Scoping study for upgrading the Defence Research and Development Canada (DRDC) underwater acoustic calibration system

Andrew B. Jantzen
DRDC – Atlantic Research Centre

Prepared For:
Centre Director, DRDC – Atlantic Research Centre
9 Grove Street,
Dartmouth, Nova Scotia, Canada B3A 3C5

Defence Research and Development Canada

Reference Document
DRDC-RDDC-2016-D058
November 2016

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Abstract

DRDC's acoustic calibration system has been in operation since 1959. Periodic upgrades are performed on the system hardware to make use of new technology as it becomes available. In 2014, new hardware was purchased for data acquisition and generation. Updates to the calibration software are required to integrate the new hardware into the system. This study included an analysis of the upgrades needed to achieve a functional and maintainable integrated system. The options for updating or redesigning the calibration software were evaluated, and recommendations are provided for software and hardware upgrades necessary before the new data acquisition hardware can be used with the system. The assessment also identified areas where the addition of equipment and environmental sensors would improve and enhance the capabilities of the system. With these upgrades to both software and hardware, the DRDC underwater calibration system will be in a position to better meet the research needs of scientists at DRDC, the Canadian Forces and other government departments, as well as offer a competitive and attractive facility for researchers in industry and academia.

Résumé

Le système d'étalonnage acoustique de RDDC est utilisé depuis 1959. Le matériel du système est régulièrement mis à niveau pour permettre l'utilisation de nouvelles technologies au fur et à mesure qu'elles deviennent disponibles. En 2014, on a acheté un nouveau matériel d'acquisition et de production de données. Il faut mettre à jour le logiciel d'étalonnage pour intégrer le nouveau matériel au système. La présente étude comporte une analyse des mises à niveau nécessaires pour obtenir un système intégré fonctionnel et facile à entretenir. On a aussi évalué les options de mise à jour ou de reprise de la conception du logiciel d'étalonnage, puis on a soumis des recommandations sur les mises à niveau du logiciel et du matériel à effectuer avant de pouvoir utiliser le nouveau matériel d'acquisition de données avec le système. L'évaluation permet également de déterminer les régions où l'ajout d'équipement et de capteurs environnementaux améliorerait et accroîtrait les capacités du système. Grâce à ces mises à niveau du logiciel et du matériel, le système d'étalonnage sous-marin de RDDC sera davantage en mesure de répondre aux besoins en recherche des scientifiques de RDDC, des Forces armées canadiennes et d'autres ministères, ainsi que d'offrir un équipement concurrentiel et attrayant pour les chercheurs du milieu industriel et universitaire.

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1 Introduction

1.1 Underwater acoustic calibration

In underwater acoustics, transducers are used to create and detect physical pressure fluctuations and create, or convert them to, an electrical analog equivalent. Sound projectors take electrical signals and project out pressure fluctuations, and hydrophones take in pressure fluctuations, converting them to electrical signals that are then interpreted by the system.

Transducers must be calibrated to ensure the signals projected and received are interpreted correctly. Calibration software controls the hardware used for data generation and acquisition, as well as analyzes, displays, and logs the results as required.

Calibration procedures conducted at the Defence Research and Development Canada (DRDC) Barge and anechoic tank, include:

- Transmitting response: The transmitting voltage (or current) response is the ratio of sound pressure apparent at the distance of one meter in a specified direction from the effective acoustic center of the transducer, to the voltage applied across (or current flowing into) the electrical input terminals.
- Receiving response: The measurement of a hydrophone's free-field voltage sensitivity by comparison to the sensitivity of a known standard hydrophone.
- Directional response: The receiving or transmitting response is measured as the transducer is rotated 360 degrees.
- Reciprocity: Used for recalibrating a standard hydrophone.
- Admittance: The measure of the electrical current/voltage.
- Impedance: The measure of the ratio voltage/current [1].

2 Statement of results

2.1 Hardware upgrades and assessment

The newly acquired hardware replaces the old system for data acquisition and generation and includes a new controller, chassis and peripheral modules. One of the most significant changes is the upgrade from a PCI system to PXI Express. The PXI Express chassis uses the latest generation of commercial PC-based PCI bus technology to provide power, cooling, and a communication bus, as well as timing and synchronization features [2]. The new system is compact and simplifies integration of its components; it contained an embedded PXIe controller and all modules within the chassis. To take advantage of the new high performance bus capabilities and integrate them into the new system, the peripheral modules for data acquisition and generation were also upgraded from PCI to PXI. In the previous system, two NI-DAQ cards were used, both providing the same data generation and acquisition functions. The difference between the two was that one operated over high frequency calibrations and the other over low frequency calibrations. In the new system, all frequency ranges are covered by the same peripherals; data generation is performed by one peripheral and data acquisition by the other, PXIe-4461 and PXI-4499 respectively. The module that previously controlled the timing and triggering of data acquisition and generation events (PCI-6602) was not replaced and no other module currently performs this function. It should be noted that some form of timing control is required for the system to operate. Table 1 provides an overview of the data acquisition hardware and their equivalents in the new system, where applicable.

