an AIS for simulation-based lifeboat training.

The competence model enables clear evaluation of learners' abilities at various levels of detail and has the capacity to reveal specific behaviors that result in successful completion of a given task in simulation-based lifeboat training. The model is additionally capable of automating the learners' classification process based on their competencies, which enables personalized and intelligent safety instructions concerning emergency lifeboat operations. The findings of this study provide an advancement in the use of AISs for maritime safety simulation-based training particularly in lifeboat training, as well as an empirical evidence that incorporating AISs enhance learners' ability to acquire new skills and accelerates their path towards proficiency.

Keywords: Adaptive instructional systems, simulation-based lifeboat training, Bayesian networks, marine safety operations.

References

[1] Sottilare, R., and Brawner, K. (2018). Exploring standardization opportunities by examining interaction between common adaptive instructional system components. In Proceedings of the 1st Adaptive Instructional Systems (AIS) Standards Workshop, US Army Research Laboratory, Orlando, FL, USA.

[2] Billard, R., Smith, J., Masharraf, M., and Veitch, B. (2020). Using Bayesian networks to model competence of lifeboat coxswains. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 14, 585-594.

[3] Smith, J., Zeinali-Torbati, R., Billard, R., Emond, B., and Veitch, B. (2023). Developing an adaptive instructional system for simulation-based lifeboat training using instructor feedback. Accepted for presentation at 14th International Conference on Applied Human Factors and Ergonomics (AHFE), San Francisco, CA, USA.

Intelligent Trailer Allocation and Truck Routing Using Deep Reinforcement Learning

Saeid Kalantari*, Yunli Wang†, Sun Sun†, Xin Wang*

* Department of Geomatics Engineering, University of Calgary, Calgary, Alberta, Canada
† Digital Technology Research Center, National Research Council Canada, Ottawa, Ontario, Canada

Abstract

The transportation industry plays a crucial role in the global economy, facilitating the movement of goods from producers to consumers [1]. Population growth, increasing urbanization, and e-commerce expansion in North America have made the Pickup and Delivery (PD) of goods one of the key challenges in logistics management [2]. Research on the trucking industry shows that depending on the product being delivered, the value of transit time is estimated to be in the range of $25 to $200 per hour [3], [4]. Therefore, optimizing the decision-making in logistics management has huge environmental, social, and economic impacts. One of the most important problems in PD logistics is how to optimally allocate hundreds or even thousands of trailers to the orders made by the customers, on top of assigning vehicles/trucks [1], [5]. As can be seen in Figure 2, the question is: given a set of orders, trucks, trailers, and customer locations, how can we assign trucks to pickup the trailers after being allocated to the orders to optimize the total traveling distance?

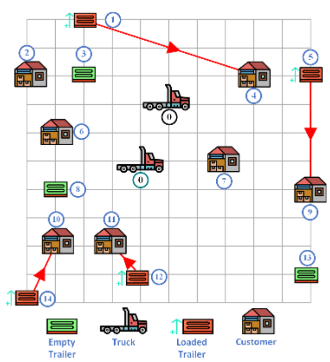


Figure 2 The problem of trailer allocation and truck routing for customer orders

In general, we can view the problem as two phases: assigning trailers to delivery orders and then finding the routes for navigating through all the orders. Since we try to find the optimal distance between trailers to the orders, this assignment problem can be considered as a bipartite matching problem [6], which is known to be NP-hard [7]. After the assignment of trailers, trucks need to be navigated to fulfill these demands, which itself is another NP-hard Combinatorial Optimization (CO) problem, named Vehicle Routing Problem (VRP) [8], [9] or specifically VRP with Mixed Pickup and Delivery (VRPMPD) [10]–[15]. In addition, utilization of Pointer Networks (PN) [16] and Graph Neural Networks (GNN) [17], [18] led to research by Nazari et al. and Kool et al. [19], [20], in which they use Deep Reinforcement Learning (DRL) to solve CO problems. However, to the best of our knowledge, sequential passing of origin and destination in VRPMPD presented in this research has not yet been investigated.

This project proposes a novel framework called Allocation and Routing for Trailers and Trucks using Deep Reinforcement Learning (ARTT-DRL) for a frequent special case in the truck industry. It is the first study to apply Bipartite Graph Assignment (BGA) for trailer allocation and DRL for truck routing incorporating strict orders with origins and destinations. The contributions of this project are as follows:

ARTT-DRL breaks down the problem into two sub-problems using a BGA heuristic to assign trailers to orders and an attention-based DRL to route the trucks, reducing computational cost.

ARTT-DRL allocates trucks to partial routes resembling trailer movement to generate full routes that include all orders.

To evaluate effectiveness, ARTT-DRL is applied to a real-world setting and results are visualized on a map using ESRI's ArcGIS Pro for transportation network analysis and visualization.

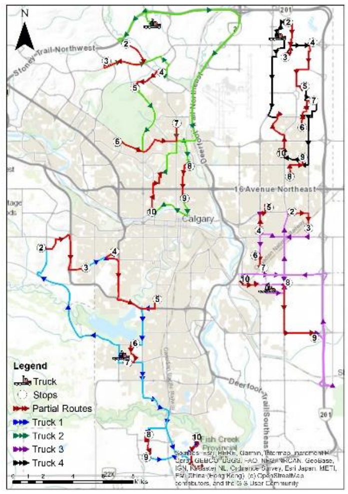


Figure 3 A sample of generated routes for the trucks. The lines with red color indicate the partial routes from trailers to customers which is the result of the trailer-customer allocation phase and other colored lines show the complete routes resulting from attention based-DRL phase for each truck.

Figure 3 shows an example of the solutions generated by ARTT-DRL on real-world data in the city of Calgary, Alberta. In summary, we solved the strict PD problem by allocating trucks, trailers, and customers in two phases using a graph-based heuristic and attention-based DRL. We evaluated our approach using two datasets and achieved significant improvement over baseline methods, demonstrating the effectiveness of ARTT-DRL for different order sizes.

Keywords: Graph Neural Networks, Deep Reinforcement Learning, Vehicle Routing Problem, Truck Transportation, Combinatorial Optimization

References

[1] W. B. Powell and H. Topaloglu, “Approximate Dynamic Programming for Large-Scale Resource Allocation Problems,” in *Models, Methods, and Applications for Innovative Decision Making*, in INFORMS TutORials in Operations Research. INFORMS, 2006, pp. 123–147. doi: 10.1287/educ.1063.0027.

[2] D. McFarlane, V. Giannikas, and W. Lu, “Intelligent logistics: Involving the customer,” *Comput. Ind.*, vol. 81, pp. 105–115, Sep. 2016, doi: 10.1016/j.compind.2015.10.002.

[3] Cambridge Systematics, “Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation,” FHWA-HOP-05-064, Sep. 2005. Accessed: Nov. 23, 2022. [Online]. Available: https://rosap.ntl.bts.gov/view/dot/20656

[4] D. Chen, J. Ignatius, D. Sun, M. Goh, and S. Zhan, “Impact of congestion pricing schemes on emissions and temporal shift of freight transport,” *Transp. Res. Part E Logist. Transp. Rev.*, vol. 118, pp. 77–105, Oct. 2018, doi: 10.1016/j.tre.2018.07.006.

[5] H. P. Simão, A. George, W. B. Powell, T. Gifford, J. Nienow, and J. Day, “Approximate Dynamic Programming Captures Fleet Operations for Schneider National,” *Interfaces*, vol. 40, no. 5, pp. 342–352, Oct. 2010, doi: 10.1287/inte.1100.0510.

[6] R. M. Karp, U. V. Vazirani, and V. V. Vazirani, “An optimal algorithm for on-line bipartite matching,” in *Proceedings of the twenty-second annual ACM symposium on Theory of Computing*, in STOC ’90. New York, NY, USA: Association for Computing Machinery, Apr. 1990, pp. 352–358. doi: 10.1145/100216.100262.

[7] M. R. Garey and D. S. Johnson, *Computers and intractability: a guide to the theory of NP-completeness*, 27. print. in A series of books in the mathematical sciences. New York [u.a]: Freeman, 2009.

[8] M. Deudon, P. Cournut, A. Lacoste, Y. Adulyasak, and L.-M. Rousseau, “Learning Heuristics for the TSP by Policy Gradient,” in *Integration of Constraint Programming, Artificial Intelligence, and Operations Research*, W.-J. van Hoeve, Ed., in Lecture Notes in Computer Science. Cham: Springer International Publishing, 2018, pp. 170–181. doi: 10.1007/978-3-319-93031-2_12.

[9] I. Bello, H. Pham, Q. V. Le, M. Norouzi, and S. Bengio, “Neural Combinatorial Optimization with Reinforcement Learning.” arXiv, Jan. 12, 2017. doi: 10.48550/arXiv.1611.09940.

[10] J. Chen, Z. Zong, Y. Zhuang, H. Yan, D. Jin, and Y. Li, “Reinforcement Learning for Practical Express Systems with Mixed Deliveries and Pickups,” *ACM Trans. Knowl. Discov. Data*, p. 3546952, Jul. 2022, doi: 10.1145/3546952.

[11] H. Hernández-Pérez and J.-J. Salazar-González, “A branch-and-cut algorithm for a traveling salesman problem with pickup and delivery,” *Discrete Appl. Math.*, vol. 145, no. 1, pp. 126–139, Dec. 2004, doi: 10.1016/j.dam.2003.09.013.

[12] S. Majidi, S.-M. Hosseini-Motlagh, and J. Ignatius, “Adaptive large neighborhood search heuristic for pollution-routing problem with simultaneous pickup and delivery,” *Soft Comput.*, vol. 22, no. 9, pp. 2851–2865, May 2018, doi: 10.1007/s00500-017-2535-5.

[13] H. N. Psaraftis, “k-Interchange procedures for local search in a precedence-constrained routing problem,” *Eur. J. Oper. Res.*, vol. 13, no. 4, pp. 391–402, Aug. 1983, doi: 10.1016/0377-2217(83)90099-1.

[14] L. J. J. van der Bruggen, J. K. Lenstra, and P. C. Schuur, “Variable-Depth Search for the Single-Vehicle Pickup and Delivery Problem with Time Windows,” *Transp. Sci.*, vol. 27, no. 3, pp. 298–311, Aug. 1993, doi: 10.1287/trsc.27.3.298.

[15] J. Crispim and J. Brandão, “Metaheuristics applied to mixed and simultaneous extensions of vehicle routing problems with backhauls,” *J. Oper. Res. Soc.*, vol. 56, no. 11, pp. 1296–1302, Nov. 2005, doi: 10.1057/palgrave.jors.2601935.

[16] O. Vinyals, M. Fortunato, and N. Jaitly, “Pointer Networks.” arXiv, Jan. 02, 2017. doi: 10.48550/arXiv.1506.03134.

[17] H. Dai, E. B. Khalil, Y. Zhang, B. Dilkina, and L. Song, “Learning Combinatorial Optimization Algorithms over Graphs.” arXiv, Feb. 21, 2018. doi: 10.48550/arXiv.1704.01665.

[18] A. Nowak, S. Villar, A. S. Bandeira, and J. Bruna, “A Note on Learning Algorithms for Quadratic Assignment with Graph Neural Networks,” p. 6.

[19] M. Nazari, A. Oroojlooy, L. V. Snyder, and M. Takáč, “Reinforcement Learning for Solving the Vehicle Routing Problem.” arXiv, May 21, 2018. doi: 10.48550/arXiv.1802.04240.

[20] W. Kool, H. van Hoof, and M. Welling, “Attention, Learn to Solve Routing Problems!,” presented at the International Conference on Learning Representations, Feb. 2022. Accessed: Oct. 14, 2022. [Online]. Available: https://openreview.net/forum?id=ByxBFsRqYm

Deep Reinforcement Learning for Drayage Operations: A Solution to Complex Scheduling and Planning Problems

Hadi Aghazadeh, Yunli Wang, Sun Sun, Xin Wang*

† Intelligent Geospatial Data Mining Lab (IGDM), University of Calgary, Calgary, Canada
† National Research Council Canada, Canada
† National Research Council Canada, Canada
† Intelligent Geospatial Data Mining Lab (IGDM), University of Calgary, Calgary, Canada

Abstract

Drayage Operations is a crucial component of the supply chain that involves delivering products from a distribution center or terminal to the final destination [1]. However, this process is complex and costly due to several factors, such as managing multiple customer orders with specific requirements and time windows, as well as managing internal resources efficiently. Drayage operations companies need to address three key issues related to their internal resources sequentially: Trailer pool management, Route planning, and Driver scheduling.

Trailer pool management requires balancing the load and empty trailer levels in yards and finding necessary movements at each time step based on load demand and demand-dependent empty trailer repositioning. The resources involved in this complexity are demonstrated in Figure 1 [2].

Route planning is another critical aspect of drayage operations that requires careful attention. The system must assign trailer repositioning obtained from trailer pool management to tractors to create feasible routes that respect time and resource constraints related to tractors. This involves developing a comprehensive understanding of the various constraints, including the availability of tractors, the amount of freight, the capacity of the tractor and compatibility with the assigned trailer, the distance between the pickup and delivery locations, and any applicable regulations.

Finally, driver scheduling is a critical component of drayage operations, as it involves assigning routes to drivers based on their availability, workload balance, and other factors. This requires a thorough understanding of the driver's work schedules, personal preferences, and other constraints, such as regulatory requirements and labor laws. The management of the three phases involved in drayage operations while accommodating compounded constraints gives rise to a complex problem that is challenging to resolve.

Traditional methods for solving drayage operations problems heavily rely on Operation Research algorithms like Mix-integer Linear Programming (MILP) [3]. However, these methods have limitations in handling the dynamicity of changing states of resources through time and are computationally expensive. Each minor change requires the model to be run from scratch [4]. Therefore, this project proposes the use of Deep Reinforcement Learning (DRL) algorithms as a solution to the limitations of traditional methods for solving drayage operations problems.

DRL is an advanced artificial intelligence algorithm that can learn how to take optimal action and learn the dynamicity of an environment only by observing the environment and doing systematic trial and error.

The objective of this research is to develop a DRL algorithm to dispatch heterogeneous trucks with respect to time, internal resources, and order constraints with minimum costs and maximum customer satisfaction. The proposed methodology involves training the DRL algorithm using a dataset of historical delivery data, which will enable the algorithm to learn how to optimize the dispatch of trucks for future deliveries.

In summary, solving drayage operations problems emphasizes the significance of effective resource management in logistics operations. By focusing on trailer pool management, route planning, and driver scheduling, the project can optimize its operations and improve the efficiency of its logistics network.

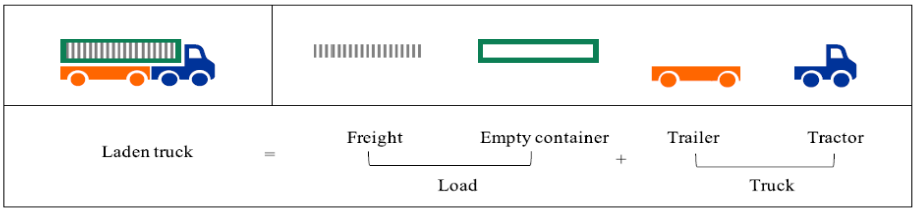


Fig.1 – Internal resources in Drayage Operations [2]

Keywords: Drayage Operations, Pickup and Delivery, Deep Reinforcement Learning, Logistics

References

[1] Zhang, R., Huang, C., & Wang, J. (2020). A novel mathematical model and a large neighborhood search algorithm for container drayage operations with multi-resource constraints. Computers & Industrial Engineering, 139, 106143.

[2] Chen, R., Meng, Q., & Jia, P. (2022). Container port drayage operations and management: Past and future. Transportation Research Part E: Logistics and Transportation Review, 159, 102633.

[3] Shiri, S., & Huynh, N. (2016). Optimization of drayage operations with time-window constraints. International Journal of Production Economics, 176, 7-20.

[4] Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. European Journal of operational research, 153(2), 400-416.

Robust and Adaptive Control Strategies for Aerial Manipulation under Uncertain Conditions: A Novel Hybrid Approach[1]

Sina Sajjadi
† Visiting Ph.D. Candidate, Toronto Metropolitan University

Abstract

Aerial manipulation is a technique that involves the use of Uncrewed Aerial Vehicles (UAVs) or drones to manipulate objects while airborne. This technique has gained interest due to its efficiency, flexibility, and cost-effectiveness, especially in hazardous or hard-to-reach environments. The recent advancements in UAV technology, coupled with the potential applications of aerial manipulation in diverse fields, have sparked considerable interest among industry and academia. The escalating interest in this domain is anticipated to yield novel and fascinating advancements in aerial manipulation, with significant prospects for numerous fields, including but not limited to agriculture, construction, search and rescue, and logistics. Consequently, there has been a noticeable surge in research endeavours, directed toward investigating the potential and limitations of aerial manipulation techniques, while simultaneously devising pioneering methodologies to enhance their efficiency, robustness, and adaptability.

Developing a robust and adaptive controller for aerial manipulation systems is of paramount importance, but it also poses significant challenges. Firstly, aerial manipulators are subject to a wide range of endogenous and exogeneous uncertainties, such as wind disturbances, turbulence, sensor (camera, lidar, IMU) noise, unmodeled dynamics, and incorrect model parameters. These uncertainties can make it difficult to accurately sense and control the UAV's motion. Secondly, aerial manipulators must account for the dynamics of the object being manipulated, which can be complex and challenging to model accurately. Thirdly, UAVs have limited power and computational resources, which can constrain the complexity of control algorithms that can be implemented. Finally, aerial manipulators operate in 3D space, which can add additional complexity to the control problem compared to ground-based manipulation systems.

Both exogenous and endogenous sources of uncertainties pose significant challenges to the development of robust and adaptive control strategies for aerial manipulation. Therefore, it is crucial to account for these uncertainties and develop control strategies that can mitigate their effects on the system's performance. To address these challenges, researchers have explored a variety of control strategies for aerial manipulators. These approaches attempt to address the uncertainties and complexities inherent in aerial manipulation tasks by accounting for the dynamics of the manipulated object and adapting the control strategy in real-time based on sensory feedback. However, despite the significant progress made in developing controllers for aerial manipulators, due to the substantial impact of the uncertainties in the perception and motion control of the aerial manipulation systems, there are still many challenges that must be overcome to enable the widespread adoption of these systems in practical applications.

In this research work, we are developing novel and state-of-art control frameworks that combine model-based and data-driven techniques to achieve robust and adaptive control of aerial manipulation systems under uncertain conditions. Specifically, we employ hybrid control architectures that integrate model predictive controllers with machine-learning-based algorithms, enabling the system to learn uncertainties from its own experience and adapt to environmental changes. We demonstrate the effectiveness of our approach through extensive simulation studies and experimental validations on a real aerial manipulator platform. The results are expected to show that our proposed controllers are capable of achieving stable and precise manipulation tasks even in the presence of significant uncertainties and disturbances.

Keywords: Unmanned Aerial Vehicle, Unmanned Aerial Systems, Uncertainty, Robust Control, Machine Learning

[1] Combining Model-Based and Data-Driven Techniques to Mitigate Uncertainties and Enhance Performance

Domain Shift through Aerial-View Object Detection in Vision Data

Fardad Dadboud†*, Varun Mehta††, Miodrag Bolic†, Iraj Mantegh††

† School of Electrical Engineering and Computer Science, University of Ottawa

†† Aerospace Research Centre, National Research Council Canada

Abstract

Drones, also known as unmanned aerial vehicles (UAVs), have grown in popularity in recent years due to their adaptability and cost-effectiveness across a variety of applications. They are used for aerial photography, surveillance, delivery, agriculture, and search-and-rescue missions. However, their widespread use has led to autonomy-related security and safety concerns, such as the possibility of crashing into other flying or static objects. Therefore, reliable and efficient detection and classification of drones and other objects from the view of the drone have become an absolute necessity [1].

Our results have been published and presented in this work [2], and we won second place in the Drone-versus-Bird Detection competition held in the 4th WOSDETC of IEEE AVSS 2021. To address the detection and classification challenge between drones and birds, we deployed a vision-based drone detector based on YOLOV5. In addition to the released dataset of the competition, which consists only of ground-view data, we utilized an air-to-air dataset. There are still unresolved issues regarding small, distant objects, data imbalances, and unseen backgrounds.

Using a Bosch PTZ camera, we have also obtained ground-view video footage. The fact that our target objects are drones and Other Flying Objects (OFO) from two distinct classes that share some components may result in confusion regarding their classification. Our ground-view videos feature footage captured by various DJI drone models from 100m to 1.5 km away. Our dataset contains approximately 200,000 annotated frames. We eventually created different sets that replicate the issues in our dataset, such as occlusion, distant small objects, and diverse backgrounds. We face the possibility of a domain shift in relation to different data sets.

As is evident, the majority of our work has been completed using ground-view data. Regarding the autonomy of drones, our input data will undergo a domain shift, in terms of different view and unseen backgrounds, resulting in a high level of uncertainty in the target domain. In this presentation, we will demonstrate our efforts to capture uncertainty and adapt our computer vision methods to our target domain using domain adaptation techniques [3].

Keywords: Deep-Learning, Object-Detection, Domain-Adaptation, UAV, Drone

References

[1] M. A. Khan, H. Menouar, A. Eldeeb, A. Abu-Dayya, and F. D. Salim, “On the detection of unauthorized drones-techniques and future perspectives: A review,” IEEE Sensors Journal, 2022.

[2] F. Dadboud, V. Patel, V. Mehta, M. Bolic, and I. Mantegh. Single-Stage UAV Detection and Classification with YOLOV5: Mosaic Data Augmentation and PANet. In 2021 17th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS), pages 1–8. IEEE, 2021.

[3] Csurka, G., Hospedales, T. M., Salzmann, M., and Tommasi, T. (2022). Visual domain adaptation in the deep learning era. Synthesis Lectures on Computer Vision, 11(1):1–190

Deep learning-Based Drone Localization using 2D Image

Hamid Azad†*, Fardad Dadboud†, Varun Mehta††, Miodrag Bolic†, Iraj Mantegh††

† School of Electrical Engineering and Computer Science, University of Ottawa

†† Aerospace Research Centre, National Research Council Canada

Abstract

In recent years, drones have become increasingly popular for various applications such as surveillance, inspection, and delivery. One of the key challenges in drone navigation is accurate localization, which is necessary for safe and efficient operation. As a particular scenario, consider the case where more than one drone (here, two) are employed for infrastructure inspection and there is a camera mounted on the chasing drone. The captured 2D images by the camera can be utilized to extract the 3D localization information of the follower drone to avoid collision between the drones.

To address this problem, a deep learning-based method has been used to estimate the distance between the drones. The approach uses a convolutional structure to predict the distance of the drone based on the features extracted from the 2D image. The network considers the distance estimation problem as a regression one. Besides, the elevation and azimuth angles of the follower drone with respect to the chaser one are estimated using the pixel information of the drone's position in the captured image.

The most important drawback of the proposed method is the necessity to have a huge amount of training data. Performing practical tests to collect such amount of data generally involves high-cost as well as time-consuming procedures. Additionally, the environmental conditions are not completely under control during the test. However, there is usually the possibility to have various conditions in the simulation environment without any additional costs. Thus, to train the deep network and evaluate the performance of the proposed method, a simulated dataset using AirSim [1] has been prepared, which includes a variety of scenarios such as different lighting conditions, and drone positions. The dataset is designed to mimic real-world scenarios and provides a reliable benchmark for evaluating the performance of the proposed method.

The final trained regressor network is also applied to some collected practical data. The data is recorded from some limited flying scenarios as well as a fixed drone on the ground at some distance from the camera. The proposed method has shown promising results in accurately estimating the distance of drones in these scenarios.

In conclusion, the proposed approach for 3D localization of drones using 2D captured images represents a significant step in the field of drone navigation and collision avoidance. The use of a simulated dataset provides a valuable resource for evaluating the performance of localization methods in a controlled and repeatable manner. Furthermore, the initial acceptable results on the practical data show that the proposed method can be potentially used for drone localization using 2D images in real-world scenarios.

Keywords: Drone localization, deep learning, optical sensor, synthetic data, AirSim

References

[1] S. Shah, D. Dey, C. Lovett, and A. Kapoor,"Airsim: High-fidelity visual and physical simulation for autonomous vehicles", in Field and Service Robotics. Springer Proceedings in Advanced Robotics, 2018

An Application of Deep Learning for Data Acquisition in Unmanned Aerial Photogrammetry

Matthew Tucsok* Dr. Homayoun Najjaran†

* Okanagan School of Engineering, University of British Columbia,

† Department of Mechanical Engineering, University of Victoria

Abstract

Photogrammetry is a powerful tool for creating high-quality 3D reconstructions of outdoor scenes and large structures. However, even with modern cameras and rapidly advancing unmanned aerial vehicle (UAV) technology, there are no guarantees that a 3D reconstruction will be of sufficient quality until after images are collected and postprocessing is completed. This can become an increasingly costly process if the 3D reconstruction is missing details required for critical infrastructure inspections. As such, my research explores how deep learning can be applied during data acquisition to produce a better 3D reconstruction. This application has been explored in [1] where we used a Single-view AutoEncoder (SAE) to improve downstream multi-view 3D reconstruction tasks by sorting views based on the Intersection-of-Union (IoU) of a preliminary 3D reconstruction. Our recent efforts have focused on using the SAE with feature-based filtering to generate a pose-ranked dataset for training a model which uses a ResNet backbone and a graph neural network (GNN) [2]. This model can consider views from spatially distant poses and embed this information within a graph representation. This graph representation is provided as input to a Long Short-Term Memory (LSTM) network to perform next-best-pose regression. This process is carried out recursively, where a pose is predicted to generate the next view, which is used to create a new graph for the LSTM to generate the next-best pose. This process should result in a set of views that can be passed to a standard photogrammetric package. To create datasets for the next-best-view regression network and simulate UAV data acquisition in an ideal environment, we have developed automated tools in Blender [3], an open-source 3D modelling environment, using the BlendTorch [4] framework. These tools integrate directly with both supervised and unsupervised deep learning environments, and allow for flexibility in the configuration of camera, scene, and lighting setups.

Keywords: Deep Learning, 3D Reconstruction, UAV Photogrammetry, View Planning, Blender

References

[1] M. Tucsok, S. H. Gazani, K. Gupta, and H. Najjaran, “3D Reconstruction from 2D Images: A Two-part Autoencoder-like Tool,” in Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 538–543. doi: 10.1109/SMC53654.2022.9945399.

[2] F. Xue, X. Wu, S. Cai, and J. Wang, “Learning Multi-view Camera Relocalization with Graph Neural Networks.”

[3] B. O. Community, “Blender 3.0 - a 3D modelling and rendering package.” Stichting Blender Foundation, Amsterdam, 2022. [Online]. Available: https://www.blender.org/download/releases/3-0/

[4] C. Heindl, L. Brunner, S. Zambal, and J. Scharinger, “BlendTorch: A Real-Time, Adaptive Domain Randomization Library,” Oct. 2020, Accessed: Jun. 04, 2022. [Online]. Available: http://arxiv.org/abs/2010.11696

Technical Challenges of Aerial High-Precision Industrial Photogrammetry using UAV Formation

Shahab Sotouni, Homayoun Najjaran*

University of Victoria, Advanced Control & Intelligent Systems Lab (ACIS)

Abstract

This research investigates the challenges of developing a coordinated multiple Unmanned Aerial System (UAS) for Beyond Visual Line of Sight (BVLOS) inspection of critical logistics infra- and superstructures. The sub-project, titled "AI-Enabled Aerial High-Precision Industrial Photogrammetry using UAV Formation," focuses on extending 3D perception [1], Mission Planning and Condition Assessment capabilities from a single-agent system to a multi-agent framework for tasks such as object detection, in-flight light perception, and waypoint generation.

The main challenges for multi-agent waypoint generation include collaborative path planning, distributed decision-making, robustness, handling uncertainty, scalability, and integration with other techniques. Collaborative path planning seeks to coordinate the movements of multiple agents while minimizing conflicts and optimizing group performance. This can be addressed using graph-based algorithms and distributed decision-making. Distributed decision-making faces the challenges of decentralized communication and coordination, handling partial information from each agent, and scalability for large numbers of agents. Key techniques for addressing these challenges include distributed consensus algorithms, decentralized optimization algorithms, and distributed graph-based algorithms.

Robustness, an essential feature of the system, involves ensuring graceful degradation in the presence of failures, resilience against environmental changes, and maintaining performance despite failures. Techniques to improve robustness include robust optimization algorithms, redundancy and failover strategies, and backup and recovery algorithms for data and agents. Handling uncertainty requires incorporating uncertain information into the waypoint generation process, ensuring robustness against unexpected events, and generating waypoints that account for multiple sources of uncertainty. Bayesian inference, Monte Carlo simulations, and robust optimization algorithms can be utilized to address these challenges.

Scalability is a crucial aspect of the proposed system, as it must be capable of real-time processing for large numbers of agents, efficient computation and memory usage, and scalable communication and coordination. Parallel processing and scalable graph-based algorithms are the key techniques to tackle these scalability challenges. Lastly, integration with other techniques is vital for the effective operation of the system. Challenges in integration include combining multiple techniques consistently, balancing the strengths and limitations of different techniques, and ensuring compatibility between different algorithms. Reinforcement learning and Integrated Guidance & Control (IGC) can be employed to address these integration challenges.

In conclusion, this research aims to address the technical challenges of a multi-agent system for BVLOS inspection of critical logistics infra- and superstructures, emphasizing key aspects such as collaborative path planning, distributed decision-making, robustness, handling uncertainty, scalability, and integration with other techniques.

Keywords: Multi-agent Unmanned Aerial System (UAS), Collaborative path planning, Distributed decision-making, Robustness and uncertainty handling, Scalability and integration

References

[5] M. Tucsok, S. H. Gazani, K. Gupta and H. Najjaran, "3D Reconstruction from 2D Images: A Two-part Autoencoder-like Tool," 2022 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Prague, Czech Republic, 2022, pp. 538-543, doi: 10.1109/SMC53654.2022.9945399.

Visual Deformation Detection Using Soft Material Simulation for Pre-training of Condition Assessment Models

Joel Sol, Amir M. Soufi Enayati, Homayoun Najjaran

University of Victoria

Abstract

Geometrical quality assurance is critical for improving manufacturing time and cost. This is more inhibiting when the visual or haptic assessment of human operators is necessary. Modern machine learning (ML) methods can solve this problem but require large datasets including diverse deformations. However, preparing those deformations using physical objects is difficult, if not impossible. In this paper, we propose to use Blender, an open-source simulation tool, to imitate object deformities and automate the preparation of synthetic datasets. Our graphics engine fetches the Computer-Aided-Design (CAD) file as the target non-deformed object. Expert information is then translated into shape key parameters attributed to a class of deformations, facilitating the data generation process for deformed and non-deformed samples. Four images from these simulated objects are collected to make a dataset for ML classification models i.e., deformed vs. non-deformed. Discrepancies in real and simulated environments due to noise can impact the performance of the ML model in classifying defects. To reduce the model sensitivity, artificial noise is applied to the simulated images. Also, to improve the model's robustness to camera positioning and mitigate the need for camera calibration in industrial settings, the datasets are generated using a wide range of randomized viewpoints. The entire data synthesis, model training, and testing are implemented using a Python API interfacing with Blender. An experiment using the Suzanne monkey head object is conducted that verifies the accuracy of the proposed pipeline.

Keywords: Deformation Detection, Supervised Learning, Synthetic Data

References

[1] Luigi Barazzetti, Luigi Mussio, Fabio Remondino, and Marco Scaioni. Targetless camera calibration. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 38:335–342, 2012.

[2] Hamdi Ben Abdallah, Igor Jovanˇcevi´c, Jean-Jos´e Orteu, and Ludovic Br`ethes. Automatic inspection of aeronautical mechanical assemblies by matching the 3d cad model and real 2d images. Journal of Imaging, 5(10):81, 2019.

[3] Aleksei Boikov, Vladimir Payor, Roman Savelev, and Alexandr Kolesnikov. Synthetic data generation for steel defect detection and classification using deep learning. Symmetry, 13(7):1176, 2021.

[4] Josef Scharinger Christoph Heindl, Sebastian Zambal. Learning to predict robot keypoints using artificially generated images. In 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), 2019.

[5] Sebastian Zambal Christoph Heindl, Lukas Brunner and Josef Scharinger. Blendtorch: A real-time, adaptive domain randomization library. In 1st Workshop on Industrial Machine Learning at International Conference on Pattern Recognition (ICPR2020), 2020.

[6] Gui-Jiang Duan and Xin Yan. A real-time quality control system based on manufacturing process data. IEEE Access, 8:208506–208517, 2020.

[7] Radu Godina and Jo˜ao CO Matias. Quality control in the context of industry 4.0. In Industrial Engineering and Operations Management II: XXIV IJCIEOM, Lisbon, Portugal, July 18–20 24, pages 177–187. Springer, 2019.

[8] Pierre Gutierrez, Maria Luschkova, Antoine Cordier, Mustafa Shukor, Mona Schappert, and Tim Dahmen. Synthetic training data generation for deep learning based quality inspection. In Fifteenth International Conference on Quality Control by Artificial Vision, volume 11794, pages 9–16. SPIE, 2021.

[9] Fei Hui, Pierre Payeur, and Ana-Maria Cretu. Visual tracking of deformation and classification of non-rigid objects with robot hand probing. Robotics, 6(1), 2017.

[10] Jie Liu, Kechen Song, Mingzheng Feng, Yunhui Yan, Zhibiao Tu, and Liu Zhu. Semi-supervised anomaly detection with dual prototypes autoencoder for industrial surface inspection. Optics and Lasers in Engineering, 136:106324, 2021.

[11] Chigozie Nwankpa, Winifred Ijomah, Anthony Gachagan, and Stephen Marshall. Activation functions: Comparison of trends in practice and research for deep learning, 2018.

[12] Thomas Pyzdek and Paul A Keller. Quality engineering handbook. CRC Press, 2003.

[13] P Ramesh Kumar and A Vijaya. Na¨ıve bayes machine learning model for image classification to assess the level of deformation of thin components. Materials Today: Proceedings, 68:2265–2274, 2022. 4th International Conference on Advances in Mechanical Engineering.

[14] F´atima A Saiz, Garazi Alfaro, I˜nigo Barandiaran, and Manuel Gra˜na. Generative adversarial networks to improve the robustness of visual defect segmentation by semantic networks in manufacturing components. Applied Sciences, 11(14):6368, 2021.

[15] Benjamin Staar, Michael L¨utjen, and Michael Freitag. Anomaly detection with convolutional neural networks for industrial surface inspection. Procedia CIRP, 79:484–489,2019.

[16] Muhammad Talha, Sheikh Faisal Rashid, Zain Iftikhar, Muhammad Touseef Afzal, and Liu Ying. Transferable learning architecture for scalable visual quality inspection. In 2022 2nd International Conference on Artificial Intelligence (ICAI), pages 26–32, 2022.

[17] Yunchao Tang, Lijuan Li, Chenglin Wang, Mingyou Chen, Wenxian Feng, Xiangjun Zou, and Kuangyu Huang. Realtime detection of surface deformation and strain in recycled aggregate concrete-filled steel tubular columns via four-ocular vision. Robotics and Computer-Integrated Manufacturing, 59:36–46, 2019.

[18] Apostolia Tsirikoglou, Gabriel Eilertsen, and Jonas Unger. A survey of image synthesis methods for visual machine learning. In Computer Graphics Forum, volume 39, pages 426–451. Wiley Online Library, 2020.

[19] Hidefumi Wakamatsu, Kousaku Takahashi, and Shinichi Hirai. Dynamic modeling of linear object deformation based on differential geometry coordinates. In Proceedings of the 2005 IEEE International Conference on Robotics and Automation, pages 1028–1033. IEEE, 2005.

[20] Mei Xiao, Yu Liu, Lei Zhang, Wenjian Jia, and Shi Dong. Extraction and expression of deformation features for wear images from four-ball friction test: For classification purpose. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 237(2):268–275, 2023.

[21] Zhihong Yan, Feitao Hu, Jing Fang, and Jianpeng Cheng. Multi-line laser structured light fast visual positioning system with assist of tof and cad. Optik, 269:169923, 2022.

[22] Stephan Zheng, Yang Song, Thomas Leung, and Ian Goodfellow. Improving the robustness of deep neural networks via stability training. In Proceedings of the ieee conference on computer vision and pattern recognition, pages 4480–4488, 2016.

A Reinforcement Learning Approach to Appearance-based Next-Best-View Planning

Sara Hatami†*, Homayoun Najjaran†

† Department of Mechanical Engineering, University of Victoria

Abstract

View planning is a critical problem in the 3D reconstruction of infrastructure using UAV-based imaging that dictates the process of intelligent data acquisition and heavily impacts the reconstruction results. Previous work in this domain either relies on a given proxy of the target to build upon while planning the views or generates a partial model using the knowledge of the agent about the target, where the incomplete regions are used to guide the agent around the target. In this setting, the agent iteratively calculates the next waypoint to attend where it can capture the next-best-view (NBV) with the highest predicted information gain. However, when the purpose is to capture views from newly recognized targets or in the case of targeting complex structures, a geometric proxy of the target might not be accessible and online 3D reconstruction to achieve guidance can be computationally expensive and time-inefficient. On the other hand, assuming adequate computation resources exist onboard the drone, algorithms that use an external model for guidance purposes mostly focus on the coverage completeness of the area, and less attention is paid to the relative visual information contained in consecutively captured views. As a result, reducing the number of required viewpoints to fully cover the target would come at the cost of sacrificing the accuracy of the generated model. In our work, we take a reinforcement learning approach to the problem of next-best-view planning which aims to satisfy appearance-based heuristics that improve the results of the reconstructed 3D model from the captured views. The key novelty of our work is the model-free nature that makes it independent of the true state of the environment both during training and inference time, allowing it to be applied to a wide range of settings. Inspired by the concept of Visual Bag of Words (VBoW) in Computer Vision, we introduce Bag of Views (BoV), a method to assess and select views to enhance the quality of the reconstructed 3D model by manipulating the data acquisition step as well as the selection of already acquired data. First, through experimental results, we demonstrate how the selection of the views using our appearance-based heuristics affects the 3D reconstruction process and use the observations to filter out the acquired dataset. Next, we bring this approach to an active level and use Soft Actor-Critic (SAC) method to train an agent that seeks to capture the target from views that cause a more drastic change in how it remembers the environment so far. The core idea of this method is to use the local visual features of the scene and their positioning to guide the agent to predict the NBV that would result in the highest number of unseen visual features as the agent remembers them. We demonstrate how this method satisfies two necessary conditions for improved reconstruction results, which are eliminating redundant views, or views with unnecessarily redundant features, and capturing views with useful features [1].

Keywords: View Planning, 3D Reconstruction, Data Acquisition, Reinforcement Learning

References

[1] M. Tucsok, S. Hatami, K. Gupta and H. Najjaran, "3D Reconstruction from 2D Images: A Two-part Autoencoder-like Tool," 2022 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2022, pp. 538-543.

Drone Collision Avoidance: A Human-AI Collaboration Solution

Varun Mehta†, Fardad Dadboud††, Miodrag Bolic††, Iraj Mantegh†

† Aerospace Research Centre, National Research Council Canada

†† School of Electrical Engineering and Computer Science, University of Ottawa

Abstract

Drones are becoming more and more common for a variety of activities, such as delivery of packages, search and rescue operations, and surveillance [1]. However, the potential for drone collisions with other objects (e.g., buildings, birds, other drones) is a major safety concern. Human operators may not always be able to react quickly and appropriately to avoid collisions. AI algorithms can help detect potential collisions and maneuver drones to avoid them, but they may not always be able to make optimal decisions in complex or uncertain situations [2].

During this presentation, we propose to present a human-AI collaboration approach for drone collision avoidance that combines the strengths of both human and AI decision-making to improve performance and decision quality. We formulate the drone collision avoidance problem as a two-state Markov decision model, where the states represent information from radar and camera data processing by an AI algorithm indicating a potential collision with another object in the drone's flight path, or no potential collision detected. The actions represent the AI algorithm taking control of the drone and maneuvering it to avoid the potential collision, or referring to a human operator to take control of the drone and avoid the potential collision. The rewards represent taking Action 1 (AI-controlled drone) resulting in a positive reward of +1, while taking Action 2 (human-controlled drone) results in a small penalty of -0.1 that increases over time. The transition probabilities represent the probability of successfully avoiding the collision or still experiencing a collision. To solve the problem and find the optimal policy, we plan to use algorithms such as Value Iteration, Policy Iteration, or reinforcement learning (e.g., Q-Learning, SARSA) [3]. In the past, we have simulated the Markov decision model to evaluate different policies and compared their performance in terms of expected cumulative reward over time. Once we determine the optimal policy, we can implement it in the drone collision avoidance system to make decisions in real-time based on the current state of the system.

In conclusion, the human-AI collaboration approach presented in this work provides a promising solution to the problem of drone collision avoidance, by combining the expertise and situational awareness of human operators with the detection and decision-making capabilities of AI algorithms. This approach can improve safety and performance in a range of drone applications, and highlights the potential for human-AI collaboration to address complex problems in a variety of domains.

Keywords: Detect & Avoid, UAV, Human-AI teaming, MDP, POMDP

References

[1] Abualigah, Laith, Ali Diabat, Putra Sumari, and Amir H. Gandomi. "Applications, deployments, and integration of internet of drones (iod): a review." IEEE Sensors Journal 21, no. 22 (2021): 25532-25546.

[2] Tang, Jun, Songyang Lao, and Yu Wan. "Systematic review of collision-avoidance approaches for unmanned aerial vehicles." IEEE Systems Journal 16, no. 3 (2021): 4356-4367.

[3] Sutton, Richard S., and Andrew G. Barto. Reinforcement learning: An introduction. MIT press, 2018.

Bridge defect detection using Inspection vehicles in real-time: Challenges and Solutions

Dariush Amirkhani *
Department of Computer Science and Engineering, University of Quebec in Outaouais

Abstract

Safety and stability of bridge transportation infrastructure are of the highest priority for ensuring the economy's seamless functioning and preventing catastrophic failures. Bridges require routine inspection and maintenance in order to detect structural defects and address them quickly. Manual bridge inspection is labor-intensive, time-consuming, and prone to human error. This project proposes novel approaches that leverage the power of artificial intelligence (AI) and drone technology to facilitate real-time defect detection in bridge transportation infrastructure, thereby improving the inspection process's efficacy, accuracy, and cost-effectiveness. The proposed drone system employs advanced computer vision, machine learning, and sensor fusion techniques to automatically detect and classify bridge defects in real time. The system utilises an autonomously navigated drone equipped with high-resolution cameras and sensors to inspect various bridge components. Images and other data captured by drones are then processed using advanced deep learning algorithms in order to detect and localize various types of defects, such as cracks, corrosion, etc. In this project, we investigated the new development of deep learning-based vision-based concrete bridge defect classification and detection. This review focuses on the main elements that are at the heart of standard frameworks. These components consist of specific challenge classification, public datasets, and evaluation measures. A taxonomy of classification and detection algorithms based on deep learning is presented, along with a comprehensive analysis of their advantages and disadvantages. We also benchmarked baseline models for classification and detection, using some popular datasets. Finally, we presented some of the greatest challenges associated with concrete defect classification and detection, as well as concerns about their implementation in real-world inspection systems. In the future, we plan to develop new methods to handle challenges that arise in various sections of the suggested bridge inspecting system. The challenge of classification, detection, segmentation, and level of severity while being faster than current techniques in order to be practical for use in drones in the real world. For instance, how to handle a stream of images (a video) in a consistent manner.

Keywords: Bridge inspection, Defect classification, Defect detection, Defect segmentation.

References

[1] Hebbache L, Amirkhani D, Allili MS, Hammouche N, Lapointe JF. Leveraging Saliency in Single-Stage Multi-Label Concrete Defect Detection Using Unmanned Aerial Vehicle Imagery. Remote Sensing. 2023 Jan;15(5):1218.

[2] Lapointe JF, Allili MS, Belliveau L, Hebbache L, Amirkhani D, Sekkati H. AI-AR forBridge Inspection by Drone. The 11th International Conference on Structural HealthMonitoring of Intelligent Infrastructure (SHMII-11), 8 - 12 August 2202.(in press)

[3] Lapointe JF, Allili MS, Belliveau L, Hebbache L, Amirkhani D, Sekkati H. AI-AR forBridge Inspection by Drone. InInternational Conference on Human-ComputerInteraction 2022 (pp. 302-313). Springer, Cham.

[4] Allili MS, Amirkhani D, Hebbache L, Lapointe JF, Hammouche N. A Review on Concrete Bridge Defect Detection (IEEE transactions on intelligent transportation systems)

Intelligent Real-Time AI-based Inspection of Concrete Bridge Defects

Loucif HEBBACHE
University of Quebec in Outaouais

Abstract

Bridges play a crucial role in the modern transportation infrastructure, and they are necessary for the safe and efficient passage of goods and people. However, similar to the rest of infrastructures, bridges may face defects due to both natural and unnatural factors, including ageing, climate change, fire, accidents, etc. Defects such as cracks can cause bridges to fail, resulting in loss of life, property damage, and disruption of transportation, so early detection can help prevent catastrophic failures, reduce maintenance costs, and extend the lifespan of bridges.

In order to maintain the safety and reliability of bridges, it is essential that these defects are quickly detected and repaired. Traditional methods of bridge inspection involve manual visual inspection, which is time-consuming, labor-intensive, and prone to human error. Machine learning algorithms have emerged as a promising way to support traditional manual inspection methods. By analyzing images and videos captured by cameras mounted on drones or inspection vehicles, computer vision algorithms can automatically detect defects in real-time. These algorithms will eventually allow faster and more accurate inspections, allowing for larger areas of the bridge to be inspected in less time, and machine learning and especially deep learning algorithms can be trained to detect defects that are difficult to see with the naked eye. Image acquisition (using cameras mounted on drones or inspection vehicles), pre-processing (enhance the images and videos), defect detection (using computer vision algorithms), and post-processing (the detected defects are analyzed to determine their severity and to help generate reports for maintenance and repair) are the typical steps in the sample pipeline for bridge defect detection.

In this project, we used a saliency-based multi-label defect detector (SMDD-Net) for bridge defect detection. SMDD-Net is a defect detection model that uses a deep learning algorithm to detect and classify defects in images and videos. It can be trained to detect a wide range of defects, including cracks, corrosion, spallation, exposed bars, and efflorescence, making it an ideal tool for bridge inspection. SMDD-Net can be integrated into the defect detection stage of the pipeline, where it can analyze pre-processed images and videos to detect defects in real-time. The results of experiments on standard data sets and real-world images show how effectively the SMDD-Net performs in comparison to cutting-edge methods.

In the future, we intend to create new algorithms with specialized functions and faster processing speeds in an attempt to maximize automation by reducing human involvement and use AI to complete various project tasks.

Keywords: bridge; inspection; one-stage concrete defect detection; saliency; deep learning; UAV imagery

References

[1] Hebbache L, Amirkhani D, Allili MS, Hammouche N, Lapointe JF. Leveraging Saliency in Single-Stage Multi-Label Concrete Defect Detection Using Unmanned Aerial Vehicle Imagery. Remote Sensing. 2023 Jan;15(5):1218.

[2] Lapointe JF, Allili MS, Belliveau L, Hebbache L, Amirkhani D, Sekkati H. AI-AR forBridge Inspection by Drone. The 11th International Conference on Structural HealthMonitoring of Intelligent Infrastructure (SHMII-11), 8 - 12 August 2202.(in press)

[3] Lapointe JF, Allili MS, Belliveau L, Hebbache L, Amirkhani D, Sekkati H. AI-AR forBridge Inspection by Drone. InInternational Conference on Human-ComputerInteraction 2022 (pp. 302-313). Springer, Cham.

Segmentation des Défauts dans l'Inspection de Ponts en Béton par Drone

Hammouche Nadir
† Université du Québec en Outaouais

Résumé

Dans le cadre des recherches entreprises dans le domaine du contrôle de santé intégré, l'inspection visuelle de pont est une tâche très importante vu les coûts budgétaires que la maintenance des ponts représente pour les états et les entreprises concernées. Le projet d'inspection de ponts en béton par drone est un projet qui se compose de plusieurs modules qui interagissent entre eux afin de former un écosystème fonctionnel qui répond aux besoins de l'inspection visuelle de pont.

Ma contribution dans ce projet concerne trois aspects différents. Le premier, c'est l'aspect interaction personne-machine. Dans cette partie, il est question de développer une application orientée réalité augmentée. Cette application a pour but d'offrir une interface interactive et intuitive au pilote en exploitant la technologie de la réalité augmenté et mixte. Cette application sera déployée sur le casque de réalité mixte Microsoft HoloLens 2. Elle permettra l'affichage des informations importantes du vol au pilote ainsi que le flux vidéo capturé par le drone [1]. Ce flux vidéo sera augmenté par des boîtes englobants les défauts décelés par des algorithmes de détection d'objet issu de l'apprentissage profond [2].

Le deuxième aspect de la contribution concerne le volet de l'apprentissage profond. Actuellement, nous menons des recherches dans le but de mettre au point un modèle de segmentation sémantique des défauts. Les recherches sont faites sur deux problématiques très liées comme précisé dans [3]. La première est sur la segmentation des différents éléments structurels d'un pont (Béton, structure métallique, acier et l'arrière-plan). Cette tâche est très importante pour le pilote lorsqu'il sera aux commandes du drone, car elle permettra de cibler des zones plus susceptibles d'avoir des défauts comme les fissures du béton. En plus, elle pourrait aussi contribuer grandement à la deuxième problématique qui concerne directement la segmentation des défauts. En effet, cette dernière est une partie cruciale qui a pour objectif d'assister les inspecteurs dans leur tâche d'inspection visuelle, car elle permettra une détection précise des défauts au niveau pixel qui vient compléter la solution [2].

Le dernier volet de la contribution se rapporte à l'aspect intégration et déploiement. Mettre en place un environnement d'exécution idéal pour les différents algorithmes de détection d'objets et de segmentation est primordiale pour le bon fonctionnement de l'ensemble de l'écosystème. Cette tâche consiste au déploiement d'un serveur sur lequel les algorithmes précédents puissent fonctionner de façon optimale. Pour cela, le choix du serveur d'inférence Triton de NVIDIA a été le plus souhaitable pour répondre à nos exigences. Ce serveur a pour caractéristique d'exploiter au maximum les ressources matérielles et plus précisément les unités de calcul graphique (GPUs) qui sont très sollicités par l'exécution d'algorithmes d'apprentissage profond.

Mots-clés : Segmentation, vision par ordinateur, déploiement, inspection, réalité mixte.

Références

[1] Lapointe, JF., Allili, M.S., Belliveau, L., Hebbache, L., Amirkhani, D., Sekkati, H. (2022). AI-AR for Bridge Inspection by Drone. In: Chen, J.Y.C., Fragomeni, G. (eds) Virtual, Augmented and Mixed Reality: Applications in Education, Aviation and Industry. HCII 2022. Lecture Notes in Computer Science, vol 13318. Springer, Cham. https://doi.org/10.1007/978-3-031-06015-1_21

[2] Hebbache, L.; Amirkhani, D.; Allili, M.S.; Hammouche, N.; Lapointe, J.-F. Leveraging Saliency in Single-Stage Multi-Label Concrete Defect Detection Using Unmanned Aerial Vehicle Imagery. Remote Sens. 2023, 15, 1218. https://doi.org/10.3390/rs15051218

[3] Zhang, C., Karim, M.M., & Qin, R. (2022). A Multitask Deep Learning Model for Parsing Bridge Elements and Segmenting Defect in Bridge Inspection Images. ArXiv, abs/2209.02190.

Safe Landing Zones Detection for UAV Imagery

Sakineh Abdollahzadeh

† Vision and artificial intelligence laboratory
Université du Québec en Outaouais (UQO)

Abstract

Unmanned Aerial Vehicles (UAVs) have gained interest for various civilian applications like surveying, search and rescue, and package delivery. However, achieving full autonomy in UAV operations poses a significant challenge, particularly identifying safe landing zones in the final step or in urgent situations. Traditional methods for selecting landing zones rely on manual analysis of the terrain, which is time-consuming and error-prone, making it difficult to scale up UAV usage. Moreover, identifying safe landing zones in unfamiliar or hazardous environments is even more challenging. Recent advances in UAV technology have introduced safe landing detection to address this challenge. This technology uses onboard cameras and machine learning algorithms to identify suitable landing zones based on terrain and environmental factors. In GPS-denied or emergency landing scenarios, safe landing detection technology can rely on other sources of data, such as inertial measurement units and magnetometers, to estimate the UAV's trajectory and predict potential landing zones. Computer vision techniques have also shown promise in helping UAVs to identify autonomously safe landing zones. However, developing a reliable and efficient computer vision system for safe landing is still a challenging task, especially in complex and dynamic environments [1], [2], [3].

My research area focuses on using deep learning approaches for detecting Safe Landing Zones (SLZ) directly from images acquired by UAVs. Our initial conference paper presented a supervised deep regression approach that uses a semantic segmentation framework to score each pixel in the image based on its landing safety, where we used a labeled dataset with three landing safety scores: Low-risk, Medium-risk, and High-risk. Our approach also accounts for upright structures such as walls, fences, and vehicles, introducing a gradual safety margin to ensure safe maneuvering during landing. Our experiments using both vertical and oblique views of urban and natural scenes demonstrated the accurate and efficient identification of safe landing zones in complex environments [4].

We are currently extending our approach by proposing a new model based on deep ordinal regression for SLZ detection. This model includes input features such as depth map and terrain characteristics like flatness and inclination, to output ordinal safety levels that correspond to the damage risk incurred from UAV landing. The proposed model partitions the safety spectrum into five ordered levels, from very unsafe to very safe. Extensive experiments on five different drone datasets have shown that our model can detect SLZ with very accuracy in both urban and natural scenes.

Future research could improve our model by incorporating 3D information about the terrain such as slope and surface orientation, requiring the extraction of 3D structure information through motion analysis and depth information. We will also extend our approach to handle more complex scenarios such as dynamic landing sites and moving vehicles or crowd. Another future direction would be to field-test developed approaches with human-in-the-loop to handle UAVs landing using augmented reality user interfaces.

In summary, we aim to propose an effective computer vision approach for identifying safe landing locations for UAVs in unknown environments. Our proposed solution has the potential to enhance the utilization of UAVs for various applications, making them safer, more efficient, and more widely adopted.

Keywords: Automatic UAV navigation, safe landing zones (SLZ), semantic segmentation, deep regression

References

[1] Alam, M. S., & Oluoch, J. (2021). A survey of safe landing zone detection techniques for autonomous unmanned aerial vehicles (UAVs). Expert Systems with Applications, 179, 115091.

[2] Kakaletsis, E., Symeonidis, C., Tzelepi, M., Mademlis, I., Tefas, A., Nikolaidis, N., & Pitas, I. (2021). Computer vision for autonomous UAV flight safety: an overview and a vision-based safe landing pipeline example. Acm Computing Surveys (Csur), 54(9), 1-37.

[3] Xin, L., Tang, Z., Gai, W., & Liu, H. (2022). Vision-Based Autonomous Landing for the UAV: A Review. Aerospace, 9(11), 634.

[4] Abdollahzadeh, S., Proulx, P. L., Allili, M. S., & Lapointe, J. F. (2022, May). Safe Landing Zones Detection for UAVs Using Deep Regression. In 2022 19th Conference on Robots and Vision (CRV) (pp. 213-218). IEEE.

User Interface for Safe Landing Zones (SLZ) Detection in UAVs Environments

Pier-Luc Proulx

Université du Québec en Outaouais (UQO) *

Abstract

Unmanned autonomous vehicles (UAV) have increased usage in recent years, helping with limited access tasks, such as medicine deliveries, bridge inspections, etc. During these missions, failure and other problems may cause the UAV to aim for a short-notice landing, needing a quick feedback from the navigation system to determine potential safe landing zones (SLZ).

While UAVs navigating autonomously may use techniques based on deep machine learning to segment the image and determine potential landing zones where to land, it may be impossible to land in conditions where the map presents no or almost no real safe zones passing a pre-defined safety threshold, causing the drone to circle zones, shortening its battery life, risking the lifespan of the UAV and the whole mission itself. On the other hand, semi-autonomous solutions involving pilots may reduce the chances of circling a field to find potential landing zones but can increase the computation time needed to find a potential landing zone, caused by information overload, increasing the chances of causing hardware damage to the UAV and surrounding as well.

In this project, based on the usage of deep machine learning and semantic segmentation techniquesi, we propose a variety of different user interface architectures, using modern technologies, such as augmented reality (AR), that present information maps, live visual streaming and more to the end-user (i.e., the pilot), supporting short-notice decisions, such as safe landing in failure situations. Afterwards, we propose a quantitative and qualitative evaluation of the proposed architectures based on the models' prediction latency, the information's flux security and more, reducing potential errors caused by information overload on the user's screen and delays related to the predictions' generation.

Keywords: UAVs, Safe landing zones (SLZ), Augmented Reality (AR),

References

[1] S. Abdollahzadeh, P. -L. Proulx, M. S. Allili and J. -F. Lapointe, "Safe Landing Zones Detection for UAVs Using Deep Regression," 2022 19th Conference on Robots and Vision (CRV), Toronto, ON, Canada, 2022, pp. 213-218, doi: 10.1109/CRV55824.2022.00035.

The Use of Distributed Fiber Optic Sensing for Long-term Monitoring of Railway Thermal Response

Fuzheng Sun 1*, Neil Hoult 1, Liam Butler 2, Merrina Zhang 3

† a Department of Civil Engineering, Queen's University, 58 University Ave., Kingston, ON K7L 3N6, Canada
b Department of Civil Engineering, York University, 4700 Keele St., Toronto, ON M3J 1P3, Canada
c National Research Council Canada, Automotive and Surface Transportation Research Centre, Ottawa, ON, Canada

Abstract

Buckling of continuous welded rail (CWR) remains a concern for railways in Canada due to the potentials for causing derailments. CWR buckling usually occurs at locations where the rail stress exceeds a critical stress value that is largely dependent on the temperature change from the rail neutral temperature (RNT), the rail eccentricity, and the level of lateral support. The prevention of rail buckling relies on the monitoring of railway thermal response during the critical periods of the year (i.e., late spring, summer and early fall) so railways can make decisions on operations and maintenance. Currently, no techniques exist to monitor these features along the length of the rail without disturbing rail traffic except regular visual inspections. This project investigated the application of distributed fiber optic sensors (DFOS) for the long-term monitoring of CWR thermal response along the length of the rail. The feasibility of the developed monitoring system was first evaluated with a series of experiments with different types of boundary conditions, applied loads and lateral restraints in a controlled lab environment. The results indicate that DFOS can be used to support the accurate evaluation of the rail response (i.e., distributed axial strain and lateral displacement) along the monitored rail length. The developed monitoring approach was then used to monitor an in-service 20 m section of tangent (August 2021) and an in-service 20 m section of curved track (August 2022) in the summer during normal railway operations. The rail surface temperature difference due to the position of sun relative to the rail was identified as a critical factor that affects field data interpretation. Machine learning techniques such as Principal Component Analysis (PCA) and Gaussian Process Regression (GPR) were used to help the interpretation of long-term monitoring data and establish a predictive model of rail response versus rail temperature. A digital twin prototype was also established based on the lab experiments using the statistical finite element method (statFEM) approach, which combines the DFOS measurements with a predictive computational finite element (FE) model for improved inference and prediction of the rail response in situations where the measurements are unavailable (i.e., when the rail stress is higher than normal). A surrogate model constructed using polynomial chaos expansion (PCE) was developed to approximately obtain the computational FE model predictions with uncertainties in statFEM, which decreases the computational cost to an acceptable range. The digital twin based on statFEM leverages the advantages of distributed sensing and computational FE models, which proves to be a more robust predictive model than FE modelling alone.

Keywords: Continuous welded railway, thermal buckling, distributed fiber optic sensing; statFEM; rail stress and lateral displacement; machine learning

Design and Experimental Evaluation of a Mobile Robot for Automatically Installing Fibre Optic Sensors on Rail Tracks

Heshan Fernando 1*, Joshua Marshall1,2 and Neil Hoult1,3

1 Ingenuity Labs Research Institute, Queen's University, Kingston, Canada
2 Department of Electrical and Computer Engineering, Queen's University, Kingston, Canada
3 Department of Civil Engineering, Queen's University, Kingston, Canada

Abstract

Distributed fibre optic sensors (DFOS) are a promising technology for monitoring of large infrastructure such as railways, bridges and pipelines [1]. The challenge for widespread use of DFOS for infrastructure monitoring is the installation process, which is difficult, labour intensive, and time consuming. For accurate measurements, the fibre optic cable must be correctly positioned and fully bonded to the infrastructure surface with adhesive over long distances (i.e., kilometres). In this presentation, we describe the mechatronics design, development, and evaluation of a mobile robotic system for automatically installing DFOS on rail tracks — where the measurements can be used for predicting rail buckling events (e.g., due to thermal effects) [2]. A design consisting of a mobile robotic platform that locomotes on rail tracks while automatically cleaning the rail and bonding fibre onto a dispensed stream of adhesive on the rail surface is conceptualized. A prototype of the system, shown in Figure 1, is built and tested in the field, together with a vision-based system for monitoring the installation quality. Results from a 10 m long automatic installation by the robotic system are compared to a 10 m long manual installation by humans. The bond quality of both installations is assessed by passing a locomotive over the instrumented area and measuring the distributed strains. The results show the robotic installation provides similar bond quality to the manual installation; however, the robotic installation is 15 times faster. Lessons learned from the field deployment of the robot prototype are discussed, and strategies for advancing the technology towards greater automation are presented.

Keywords: field robotics, automation, fibre optic sensing, railway monitoring

Figure 4. Image of a prototype mobile robot for installing fibre optic sensors on railways

References

[1] H. Wijaya, P. Rajeev, and E. Gad, "Distributed optical fibre sensor for infrastructure monitoring: Field applications," Optical Fiber Technology, vol. 64, p. 102577, Jul. 2021.

[2] F. Sun, N. A. Hoult, L. J. Butler, and M. Zhang, "Distributed monitoring of rail lateral buckling under axial loading," Journal of Civil Structural Health Monitoring, pp. 757–774, Jul. 2021.

Application of Machine Learning for Pavement Performance Prediction

Jianqi Kang, Pejoohan Tavassoti, Hassan Baaj *, Moojan Ghafurian

† University of Waterloo, Faculty of Engineering

Abstract

The effectiveness of pavement maintenance and Rehabilitation (M&R) planning and cost optimization strongly relies on the performance prediction models. This has been especially challenging due to the large number of variables that would contribute to the overall pavement performance and the considerably high level of uncertainty in predicting future traffic, climatic variables, deteriorations, and changes in materials property. During the past few years, research on Machine-Learning (ML) aided predictive modelling for pavements performance evolution with time has been gaining momentum. To this end, several algorithms trained on different datasets have been used by researchers, which varied in the accuracy depending on the model and dataset used. This study provides a summary of the state of the practice and art in the application of Artificial Intelligence (AI) for pavements performance prediction. It was recognized that while the majority of the models use methods that are not explainable (e.g.. Neural Networks), explainable ML algorithms can be beneficial for the purpose of pavement management since it can be informative for users to also understand the decision-process. International Roughness Index (IRI), as one of the main functional performance indicators for pavements, has been selected to be further studied. The historical IRI data for several flexible pavement sections in North America was retrieved from the Long-Term Pavement Performance (LTPP) database. The data was carefully evaluated for inconsistencies and was refined before utilizing it for the modelling. A Decision Tree (DT) model and a Random Forest (RF) model were developed using the most commonly used input data for IRI prediction, retrieved from the LTPP database. The results supported the feasibility of using explainable (i.e., Decision Trees) or interpretable (i.e., Random Forests) machine learning algorithms for pavement performance prediction, the accuracies of which need to be improved in the future research.

Keywords: Pavement Performance, Machine Learning, Random Forest, Decision Tree, International Roughness Index (IRI), Artificial Intelligence, Long-Term Pavement Performance (LTPP).

Instrumentation and Field Construction for a Smart Flexible Pavement

Matea Ceric, Shenglin Wang, Pejoohan Tavassoti, Hassan Baaj*, Omran Maadani?, Mohammad Shafiee?

† Department of Civil and Environmental Engineering, University of Waterloo

? National Research Council of Canada (NRC)

Abstract

Nowadays, there is an urgent demand for more intelligent and cost-effective solutions for safer and more sustainable transportation infrastructure. To address this issue, smart pavement technology is gaining higher momentum thanks to its advantages, including advanced data collection, labour reduction, and real-time monitoring of infrastructure under traffic loading and environmental impacts. With the help of advanced instrumentation and wireless data transmission technology, the traffic and pavement performance conditions could be easily accessed and analyzed in all geographical and environmental influences. This presentation centers on a smart flexible pavement construction and sensor instrumentation project carried out in October 2022 within the City of Kitchener, Ontario. The project involved a 10-meter-long test section fitted with eight horizontal asphalt stain gauges (ASGs) and four vertical ASGs embedded in the bottom layer of asphalt concrete. In addition, earth pressure cells (EPCs) were laid in the granular base, subbase, and subgrade layers. Both the ASGs and EPCs were laid underneath the wheel track to evaluate the instant response from each pavement structural layer under the effect of traffic loading. Moreover, multiple moisture probes and temperature sensors were used at different depth of the pavement structure, spanning from the subgrade to the asphalt concrete layer, to record the moisture and temperature variation within the different layers during daily and seasonal weather changes. All the sensors were connected to an integrated data acquisition system (DAS) which includes multiple data loggers, a core data logger, a wireless modem, and a power system. Therefore, the real-time data could be stored and transferred remotely for post-processing. Overall, this presentation will showcase the design, calibration, and instrumentation process for the test section after construction, as well as a truck test also performed soon after to be able to assess pavement responses during construction. The current system is gathering engineering and environmental data from the test section continuously. The collected data will be analyzed using Artificial Intelligence (AI) optimization algorithms developed as part of the research. Furthermore, the research aims to advance the use of AI for monitoring and predicting pavement performance under local traffic and environmental conditions.

Keywords: Smart pavement, Instrumentation, In-situ response, Data collection, Construction, Artificial Intelligence

References

[1] Shi, X., More than smart pavements: connected infrastructure paves the way for enhanced winter safety and mobility on highways. Journal of Infrastructure Preservation and Resilience, 2020. **1**(1).

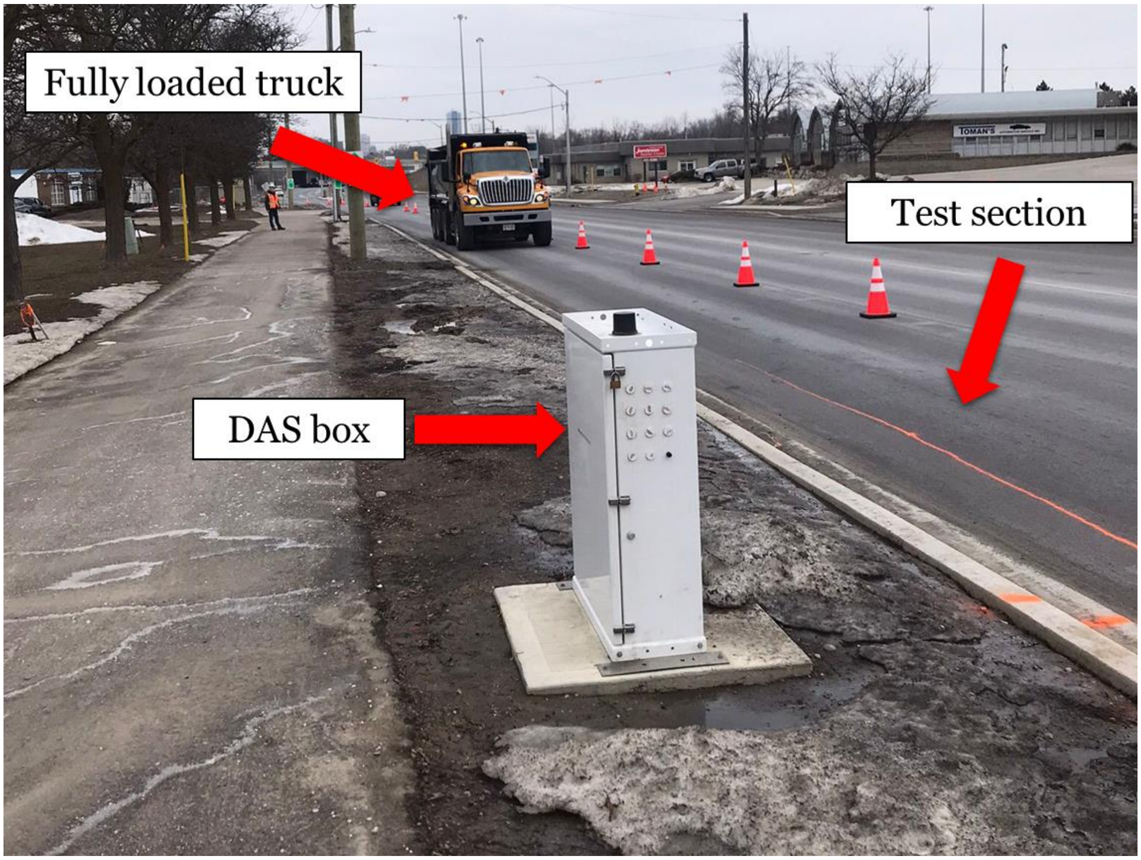


Figure 1 Test section and the truck loading test. Such test will be conducted three times a year in the spring, summer, and winter.

Towards the Development of Pavement Structural Health Monitoring Systems with AI

Matea Ceric†, Abimbola Grace Oyeyi†, Pejoohan Tavassoti†, Hassan Baaj*†, Moojan Ghafurian°, Omran Maadani?, Mohammad Shafiee?

† Department of Civil and Environmental Engineering, University of Waterloo
∘ Department of Electrical and Computer Engineering, University of Waterloo
? National Research Council of Canada (NRC)

Abstract

Canada heavily relies on roads as they play a vital role in transportation which has significant economic and environmental implications. To ensure that road pavements perform adequately and have a longer service life, understanding the trigger points for pavement deterioration is crucial. During the design phase, critical stresses and strains are considered to account for the pavement deterioration and failures. However, the lack of reliable models that can accurately translate these mechanistic responses of pavement structures to short- and long-term performance is a significant issue preventing effective pavement management. Thus, a system to track and evaluate continuous pavement health in terms of these critical responses over extended periods and under varying environmental conditions is required. This study aims to achieve this by using artificial intelligence (AI)-based forecasting models developed from pavement responses to changing traffic and weather conditions. It involves gathering information from a flexible pavement test section equipped with pressure cells, strain gauges, moisture, and temperature sensors. Typical layer and material parameters for Ontario, Canada will also be gathered. The flexible pavement test section was designed, built, and instrumented as part of a prior project phase in the Region of Waterloo, Ontario. This study presents a preliminary analysis of data obtained from this section at different traffic load levels across varying speeds and temperatures. This is to provide an indication of the nature of pavement response to inform the development of AI predictive models. Additionally, the study provides a description of the present strategy for creating a database on the pavement's structural and durability features retrieved from the pavement section.

Keywords: Pavement, Stress, Strain, Artificial Intelligence, Performance models, Temperature

References

[1] Transport Canada, *Transportation_in_Canada-Overview_Report-2019*. 2019.

Application of Machine Learning for Real-Time Pavement Conditions Monitoring of a Test Road in Alberta

Yunyan Huang1, Taher Baghaee Moghaddam1, Alireza Bayat1 , and Leila Hashemian1*

1 Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, T6G 1H9, Canada

Abstract

The efficient transport of goods on Canada's road network is critical to the country's economy. However, the current reactive approach to road management is costly and inefficient. Fortunately, artificial intelligence (AI) can offer a more proactive and cost-effective approach to road management. To address this need, the National Research Council (NRC) has allocated funding for the construction of a new road test section close to the Edmonton Waste Management Center (EWMC) in Alberta. The new test section is equipped with advanced sensors that collect data on pavement moisture content, pavement temperature, strain at the bottom of the asphalt layer, and stress in the granular layer. In addition, an annual Falling Weight Deflection (FWD) test is conducted to monitor changes in the structural capacity of the pavement, while a weighing-in-motion system collects data on traffic loads. Therefore, the new road test section is a great asset which can provide valuable data for understanding pavement performance in a region with a cold climate.

The AI system will be built to alert on unsafe driving conditions or loss of structural capacity based on the real-time dataset of road structural capacity and road surface conditions. Machine learning (ML) models have been used before to report the environmental factors (pavement temperature and moisture content) of the pavement in real time [1–3]. To avoid damage from heavy traffic during the thawing period, spring load restrictions (SLR) and winter weight premiums (WWP) are applied in many cold regions. Currently, policies are based on fixed dates rather than the actual structural capacity of the road [4]. With the application of ML models, it would be possible to estimate the real-time freezing and thawing depths by air temperature and replace the fixed-date SLR and WWP with dynamic load limits set in real time. In future research, Artificial Neural Network (ANN) models will be used to monitor the real-time structural capacity. In this regard, a real-time data monitoring system will be developed to capture pavement response data (strain and stress). Furthermore, laboratory investigations will be conducted to study the properties of unbound pavement materials and subgrade soils under controlled freeze-thaw cycles. Using the materials properties, in-situ pavement environmental measurements from the sensors, traffic loadings recorded by weigh in motion (WIM) system, and dynamic responses from the asphalt strain gauges, real-time pavement performance models will be developed.

Keywords: pavement temperature, moisture content, freeze-thaw depths, structural capacity, road surface conditions, real-time monitoring, machine learning models

References

[1] Huang, Y., Molavi Nojumi, M., Ansari, S., Hashemian, L. and Bayat, A. Evaluating the use of machine learning for moisture content prediction in base and subgrade layers. Road Materials and Pavement Design, 2023, pp.1-19.

[2] Huang, Y., Molavi Nojumi, M., Hashemian, L. and Bayat, A. Evaluation of a Machine Learning Approach for Temperature Prediction in Pavement Base and Subgrade Layers in Alberta, Canada. Journal of Transportation Engineering, Part B: Pavements, Vol. 149, No. 1, 2023, p.04022076

[3] Molavi Nojumi, M., Huang, Y.L. Hashemian, L. and Bayat, A. Application of Machine Learning for Temperature Prediction in A Test Road in Alberta. International Journal of Pavement Research and Technology, Vol. 15, No. 2, 2022, pp. 303-319.

[4] Asefzadeh, A., Hashemian, L., Haghi, N.T., and Bayat, A. Evaluation of spring load restrictions and winter weight premium duration prediction methods in cold regions according to field data. Canadian Journal of Civil Engineering, Vol. 43, No. 7, 2016, pp. 667–674. https://doi.org/10.1139/cjce-2015-0554.

The Use of Sensing Technology for Pavement Performance Monitoring

Silas Henrique Barbosa de Carvalho Linares1, Taher Baghaee Moghaddam1, Leila Hashemian1*

Alireza Bayat1

[1] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, T6G 1H9, Canada

Abstract

Pavement structures are continuously subjected to external factors, such as the weather and variable traffic loads. Consequently, different types of pavement failures can occur depending on specific circumstances and construction features. Thus, it is crucial to have a well-planned maintenance strategy in place to ensure adequate pavement performance over its service life. In this regard, in-situ pavement-sensing technology can be used as an accepted method for continuously monitoring pavement and its health conditions [1]. This can be done by collecting environmental and performance data using different sensors installed in the pavement structure. In other words, the embedded instrumentation in the pavements can effectively collect invaluable data such as temperature, moisture, pressure, and induced stresses and strains within the pavement structure. In addition, the measurements of these parameters can lead to more precise pavement models and, consequently, greater pavement design approaches [2]. This would allow professionals in the field to continuously monitor the pavement condition and determine the appropriate maintenance approach based on the collected information.

In order to improve the monitoring of pavement performance, a new instrumented test section was constructed in Edmonton, Alberta, in July 2022. The section is located on the access road from Aurum road to the Edmonton Waste Management Centre (EWMC), accommodating over 2,000 vehicles per day, primarily heavy garbage trucks. The construction of the section was carried out with the help of the City of Edmonton by removing the entire asphalt layer and part of the Granular Base Course (GBC) to a depth of 70 cm from the surface. Various sensors were then installed at different depths in the subgrade (2.25 m below the road surface), including at the bottom (70 cm depth), in the middle (47.5 cm depth), and on top (25 cm depth) of the GBC layer. After placing the sensors, the excavated area was backfilled and compacted. The embedded sensors measure the pavement's response to traffic loading as well as environmental parameters. To measure the pavement's response to traffic loading, vertical and horizontal asphalt strain transducers (VAST/HAST) and earth pressure cells (EPC) were installed to measure the axial strain under high-frequency (dynamic) loading and total pressure in granular layers, respectively. For environmental parameters, thermistors and soil moisture sensors were installed to measure the soil's temperature and volumetric water content, respectively. A total of 36 sensors were used in the pavement structure, including 12 HASTs, six VASTs, six EPCs, six thermistors, and six soil moisture sensors. All sensors are connected to a data logger, and the data is transferred to the researchers at the University of Alberta for analysis. The collected data can provide sensitive and meaningful real-time information on pavement performance, guiding present and future actions regarding the maintenance of pavement structures.

Keywords: pavement instrumentation, pavement sensors, pavement maintenance, pavement structural health monitoring, data collection

References

[1] Barriera, M. Pouget, S. Lebental, B. Van Rompu, J. (2020) In Situ Pavement Monitoring: A Review. Infrastructures. 5(2):18. https://doi.org/10.3390/infrastructures5020018

[2] Al-Qadi, I. Loulizi, A. Elseifi, M. Lahouar, S. (2004). The Virginia Smart Road: The Impact of Pavement Instrumentation on Understanding Pavement Performance. Journal of the Association of Asphalt Paving Technologists. 73.3, 427-465.

Soil Temperature Prediction in Ordinary and Extremely Hot Weather using Genetic Programming

Xiatong Cai 1*
1 Department of Civil Engineering, University of Ottawa, 161 Louis Pasteur, CBY A114, Ottawa, ON K1N 6N5, Canada

Abstract

The prediction of soil temperature under climate change plays an important role in understanding hydrological processes [1]. However, widely used linear models cannot provide accurate results for soil temperature prediction. AI models are well performed in capturing the hidden mechanisms of soil temperature dynamics, but they are usually black box models [2]. Genetic programming can create a mathematical equation that can be used for predictions with very high efficiency due to its explicit analytical form [3]. However, it is rarely used in soil temperature prediction, especially in extremely hot weather conditions. In this study, we compared the performance of single-gene genetic programming (SGGP) and multi-gene genetic programming (MGGP) with benchmark linear (linear regression, lasso, ridge, elastic net) and AI models (nearest neighbors, random forest (RF), gradient boosting, extreme gradient (XG) boosting, support vector machine (SVM), stacking method, multi-layer perceptron (MLP), deep learning, and adaptive neuro-fuzzy inference system (ANFIS)), as reported in Imanian et al. (2022) [2]. The performance was evaluated using R-squared, root mean squared error (RMSE), mean absolute error (MAE), and mean squared error (MSE). The fitness of multi-gene genetic programming (MGGP) in ordinary weather was found to be $\boldsymbol{R^2}$=0.97, and $\boldsymbol{R^2}$=0.83 in extremely hot weather. The sensitivity analysis showed different patterns of contribution of the variables in ordinary and extreme weather. Most significantly, the importance of air temperature increased. Besides, evaporation, which was ranked third in ordinary weather, was replaced by dew point temperatures in extreme weather. Results show MGGP outperforms SGGP, linear models and is comparable with some distance-based (nearest neighbor and SVM) and tree-based benchmark AI models (RF, Gradient Boost, XG Boost) in both ordinary and extremely hot weather (Figure 1). MGGP underperformed the artificial neural network. The advantage of this work, despite the lower accuracy in soil temperature prediction compared to deep learning, is the ability to generate a mathematical formula. Using only a polynomial equation rather than executing a complicated model with a large input dataset, MGGP shows good simplification in soil temperature prediction.

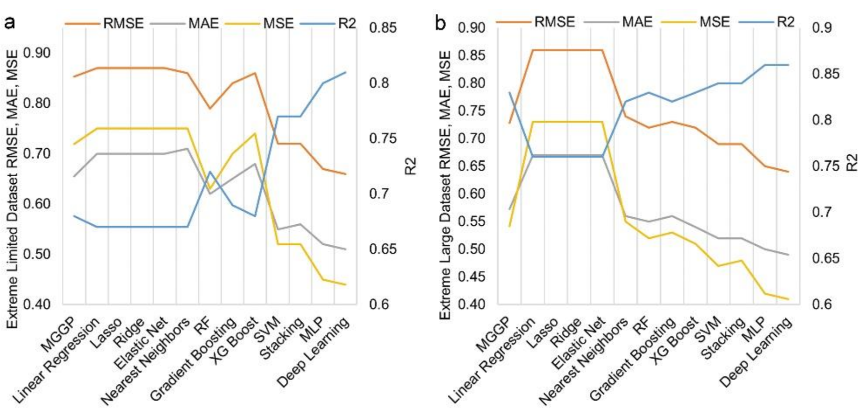


Figure 1. Fitness of MGGP and other models in extreme weather with (a) limited and (b) large datasets.

Keywords: genetic programming, soil temperature, symbolic regression, extreme weather, climate prediction, artificial intelligence

References

[1] Vogel, M. M., Zscheischler, J., & Seneviratne, S. I. (2018). Varying soil moisture–atmosphere feedbacks explain divergent temperature extremes and precipitation projections in central Europe. Earth System Dynamics, 9(3), 1107–1125.

[2] Imanian, H, Cobo J.H., Payeur, P., Shirkhani, H., & Mohammadian, A. (2022). A comprehensive study of artificial intelligence applications for soil temperature prediction in ordinary climate conditions and extremely hot events. Sustainability, 13.

[3] Searson, D.P. (2015). GPTIPS 2: An Open-Source Software Platform for Symbolic Data Mining. In A. H. Gandomi, A. H. Alavi, & C. Ryan (Eds.), Handbook of Genetic Programming Applications (pp. 551–573). Springer International Publishing.

A Convolutional Neural Network Model for Soil Temperature Prediction under Ordinary and Hot Weather Conditions: Comparison with a Multilayer Perceptron Model

Vahid Farhangmehr *

† Department of Civil Engineering, University of Ottawa, Ottawa, ON K1N 6N5, Canada

Abstract

Soil temperature is a critical parameter in soil science and agriculture and directly or indirectly affects the four growth stages of plants, i.e., seed germination, root development, flowering, and reproduction, as well as the physical, chemical, and biochemical processes in soil, including nitrification, transpiration, ventilation, and respiration of soil, and the microbiological activity of microorganisms available in soil. It also affects soil properties, such as soil moisture, air, and nutrient content, as well as the capillary transport of water and nutritious solutes through plant foliage. Soil temperature is also a critical parameter in hydrology, water resources engineering, meteorology, and geo-environmental engineering that influences the rate of evaporation on the soil surface, the thermal energy balance between the atmosphere and the land surface, and the rate of decomposition of organic matter and its transformation to carbon dioxide in the atmosphere. Thus, accurate and cost-effective measurement or prediction of soil temperature on the ground surface and underground is so important. Machine learning models are widely employed for surface, near-surface, and subsurface soil temperature predictions. The present study employed a properly designed one-dimensional convolutional neural network model to predict the hourly soil temperature at a subsurface depth of 0-7 cm. The annual input dataset for this model included eight hourly climatic features including air temperature, wind gust, surface net solar radiation, surface net thermal radiation, dewpoint temperature, surface pressure, evaporation, and total precipitation. The performance of this model was assessed using a wide range of evaluation metrics and compared to that of a multilayer perceptron model. A detailed sensitivity analysis was conducted on each feature to determine its importance in predicting the soil temperature. This analysis showed that air temperature had the greatest impact and surface thermal radiation had the least impact on soil temperature prediction. It was concluded that the one-dimensional convolutional model performed better than the multilayer perceptron model in predicting the soil temperature under both normal and hot weather conditions. It was concluded that this model could predict the daily maximum soil temperature.

Keywords: machine learning, convolutional neural network, multilayer perceptron, soil temperature prediction, time-series regression

Optimizing Long Short-Term Memory (LSTM) Models for Accurate Soil Temperature Prediction in Various Climatic Conditions

Danial Goodarzi *,†

† Department of Civil Engineering, University of Ottawa, Ottawa, Canada

Abstract

Soil temperature plays a crucial role in water resources management, agriculture, and irrigation engineering. Accurate and cost-effective models for soil temperature prediction are essential for informed decision-making and effective resource allocation. While recent studies have demonstrated the effectiveness of various artificial intelligence (AI) approaches for soil temperature forecasting, the application of Long Short-Term Memory (LSTM) models, a type of recurrent neural network (RNN) architecture, has not been thoroughly investigated in this context. The LSTM model offers several advantages, such as its ability to capture long-term dependencies and handle time series data effectively, making it well-suited for predicting soil temperature based on historical data. This study aims to evaluate the performance of LSTM models in predicting soil temperature under different climatic conditions, with a specific focus on the hyperparameters' effects on model accuracy and computational cost [1].

To develop a robust LSTM model, a diverse set of land and atmospheric variables were employed as input features. A sensitivity analysis was conducted to identify the most influential variables for soil temperature prediction, leading to a more efficient model. A systematic comparison was performed by varying the layer size and the number of layers in the LSTM architecture, allowing the investigation of their impact on model accuracy and computational cost. The LSTM model was then compared with other AI techniques, such as deep learning, multi-layer perceptron, and conventional regression approaches.

The results revealed that the LSTM model with the optimal hyperparameters outperformed other methods in predicting soil temperature, achieving an R-squared of 0.9870 and a normalized RMSE of 1.1569%. Moreover, the optimal LSTM model demonstrated exceptional performance in predicting soil temperature during extremely hot events, with an R-squared of 0.9379 and an NRMSE of 0.7487%. The findings of this study suggest that LSTM models, with appropriate tuning of layer size and number, offer a promising and accurate approach for soil temperature prediction, contributing to improved agricultural and water resources management in the face of climatic uncertainties.

Keywords: artificial intelligence (AI), soil temperature prediction, Long Short-Term Memory (LSTM), neural network, sensitivity analysis.

References

[1] Hochreiter, S., & Schmidhuber, J. (1997). Long short-term memory. Neural computation, 9(8), 1735-1780.

Soil Temperature Prediction in Ordinary Climate Conditions and Extremely Hot Events and its Interpolation along Railroad using Artificial Intelligence

Hanifeh Imanian *

† Department of Civil Engineering, University of Ottawa, Ottawa, Canada

Abstract

Soil temperature is a fundamental parameter in water resources, meteorology, hydrology and irrigation engineering. A cost-effective model that can accurately forecast soil temperature is urgently needed. Two contributions have been done to this project: i) attempts were made to deliver a comprehensive and detailed assessment of the performance of a wide range of AI approaches in soil temperature prediction, ii) aimed to evaluate some AI approaches for interpolating soil temperature in southeast Canada region with an area of 1000 km by 550 km.

For the first part, thirteen approaches, from classic regressions of Linear Regression, Ridge, Lasso, and Elastic Net to well-established methods of kNN, RF, SVM, Gradient Boosting, XG Boosting, and Stacking method, to more advanced AI techniques, such as ANFIS, MLP and deep learning, were considered. Meanwhile, great varieties of land and atmospheric variables were applied as model inputs. The study area was Ottawa, the capital city of Canada located in the southeast of the country. The used variables were the hourly weather conditions, including air temperature, total precipitation, surface pressure, evaporation, instantaneous wind at 10 m above the surface, dewpoint temperature, surface net solar radiation and surface net thermal radiation. A sensitivity analysis was conducted on input climate variables to determine the importance of each variable in predicting soil temperature. This examination reduced the number of input variables from 8 to 7, which decreased the simulation load. Additionally, this showed that air temperature and solar radiation play the most important roles in soil temperature prediction, while precipitation can be neglected in forecast AI models. The comparison of soil temperature predicted by different AI models showed that deep learning demonstrated the best performance with an R-squared of 0.980 and NRMSE of 2.237%, followed by MLP with an R-squared of 0.980 and NRMSE of 2.266%. In addition, the performance of developed AI models was evaluated in extremely hot events since heat warnings are essential to protect lives and properties. The assessment showed that deep learning and MLP methods still have the best prediction. However, their R-squared decreased to 0.862 and 0.859, and NRMSE increased to 6.519% and 6.601%, respectively.

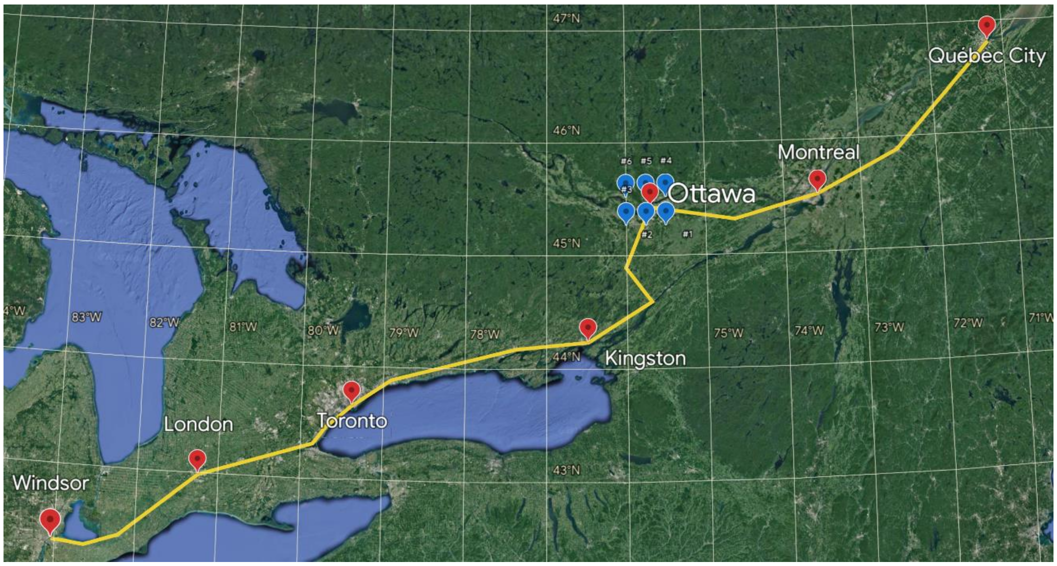
In the second part, the radial basis function neural networks (RBFN) and the deep learning approach were used to estimate soil temperature along a railroad after conventional strategies for spatial interpolation failed to interpolate gridded soil temperature data on the desired locations. The conventional method showed weaknesses in interpolating soil temperature data in areas with sudden changes. This limitation did not improve even by increasing the nonlinearity of the method. Although both RBFN and the deep learning approach had successful performances in interpolating soil temperature data even in sharp transition areas, deep learning outperformed the former method with a normalized RMSE of 9.0% against 16.2% and an R-squared of 89.2% against 53.8%. This finding was confirmed in the same investigation on soil water content.

Keywords: artificial intelligence, soil temperature, rail infrastructure, climate prediction, extreme heat events, interpolation

References

[1] Imanian, H.; Hiedra Cobo, J.; Payeur, P.; Shirkhani, H.; Mohammadian, A. A Comprehensive Study of Artificial Intelligence Applications for Soil Temperature Prediction in Ordinary Climate Conditions and Extremely Hot Events. Sustainability, 2022, 14, 8065. https://doi.org/10.3390/su14138065

[2] Imanian, H.; Shirkhani, H.; Mohammadian, A.; Hiedra Cobo, J.; Payeur, P. Spatial Interpolation of Soil Temperature and Water Content in the Land-Water Interface Using Artificial Intelligence. Water, 2023, 15, 473. https://doi.org/10.3390/w15030473



A Review of Machine Learning Approaches to Soil Temperature Estimation

Mercedeh Taheri*

Department of Civil Engineering, University of Ottawa, Ottawa, ON K1N 6N5, Canada; mtahe067@uottawa.ca

Abstract

The soil temperature is a crucial environmental factor in agricultural, meteorological, and hydrological studies. Its accurate estimation is affected by physical, chemical, and biological processes governing the soil-plant-atmosphere system. Direct measurement of soil temperature, despite the high accuracy, is impractical on a large scale due to its high cost and time requirements. Therefore, indirect methods including empirical and physical models have gained much attention. Empirical models, which use statistical regression techniques and parametric functions to retrieve soil temperature, are simple to implement with a few input data requirements. Despite the advantages of the empirical models, they are valid only under specific operational conditions in which the reference samples of the desired target variable were collected. On the other hand, physical models, as another alternative to in situ measurement approach, employ assumptions simplifying the real phenomena. High complexity, high computational cost, and intensive input data requirement limit their application in estimating near-real-time soil temperature.

To overcome these drawbacks, machine learning (ML) techniques, known as computational artificial intelligence-based (AI) models, are widely used to estimate soil temperature. ML methods are considered a group of data-driven models, which are capable of approximating complex nonlinear relationships by analyzing data attributes. Due to their advanced learning strategies, ML techniques can estimate target variables with limited assumptions about data distribution and predefined conceptual relationships between input and output data. However, the application of these methods is restricted by their sensitivity to input data and the requirement for a large amount of training data. The current research addresses the application of different types of ML techniques implemented for soil temperature determination as well as their challenges and milestones achieved in this domain.

Keywords: soil temperature, direct measurement, empirical methods, physical models, machine learning, artificial intelligence-based models.

Time Series Classification for Emergency Response in Freight Transportation Fires

Allan Zhang[a],*, M. Hamed Mozaffari[b], Yoon Ko[c], Nour Elsagan[d], Chi-Guhn Lee[e]

a,e University of Toronto

b,c,d National Research Council Canada

Abstract

In responding to freight transportation fire incidents, first responders refer to the hazardous materials labeled on the freights and the Emergency Response Guidebook (ERG) [1] for guidance on the initial response. However, when the burning goods are mixed or unknown, first responders require support on the appropriate response strategy. In this work, we propose an artificial intelligence (AI) enabled tool to aid first responders in the initial emergency response to fire incidents involving mixed or unknown materials. We used many different machine learning models, including MultiRocket [2], Omni-Scale CNN (OS-CNN) [3], Time Series Forest (TSF) [4], the Random Interval Spectral Ensemble (RISE) [5], and InceptionTime [6], to develop a trained machine learning (ML) model integrated into the AI tool. The ML model identifies the hazard characteristics (e.g., toxicity and explosivity) of a given fire, based on chemicals found in the effluent. The effluent data was collected from samples of burning materials using a cone calorimeter and a Fourier Transform Infrared Spectroscopy (FTIR) gas analyzer. We discuss the methodologies behind developing the ML model and demonstrate its high classification accuracy with time series augmentations to enhance the training dataset. We also implemented Self-Supervised Learning, Domain-Agnostic Contrastive Learning (DACL) [7], and Adversarial Perturbation-based Latent Construction (APLR) [8] to further improve the model. The results show that MultiRocket outperforms other models in terms of accuracy and running time. Furthermore, we developed a user interface for our AI-enabled tool, which uses a data sample as input to provide not only predictions of the fire hazards but also actionable intelligence to the first responders for safe and effective fire suppression strategies. Our proposed toolkit benefiting from AI will pave the way to further research in accessible, easily-deployable AI-enabled tools in fire sciences and management.

Environmental Implications: We leverage machine learning to predict the hazard classification of materials that may not be considered hazardous by Emergency Response Guidebook (ERG) used by Transport Canada, but may release toxic substances when burning. For example, polyvinyl chloride is not considered as hazardous by ERG, but toxic and corrosive hydrochloric gas is produced when burning. We aim to provide more decision support to first responders in freight transportation fires involving non-hazardous or unknown materials to identify the scope of the emergency from the early stage of the fire, which is critical to protect the environment from the effects of the fire.

Keywords: time series classification, time series augmentation, self-supervised learning, decision support systems, applied machine learning

References

[1] Transport Canada. (2020). Emergency Response Guidebook. Retrieved from https://tc.canada.ca/en/dangerous-goods/canutec/2020-emergency-response-guidebook

[2] Bagnall A, Lines J, Bostrom A, Large J, Keogh E (2017) The great time series classification bake off: a review and experimental evaluation of recent algorithmic advances. Data Min Knowl Disc 31(3):606–660

[3] Bhattacharjee, B., Dubey, A., Dua, A., & Kapoor, K. (2020). A Survey of Deep Learning Techniques for Cyber Security. arXiv preprint arXiv:2002.10061.

[4] Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S., & Dean, J. (2013). Distributed representations of words and phrases and their compositionality. arXiv preprint arXiv:1302.2277.

[5] Flynn, M., & Large, J. (2013). The Contract Random Interval Spectral Ensemble (CRISE) model for simulating musical improvisation. Journal of New Music Research, 42(3), 201-215.

[6] Wang, S., Wang, Y., Ye, Q., & Zhang, J. (2019). A comprehensive survey on graph neural networks. arXiv preprint arXiv:1909.04939.

[7] Altwaijry, H., Alsheikh, M. A., & Al-Muhtadi, J. (2020). A Survey on Federated Learning Systems: Vision, Hype and Reality for Data Privacy and Protection. arXiv preprint arXiv:2011.04419.

[8] Wu, M., Shao, H., Zhang, X., & Lu, J. (2022). Double-sided contextual bandits with unbiased learning. Journal of Machine Learning Research, 23(42), 1-51.

DSA-SCL : Device-specific Similarity Analysis using Siamese CNN and LSTM Networks for Malware Detection in IoT Environments

Tinshu Sasi*
† Arash Habibi Lashkari, Rongxing Lu

Abstract

Malware has emerged as a severe issue with rising infection rates and complexity levels with the surge in IoT devices and technologies entering service. Without robust security measures, a vast quantity of sensitive data is vulnerable to vulnerabilities and may thus be readily utilized by cybercriminals to engage in various illegal activities. Robust network security systems that can analyze traffic in real-time are needed to mitigate harmful or malicious traffic. Machine learning (ML) and deep learning are the foundation of many widely used malware detection techniques. The ML-based system classifies and detects malicious network traffic behavior by analyzing the manually extracted network traffic features. In contrast, the DL-based system can analyze the manually extracted features and automatically extract the features from the original traffic. As a result, DL-based methods can circumvent the manual feature extraction problem and enhance detection accuracy compared to generic ML-based systems. Thus, this paper develops a DSA-SCL (Device-specific Similarity Analysis based on Siamese CNN and LSTM networks) framework for malware detection in IoT devices, which uses a Siamese hybrid network of Convolutional Neural Network (CNN) and Long Short-Term Memory Network (LSTM) to extract the spatial and temporal features of benign and malicious network traffic data for similarity analysis. Also, we will be testing the DSA-SCL framework on the CIC IoT Dataset 2022 dataset, a state-of-the-art dataset for profiling, behavioral analysis, and vulnerability testing of different IoT devices with other protocols such as IEEE 802.11, Zigbee-based, and Z-Wave.

Keywords: Malware Detection, IoT, Similarity Analysis, Behavioral analysis

Privacy-Preserving Services for Fog-aided Intelligent Transportation Systems

Yunguo Guan *

† Rongxing Lu

Abstract

The development of Internet of Things (IoT) technology has enabled the use of smart technologies to enhance transportation systems' efficiency, in which fog computing is usually employed to provide flexible computing resources and deliver locality-sensitive services. However, this has led to the collection and transmitting of vast amounts of data, raising concerns about users' privacy. For example, collecting users' locations and timestamps to train smart traffic lights can enable the adversary to infer their trajectories and point-of-interest preferences, compromising their privacy. Therefore, privacy preservation is crucial to the development of intelligent transportation systems.

In this project, we consider two applications in intelligent transportation systems (ITS), namely, mobile crowdsourcing [1]-[2] and query services [3]. In mobile crowdsourcing applications, the workers submit their locations or future trajectories, along with other properties, to the fog servers, and the latter selects the best worker according to task requirements. We consider protecting the privacy of the workers' data, the task requirements, and the matching results. As for query services, the query users retrieve the data they need from a dataset by submitting queries to the fog servers, and we aim to protect the privacy of the dataset, user queries, and the retrieved data. These are two typical applications in ITS, in which the first computes result from user inputs, and the second returns record from pre-obtained datasets based on users' queries.

Our proposed schemes have been published in reputable conferences such as the IEEE International Conference on Communication (ICC) and IEEE GLOBECOM. By addressing privacy concerns, our solutions provide a foundation for developing privacy-preserving smart transportation systems that maintain the benefits of smart technologies while ensuring users' privacy. Privacy preservation is a critical step toward developing intelligent transportation systems, and our proposed solutions offer practical ways to achieve it.

Keywords: Intelligent Transportation Systems, IoT, Privacy-Preserving

References

[1] Y. Guan, P. Xiong, S. Zhang, and R. Lu, Privacy-Preserving Outsourced Task Scheduling in Mobile Crowdsourcing, Proc. IEEE Globecom'22, Rio de Janeiro, Brazil, Dec. 4-8, 2022.

[2] Y. Guan, P. Xiong, and R. Lu, Privacy-Preserving Fog-Based Multi-Location Task Allocation in Mobile Crowdsourcing, Proc. IEEE Globecom'21, Madrid, Spain, Dec. 7-11, 2021.

[3] Y. Guan, P. Xiong, and R. Lu, EVRQ: Achieving Efficient and Verifiable Range Query over Encrypted Traffic Data, IEEE ICC'22, Seoul, South Korea, 16 - 20 May 2022.

Advanced Persistent Threat Detection in Industrial IoT Systems

First Author: Erfan Ghiasvand *
† Faculty of Computer Science, UNB

Abstract

Over the past few years, the Industrial Internet of Things (IIoT) has gained popularity due to its benefits for various industrial applications. However, this increased adoption has also made IIoT devices attractive targets for cyber threats. These devices are heterogeneous and resource-constrained, making conventional cybersecurity methods ineffective. Advanced persistent threats (APTs) pose a significant risk to IIoT networks due to their low and slow approach, which makes them difficult to detect. Real-world examples, such as the Stuxnet attack on the Iranian nuclear program, the 2014 attack on a German factory, and the 2015 attack on Ukrainian companies, demonstrate the severity of these threats to IIoT systems. This project proposes a graph-based machine-learning method for detecting APT attacks in IIoT systems. While most available datasets in the IIoT context only consist of network packets captured during experiments, APT attacks typically require more sophisticated data sources for detection. For instance, using provenance data is common in many APT detection systems [1]. Thus, the first step of this project is to generate a comprehensive dataset that includes various data sources, such as network packets, system logs, and IDS alerts. To achieve this, different IIoT testbeds, such as Brown-IIoTbed [2], can be used. The next step is to use this dataset and all the available data sources to detect different phases of the APT attack. Finally, the results of these detection steps are correlated to generate a high-level APT scenario graph that can assist cyber analysts in mitigating these attacks. Overall, the proposed method provides a novel approach for APT detection in IIoT systems and has the potential to improve the security of these systems against advanced cyber threats.

Keywords: Industrial IoT, Advanced persistent threat, graph-based detection, data provenance

References

[4] Zipperle, Michael, et al. "Provenance-based intrusion detection systems: A survey." ACM Computing Surveys 55.7 (2022)

[5] Al-Hawawreh, Muna, and Elena Sitnikova. "Developing a security testbed for industrial internet of things." IEEE Internet of Things Journal 8.7 (2020)

An Effective Approach to Detect Label Noise

Mahdi Abrishami *

† Faculty of Computer Science, UNB
Fredericton, Canada

Abstract

With the increased usage of Internet of Things (IoT) devices in recent years, different Machine Learning (ML) methods have also developed dramatically for attack detection in this domain. However, ML models are vulnerable to various classes of adversarial attacks that aim to fool a model into making an incorrect prediction. For instance, label manipulation or label flipping is a type of adversarial attack in which the attacker attempts to manipulate the label of training data, thereby causing the trained model to be biased and/or with decreased performance. However, the number of samples that can be flipped in this type of attack can be limited, giving the attacker a limited target selection. Due to the importance of securing ML models against Adversarial Machine Learning (AML) attacks, particularly in the IoT domain, this research presents an extensive review of AML in IoT. Then, a classification of AML attacks is proposed based on the literature, creating a foundation for future research in this domain. Next, more specifically, this research investigates the negative impact levels of applying malicious label flipping attacks (intentional label noise) on IoT data. As accurate labels are necessary for ML training, exploring adversarial label noise is an important research topic [1]. However, the label noise in datasets is not always adversarial and may be caused due to several other reasons, such as careless data labelling. Classification is an essential task in machine learning, where the main objective is to predict the categories of unseen data. The existence of label noise in training datasets can negatively impact the performance of supervised classification, whether it is adversarial or non-adversarial. Due to the growing interest in the data-centric AI that aims at improving the quality of training data without enhancing the complexity of models, a range of research has been undertaken to tackle the label noise problem. However, few works have investigated this problem in the IoT network intrusion detection domain. This research addresses the issue of label noise in the intrusion detection domain by presenting a framework to detect samples with noisy labels. The proposed framework's main components are the decision tree classification algorithm and active learning. The framework is composed of two steps: making a decision tree robust against the label noise in a dataset and then using this robust model with the help of active learning with uncertainty sampling to detect noisy samples effectively. In this way, the inherent resiliency of the decision tree algorithm against label noise is utilized to tackle this issue in datasets. Based on the results of our experiments, the proposed framework can detect a considerable number of noisy samples in the training dataset, with up to 98% noise reduction. The proposed detection method can also be leveraged as a defense against random label flipping attacks where adversarial label manipulation is applied randomly [2].

Keywords: IoT, Adversarial Machine Learning, Classification of Adversarial Attacks, Label Manipulation, Data-centric AI, Active Learning

References

[1] M. Abrishami et al., "Classification and Analysis of Adversarial Machine Learning Attacks in IoT: a Label Flipping Attack Case Study," 2022 32nd Conference of Open Innovations Association (FRUCT), Tampere, Finland, 2022, pp. 3-14, doi: 10.23919/FRUCT56874.2022.9953823.

[2] M. Abrishami et al., "Label Noise Detection in IoT Security based on Decision Tree and Active Learning," 2022 IEEE 19th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET), Marietta, GA, USA, 2022, pp. 046-053, doi: 10.1109/HONET56683.2022.10019152.

Intrusion Detection Systems for Mitigating Security Issues in Internet of Vehicle (IoV)

First Author * Euclides Carlos Pinto Neto
† Faculty of Computer Science, UNB

Abstract

Nowadays, connected vehicles have a major role in enhancing the driving experience. Connected vehicles in the network share their knowledge with the help of the network known as the Internet of Vehicles (IoV). However, connection through the network comes with risks ranging from privacy concerns to security vulnerabilities in the network. Inside vehicles, many sensors and Electronic Control Units (ECUs) are connected via specific network protocols, known as Intra-Vehicle communications, to assist the driver in tasks such as autonomous driving. Communicating through different protocols results in security openness for attackers to disturb the normal functioning of sensors and ECUs, which sometimes has detrimental effects. Moreover, in IoV, there is active communication between vehicles and other vehicles or road infrastructures alongside the network, known as Inter-Vehicle communications. Inter-Vehicle communications can also be an open vulnerability to intruders. Motivated by the mentioned security problems, many research initiatives have elaborated on building Intrusion Detection Systems (IDS) to detect malicious behavior threatening the confidentiality, integrity, availability, and authenticity of IoV. Specifically, in-vehicle networks handle the communication among Electronic Control Units (ECUs) and sensors with a serial protocol called Controller Area Network (CAN), which takes advantage of a broadcast mechanism for transferring data. However, the lack of authentication and encryption in CAN bus might lead to the vehicle being compromised by an untrusted agent. Meanwhile, AI-based Network IDS introduced in the literature requires a centralized cloud server to undertake the resource-consuming task of processing network data, which also occupies the bandwidth while transferring data from vehicles to the remote server. Moreover, many car manufacturers avoid sharing information with the remote server to prevent further exposure of vehicles' private data. We utilize Federated Learning (FL) as a suitable solution to previous challenges, where data is trained locally on the vehicle side, and partially trained models are sent to the server. Nevertheless, private training inside the vehicle requires low memory utilization while achieving low latency and high performance compared to Centralized Learning (CL) approaches. In this study, we propose a practical privacy-preserving IDS (ImageFed) approach by employing federated Convolutional Neural Network (CNN). To evaluate the robustness of ImageFed in real-world applications, we investigate two scenarios that may cause performance degradation in FL, such as non-independent and identically distributed (non-iid) clients and scarcity of training data during the process. The resulting analysis proves the robustness of ImageFed while delivering high performance and low latency.

Keywords:detection latency, Internet of Vehicle (IoV), Intrusion Detection System(IDS),Federated Learning(FL), Deep Learning(DL)

References

[1] Taslimasa, Hamideh, et al. "ImageFed: Practical Privacy Preserving Intrusion Detection System for In-Vehicle CAN Bus Protocol", IEEE BigDataSecurity, 2023.

[2] Taslimasa, Hamideh, et al. " Security Issues in Internet of Vehicles (IoV): A Comprehensive Survey", submitted to Internet of Things Eslevier Journal.

IoT Network Monitoring using IoT Device Profiling, Fingerprinting and Identification

Amir Firouzi, Alireza Zohourian

University of New Brunswick (UNB), Canadian Institute for Cybersecurity (CIC)

Abstract

The Internet of Things (IoT) has emerged as a pervasive trend and is experiencing widespread adoption across numerous applications globally. IoT has been integrated into various sectors, including healthcare, transportation, manufacturing, and agriculture. [1] The rapid expansion of IoT devices, protocols, and technologies has led to increasingly intricate IoT networks. Moreover, these networks exhibit heterogeneous characteristics, comprising an array of devices with diverse capabilities and communication protocols. These devices often encounter resource constraints such as limited battery life, memory, and processing power, rendering them susceptible to attacks. Traditional network monitoring systems are ill-equipped to manage the complexities inherent in IoT networks. [2] To tackle the challenges associated with IoT network monitoring, we propose an IoT profiling solution that employs device identification and fingerprinting techniques to continuously scrutinize devices within the network and ensure their legitimacy. The IoT profiling framework offers a comprehensive approach to IoT network monitoring, addressing issues related to complexity, heterogeneity, and proliferation of IoT. By identifying and continuously monitoring each device within the network, the IoT profiling framework enhances security and stability in the IoT ecosystem. [3] The IoT profiling workflow commences as a new device connects to the network. The device is promptly isolated in a quarantine zone, where its behavior undergoes analysis for identification and fingerprint creation. Based on the device's characteristics, a risk or vulnerability score is computed. Subsequently, depending on its risk score, the device is granted or denied access to a specific network segment. Upon entering the network, the device's behavior is perpetually monitored, with any anomalies or intrusions reported to the network administrator for further examination. [4] Furthermore, IoT profiling is equipped with mobility detection, which assesses the device's movement within the network. In the event of a change in movement behavior, the network administrator is notified. Employing this workflow, IoT profiling delivers a comprehensive approach to IoT network monitoring that addresses the challenges presented by the complexity, heterogeneity, and proliferation of IoT devices.

Keywords: Internet of Things, IoT Profiling, Device Identification, Device Fingerprinting, Network Traffic Analysis.

References

[1] Schiller, Eryk, Andy Aidoo, Jara Fuhrer, Jonathan Stahl, Michael Ziörjen, and Burkhard Stiller. "Landscape of IoT security." Computer Science Review 44 (2022): 100467.

[2] Neshenko, Nataliia, Elias Bou-Harb, Jorge Crichigno, Georges Kaddoum, and Nasir Ghani. "Demystifying IoT security: an exhaustive survey on IoT vulnerabilities and a first empirical look on internet-scale IoT exploitations." IEEE Communications Surveys & Tutorials 21, no. 3 (2019): 2702-2733.

[3] Safi, Miraqa, Sajjad Dadkhah, Farzaneh Shoeleh, Hassan Mahdikhani, Heather Molyneaux, and Ali A. Ghorbani. "A Survey on IoT Profiling, Fingerprinting, and Identification." ACM Transactions on Internet of Things 3, no. 4 (2022): 1-39.

[4] Danso, Priscilla Kyei, Euclides Carlos Pinto Neto, Sajjad Dadkhah, Alireza Zohourian, Heather Molyneaux, and Ali A. Ghorbani. "Ensemble-based Intrusion Detection for Internet of Things Devices." In 2022 IEEE 19th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET), pp. 034-039. IEEE, 2022.

From Autonomous Driving to Aerial Robotics with CARLA

Ricardo de Azambuja *
† Polytechnique Montréal

Abstract

Companies have been integrating Remote Piloted Aircraft Systems (RPAS) into the supply chain, leading to significant technological advancements in recent years [1]. However, the safety and security implications of their usage cannot be ignored. Many potential threats posed by inadequately designed and operated RPAS can result in risks to the supply chain and the public at large. In particular, issues with geolocation and sensory information could lead to unsafe landing conditions. It has been shown before that drones can be hijacked by using Radio Frequency (RF) interference and the transmission of fake or spoofed signals [2]. Still, research in this field demands specialised datasets that are generally not openly available and would need to be physically collected, a laborious operation. To fill the data gap needed for researchers in this field, we designed a framework to assist the development of automatic systems capable of safely landing a drone only using its internal sensors. Our framework builds on top of CARLA (Car Learning to Act) [3], simplifying the generation of synthetic datasets, and enabling an easier path to prototyping and testing of systems based on the Robot Operating System 2 (ROS 2) [4]. Given that CARLA was designed as a platform for self-driving cars (ground vehicles), many adaptations had to be implemented to allow its use with aerial vehicles. Our framework will enable users to create realistic scenarios that can be used to test the performance of RPAS and associated technologies in a safe and controlled environment. The generated data can be used to train and validate machine learning models to improve the accuracy of RPAS geolocation and other sensory information. Furthermore, the adapted CARLA simulator will enable users to test the effectiveness of proposed solutions for addressing the high level effects of RF interference and spoofing attacks. The availability of this simulator package will provide a valuable resource for researchers and practitioners in the field of RPAS and supply chain management, aiding the development of safe and efficient systems.

Keywords: aerial robotics, synthetic datasets, sim2real, ros2, simulator

References

[1] Benarbia, Taha, and Kyandoghere Kyamakya. "A literature review of drone-based package delivery logistics systems and their implementation feasibility." Sustainability 14.1 (2022): 360.

[2] Noh, Juhwan, et al. "Tractor beam: Safe-hijacking of consumer drones with adaptive GPS spoofing." ACM Transactions on Privacy and Security (TOPS) 22.2 (2019): 1-26.

[3] Dosovitskiy, Alexey, et al. "CARLA: An open urban driving simulator." Conference on robot learning. PMLR, 2017.

[4] Macenski, Steven, et al. "Robot Operating System 2: Design, architecture, and uses in the wild." Science Robotics 7.66 (2022): eabm6074.

A Lightweight Visual Semantic Simultaneous Localization and Mapping Design for Unmanned Aircraft Systems

Rongge Zhang *
† Polytechnique Montreal

Abstract

Accurate location information and region identification in real-time are important when the drone performs path planning and obstacle avoidance tasks. A robust and accurate visual odometry is especially essential for a secure self-landing objective for unmanned aircraft systems in GPS failure case [1]. For this objective, we proposed a lightweight visual semantic simultaneous localization and mapping (SLAM) design. Firstly, based on ORB-SLAM3 [2], we implemented our visual odometry. There is hardly any suitable public dataset for our unique situation to evaluate the algorithm in the specific drone safe-landing use case. So, we created a CARLA simulation environment and integrated our visual odometry pipeline into the simulation [3]. We carried out a real-time visual odometry simulation. The SLAM node can be set to work in pure location mode to save the computing cost, or to work in mapping mode, adding local and global map matching functions and loop closure functions to improve the localization accuracy. Furthermore, in the mapping mode, a lightweight deep learning model Erf-Net [4] was used to do semantic segmentation, so as to assist the drone with detecting and identifying the safe landing place in large-scale scenes. The semantic segmentation was tested and the semantic mapping experiment was carried out in simulation. An ortho-map [5] from the drone's view was built and the point cloud from the camera was projected onto the ground 2D plane to build the semantic map. Different kinds of objects and regions like roads, buildings, vehicles, and grass were classified and displayed in different colors. For CARLA simulation, we are the first to validate drone safe-landing use case, as well as to support SLAM for drone, since CARLA is built specifically to test self-driving cars. For our project, the results from the visual odometry will enable the drone to conduct real-time localization without GPS. The localization results will support the drone's path planning and obstacle avoidance functions in the project. Also, the lightweight segmentation model can assist the drone with identifying the safe landing place in the environment in real-time. In the following work, this model can be combined with other previous research results to improve the accuracy of safe location detection and improve the safety of drone landing.

Keywords: Semantic SLAM, visual odometry, aerial mapping, CARLA, UAS,

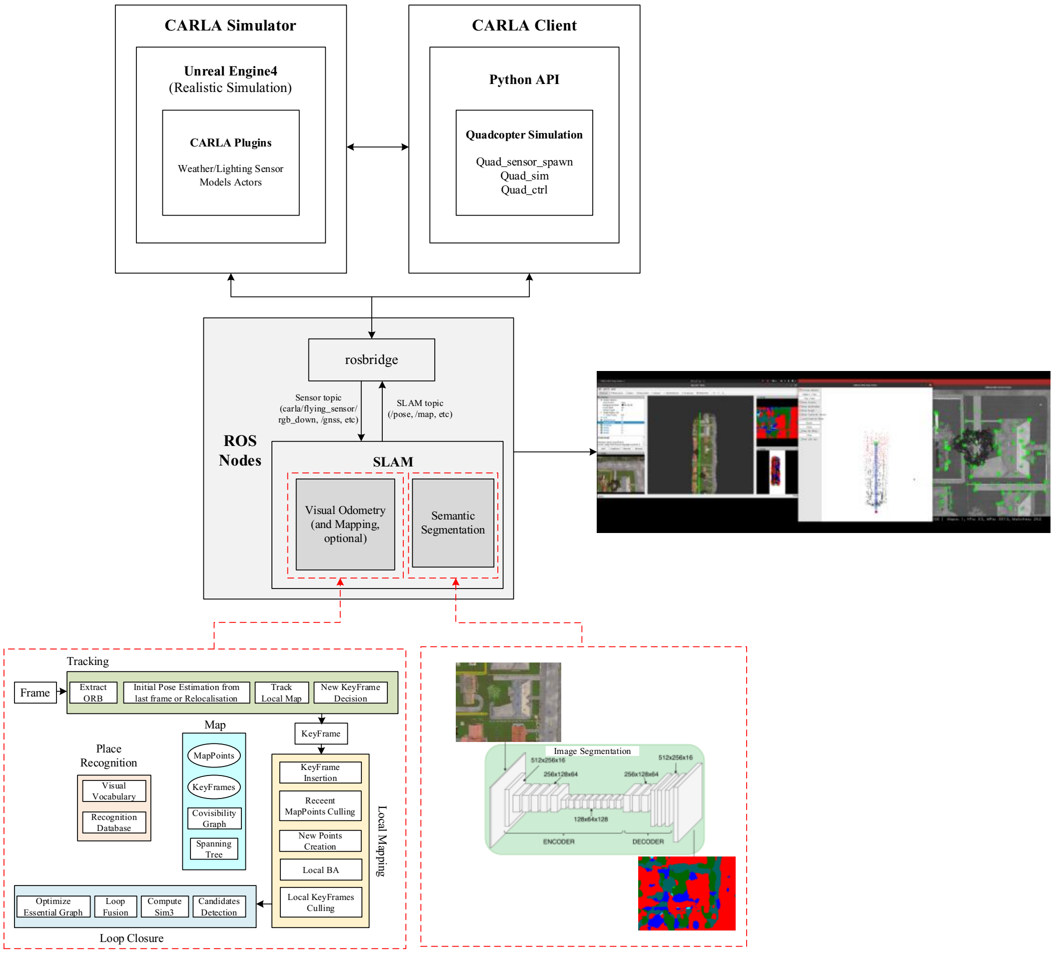


Fig 1. System overview of the proposed design.

References

[1] Hinzmann, T., et al. Mapping on the fly: Real-time 3D dense reconstruction, digital surface map and incremental orthomosaic generation for unmanned aerial vehicles. in Field and Service Robotics: Results of the 11th International Conference. 2018. Springer.

[2] Campos, C., et al., ORB-SLAM3: An Accurate Open-Source Library for Visual, Visual–Inertial, and Multimap SLAM. IEEE Transactions on Robotics, 2021. 37(6): p. 1874-1890.

[3] Dosovitskiy, Alexey, et al. "CARLA: An open urban driving simulator." Conference on robot learning. PMLR, 2017.

[4] Romera, Eduardo, et al. "Erfnet: Efficient residual factorized convnet for real-time semantic segmentation." IEEE Transactions on Intelligent Transportation Systems 19.1 (2017): 263-272.

[5] Miller, I.D., et al., Stronger Together: Air-Ground Robotic Collaboration Using Semantics. IEEE Robotics and Automation Letters, 2022. 7(4): p. 9643-9650.

TMRL: Deep RL for Real-Time Applications

Yann Bouteiller *, Giovanni Beltrame

† Polytechnique Montréal

Abstract

Reinforcement Learning research has witnessed tremendous progress over the last decade, driven by the success of function approximation. While still largely restricted to solving toy tasks [1], these advances are gaining high-impact industrial traction, for instance in bioinformatics [2] and recent large language models [3]. Therefore, we expect to see the industrial adoption of the field grow dramatically in the near future. To foster progress in this direction, we propose an open-source framework that highly facilitates the design and training of Reinforcement Learning agents in Real-Time applications. These applications are not what Reinforcement Learning researchers are typically familiar with, because they embed time in their Markov structure. In other words, they deal with environments in which time cannot be paused for action inference, observation capture, and other sources of delay [4]. Nevertheless, they are highly relevant for the industry: they include a broad range of real-world tasks such as autonomous driving, robot control, high-frequency trading, etc. Our effort provides tools for professionals and researchers who wish to deal with these tasks. Furthermore, it attracts newcomers to the field, sensibilizes them to the challenges of real-world Reinforcement Learning, and helps them design Reinforcement Learning solutions for their own control tasks. Our framework is divided into two modules. The first of these modules, Real-Time Gym [5], is a user-friendly helper that enables practitioners to cast their real-time tasks into Gymnasium environments (formerly OpenAI Gym). It consists of a threaded engine that clocks the user's environment in the background, so that it can be used similarly to any regular Gymnasium environment from the front-end perspective.

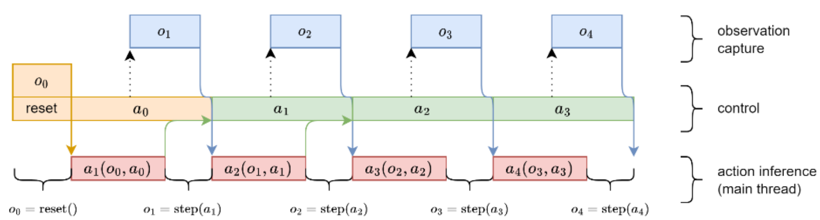


Figure 5: Real-Time Gym interface for real-world applications

The second module, TMRL [6], is a distributed Reinforcement Learning training framework geared toward the development of highly optimized ad-hoc training pipelines. TMRL is also a landing point for newcomers and researchers in the field, as it provides a readily implemented training pipeline for the popular TrackMania video game. Our Real-Time Gym environment for TrackMania is featured as a third-party autonomous driving environment on the Gymnasium website [7]. Both Real-Time Gym and TMRL come with tutorials targeting different audiences to quickly get professionals, researchers and hobbyists started.

Figure 6: Vision-based agent trained with TMRL, racing in a real-time video game. The agent infers its dynamics from camera images equally spaced in time (20FPS)

Keywords: reinforcement learning, deep learning, real-time, high frequency, control, robotics

References

[1] Irpan, A. “Reinforcement learning doesn’t work yet.” Blog post. URL: https://www.alexirpan.com/2018/02/14/rl-hard.html

[2] Ruff, Kiersten M., and Rohit V. Pappu. "AlphaFold and implications for intrinsically disordered proteins." Journal of Molecular Biology 433.20 (2021): 167208.

[3] OpenAI. “GPT-4 Technical Report”

[4] Bouteiller, Y., Ramstedt, S., Beltrame, G., Pal, C., & Binas, J. (2021, May). Reinforcement learning with random delays. In International conference on learning representations.

[5] Bouteiller, Y., and Beltrame, G. “Real-Time Gym.” URL: https://github.com/yannbouteiller/rtgym

[6] Bouteiller, Y., Geze, E, and Beltrame, G. “TMRL.” URL: https://github.com/trackmania-rl/tmrl

[7] Farama. “Gymnasium.” URL: https://gymnasium.farama.org

3D Path Planning For Unmanned Aerial Vehicles Using Deep Neural Networks

Hae Chan Mark Bong *
† Polytechnique Montréal

Abstract

The recent rise of interest in unmanned aerial vehicles (UAV) from industries and academia generated novel technological advancements in aerial robotics. Although promising, the safety of having UAVs in public space is still uncertain [1][2]. It is critical for UAVs to perform urgent landing without human assistance if there is a technical malfunction. The main objective of this project is to build innovative approaches to perform safe landing of UAVs. This project combines multiple domains of research, including computer vision, robotics and deep learning (DL). This abstract describes two components among the project: 3D path planning and realistic map generation. The idea behind the two components is to build a 3D path planning algorithm and test it on real or close to real environments for validation.

Technological challenges are present for path planning algorithms when dynamic 3D obstacle avoidance is necessary. [3] proposed an approach to use artificial potential field as a guidance to perform 2D path planning on simple environments. By expanding the artificial potential field path planner algorithm, this project proposes a 3D path planner that uses Convolutional Neural Networks (CNN) to learn the behavior of attraction towards the goal and repulsion from areas further from the goal and obstacles. Training CNN for this purpose requires high resolution 3D aerial datasets that are realistic and at ideal distance from ground level (in between 100m to 20m). However, there is a lack of such datasets available for public use. Popular open-source autonomous driving simulator such as CARLA [4] can be used to generate 3D aerial datasets, but the aerial view from the simulator is not realistic enough to portray realistic scenarios. Therefore, the second component of this project is proposed to generate a realistic 3D map from real locations and collect aerial datasets.

There are numerous approaches to generate 3D maps [5][6][7], but generating a realistic 3D aerial map is difficult. Not only do they have to have realistic 3D meshes, but they also have to comply to physics engines (reflect on light, collide using colliders, etc.). Combining images from Google Maps and graphics editor Blender, we were able to generate and render a 3D map of Polytechnique Montréal (figure 1), which is close to realistic 3D environment. Next logical approach was to import the map to CARLA given its robustness of dynamic obstacle generation capabilities (generate pedestrians and cars that move using artificial intelligence). The generated map can be used to collect realistic 3D aerial images by flying around the map and train CNN with the generated dataset. Given that this specific map is learned already, we will need to test the path planner on other generated maps and in real outdoor environments for validation.

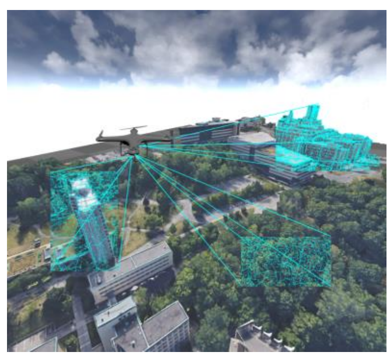


Figure 1: Drone Performing Image Analysis on 3D Generated Map of Polytechnique Montréal

Keywords: UAV, DL, Path Planning, Map Generation, Artificial Potential Field, CNN

References

[1] Qin Xiao, Yapeng Li, Fan Luo, Hui Liu, Analysis and assessment of risks to public safety from unmanned aerial vehicles using fault tree analysis and Bayesian network, *Technology in Society,* Volume 73, 2023, 102229, ISSN 0160-791X, https://doi.org/10.1016/j.techsoc.2023.102229.

[2] Di Mu, Chaolong Yue, An Chen, Are we working on the safety of UAVs? An LDA-based study of UAV safety technology trends, Safety Science, Volume 152, 2022, 105767, ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2022.105767.

[3] M. Moussa and G. Beltrame, "Real-Time Path Planning With Virtual Magnetic Fields," in IEEE Robotics and Automation Letters, vol. 6, no. 2, pp. 3279-3286, April 2021, doi: 10.1109/LRA.2021.3063992.

[4] Alexey Dosovitskiy, German Ros, Felipe Codevilla, Antonio Lopez, Vladlen Koltun, "CARLA: An Open Urban Driving Simulator", Proceedings of the 1st Annual Conference on Robot Learning, PMLR 78:1-16, 2017.

[5] R. Lopez-Campos and J. Martinez-Carranza, "ESPADA: Extended Synthetic and Photogrammetric Aerial-Image Dataset," in IEEE Robotics and Automation Letters, vol. 6, no. 4, pp. 7981-7988, Oct. 2021, doi: 10.1109/LRA.2021.3101879.

[6] Chen, Lyujie et al. "VALID: A Comprehensive Virtual Aerial Image Dataset." 2020 IEEE International Conference on Robotics and Automation (ICRA) (2020): 2009-2016.

[7] Meida Chen, Qingyong Hu, Zifan Yu, Hugues Thomas, Andrew Feng, Yu Hou, Kyle McCullough, Fengbo Ren, & Lucio Soibelman (2022). STPLS3D: A Large-Scale Synthetic and Real Aerial Photogrammetry 3D Point Cloud Dataset. In 33rd British Machine Vision Conference 2022, BMVC 2022, London, UK, November 21-24, 2022. BMVA Press.

XRT4TEAMS – Evaluating a Virtual Reality Training Tool for First Responders

Maxine Berthiaume*†, Natalia Cooper†, Bruno Emond‡, Jean-François Lapointe‡, Max Kinateder†, Ishika Obeegadoo†

† Construction Research Center

‡ Digital Technologies Research Center

Abstract

First responders in remote areas face challenges in accessing training for handling dangerous goods. Virtual reality (VR) offers a promising solution to this issue, as it is cost-effective, safe, and allows for the simulation of realistic scenarios that may be dangerous or difficult to replicate in the real world. However, there is a lack of rigorous evaluations of VR training tools for first responders. To address this issue, the XRT4TEAMS project team developed a simple VR training tool to train firefighters on how to approach a capsized truck with a trailer and collect information about transported hazardous materials (Figure 1). Here, the authors report on an exploratory user study that involved 24 professional firefighters who completed two training scenarios. Participants provided feedback on cybersickness, perceived workload, and usability. Overall, the VR tool was found to be user-friendly, but there was a wide range of responses from individuals. The authors discuss future directions for improving the VR training tool, general implications for VR training tools, and suggestions for future research.

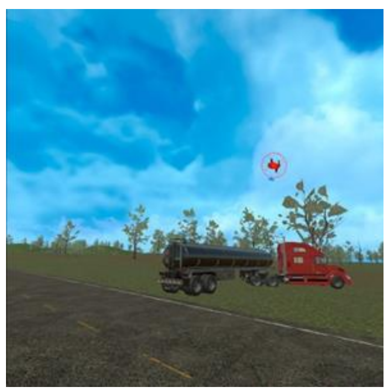


Figure 1. Screenshot of the Virtual Reality training tool

Keywords: first responders, training, dangerous goods, virtual reality, firefighting

Text Augmentation Using AMR Graphs & CLONALG

Hadeer Ahmed *

† Issa Traore, Mohammad Mamun and Sherif Saad

Abstract

Training machine learning models to identify and prevent data leaks and exfiltration is a challenge for enterprises as sensitive data is often scarce. Accurate identification and protection of sensitive information require high-quality annotated data. However, generating such data is a time-consuming and labor-intensive process. Moreover, relying on human annotators to generate such data can introduce biases, inaccuracies, and errors, making it a complex task that generates faulty datasets. To overcome these challenges, researchers are exploring various techniques to improve the quality of training and testing datasets, and one such technique is text augmentation. Text augmentation involves creating new data from existing data to augment the training dataset. Recently, text augmentation techniques have become an active research topic, especially with the widespread adoption of deep learning models that require a massive amount of training data. Most of the literature focuses on tabular and image data augmentation techniques. However, data augmentation techniques for textual data and NLP applications have become necessary. In this research, we tackle some key limitations of text augmentation by introducing a new method using the clonal selection algorithm (CLONAG) and abstract meaning representation (AMR) graphs. The use of an AMR graph to keep the structure of the initial text enables generating different augmented texts while retaining control over the mutations made to the text. This allows us writing rules that preserve domain- specific keywords and preserve the texts' domain. In addition, by using the fitness function of the CLONAG to discard unsuitable samples generated during each iteration of the text mutation, we can generate a larger number of augmented texts from small input samples while preserving the label of the generated text and preventing any drift from occurring in the text.

Keywords: sensitive data, text, data augmentation, AMR Graphs

References

[1] Ahmed, Hadeer, et al. "Text augmentation using a graph-based approach and clonal selection algorithm." Machine Learning with Applications, vol. 11, 15 Mar. 2023, p. 100452, doi:10.1016/j.mlwa.2023.100452.

[2] Ahmed, Hadeer, et al. "Automated detection of unstructured context-dependent sensitive information using deep learning." Internet of Things, vol. 16, 1 Dec. 2021, p. 100444, doi:10.1016/j.iot.2021.100444.

List of Authors

NRC·CNRC

NR16-424/2023E-PDF
ISBN: 978-0-660-48565-2