Table 1: *Data acquisition hardware.*

Pre-existing hardware	New hardware	Function
PC – Operating on Window XP with LabVIEW 8.6	NI PXIe-8135 Core i7-3610QE 2.3 GHz Controller, Win 7 (64 bit)	Controller: CPU, memory, I/O
Desktop enclosure	NI PXIe 1085, 18 Slot 3U PXI Express Chassis	Bus, Synchronization
PC Card	NI PXI-8232, GIGE and GPIB Controller for Windows and LabVIEW RT	Peripheral Module: Additional connection to GPIB hardware
National Instruments PCI-6602	(none)	Peripheral Module: This counter controls triggering of data acquisition and generation
National Instruments PCI 6110 or 4452	NI PXI-4461-24 Bit Sigma-Delta ADCs, 204.8 kS/s Max Sampling Rate, 2 Input / 2 Output Simultaneous, Anti-Aliasing Filters, IEPE, 118 dB Dynamic Range	Peripheral Module: Generates signal that goes to amplifier, then to the transducer

Pre-existing hardware	New hardware	Function
	NI PXIe-4499 – 24 Bit Sigma-Delta ADCs, 204.8 kS/s Max Sampling Rate, 16 Input Simultaneous, 4 Gain Ranges, Anti-Aliasing Filters, TEDS, 0.5 Hz AC/DC coupled, IEPE	Peripheral Module: Acquires data from four channels to monitor outputs and measure inputs **Note: Previously, both these functions were performed by both NI-DAQ cards. PCI- 6110 performed high frequency measurements, PCI-4452 performed low frequency measurements.*

The hardware used for signal generation and processing is described in Table 2. None of the components in Table 2 were replaced in the 2014 system upgrade. The Krohn-Hite dual Filter Model 2988 uses a GPIB connection for communication, a relatively old technology. The system also does not have built in instrumentation for measurements to calculate the speed of sound underwater, which is also used to calculate the distance between the hydrophone and projector. A sound velocity profiler is borrowed for occasional use, but is not a permanent fixture at the barge. Where the speed of sound underwater is not generally measured at the time of calibration, and this data is used to calculate the test separation, a potentially significant margin of error is introduced into the calibration. Other environmental factors are also not measured and recorded, such as water current, turbidity, barge dynamics, air temperature and wind. These factors are all known to affect the speed of sound underwater or the stability of the calibration system [3]. The water temperature is one factor that is measured with a sensor readily available at the barge. However, this sensor is not, and cannot, be integrated into the software system.

Lastly, the response of many transducers is directionally dependent, so it is important that the orientation or alignment is known. Types of non-rigid rigging or mounts, combined with water current, can result in a change in a transducer's orientation. Currently, the only ways to determine orientation are by using an underwater camera or by interpreting the results and rotating the station on which it is mounted if expected results are not seen. Both of these are time consuming and not always reliable. Overall, environmental conditions are important to document since a calibration of a transducer is only valid for the environmental conditions in which it was calibrated [4]. If sensors are not present, these assumptions must be documented.

Table 2: Signal generation and processing hardware.

Pre-existing hardware	Function
300 Watt B&K Amplifier	Outputs up to 300 watts of power to a projector/transducer with variable gain settings and impedance selection
Krohn-Hite dual filter Model 3988	Works in conjunction with the calibration software to adjust sound levels on the display and acts as a Low, High, or Bandpass filter
Instruments Inc. Voltage and Current Sensor Model VIT-13	Inserted between the output of the power amplifier and the load to match phase and high frequency measurements of high voltage (up to 1000 V) and currents (up to 100 A)
16 kW Power Amplifier by Instruments Inc.	Amplifier able to produce a variable voltage/current output to a transducer/projector up to a maximum of 16 kW of power
Wavetek 50MHz Synthesized Arbitrary Waveform Generator Model 296	Used to create advanced waveforms that cannot be created by the calibration software. Typically used for a single, continuous tone at a specified frequency with voltage adjustability
Tektronix 2024C TDS Oscilloscope	Monitors what is coming from the A-to-D to the VIT-13 (the signals from calibration software going to the projector) and what the hydrophone receives
Minilog-II-T and VFR Kit Reader	Water temperature sensor, not connected to the calibration software

2.2 Calibration software assessment

An assessment was carried out to determine the feasibility of modifying the existing software to function with the newly acquired hardware.

The current software solution was developed in 1995 in the LabVIEW programming language and underwent a complete redesigned in 1997 to add functionality and upgrade to LabVIEW version 3.1.1 [5]. Additional updates have been made since then to include additional calibration techniques and to adjust software to communicate with new equipment as needed. During these upgrades, the software was converted up from LabVIEW version 3.1.1. to version 8.6 (released in 2008). Compatibility Virtual Instrument's (VI) were used to convert the program, which has resulted in the existing calibration software only utilizing the functionality from LabVIEW 3.1.1. In addition, the overall structure of the code remains as was originally developed in 1997 and does not use any of the programming techniques developed after that time. During this assessment, the code was updated to LabVIEW 2014, again using compatibility VI's. Figure 1 shows a sample portion of the existing code.

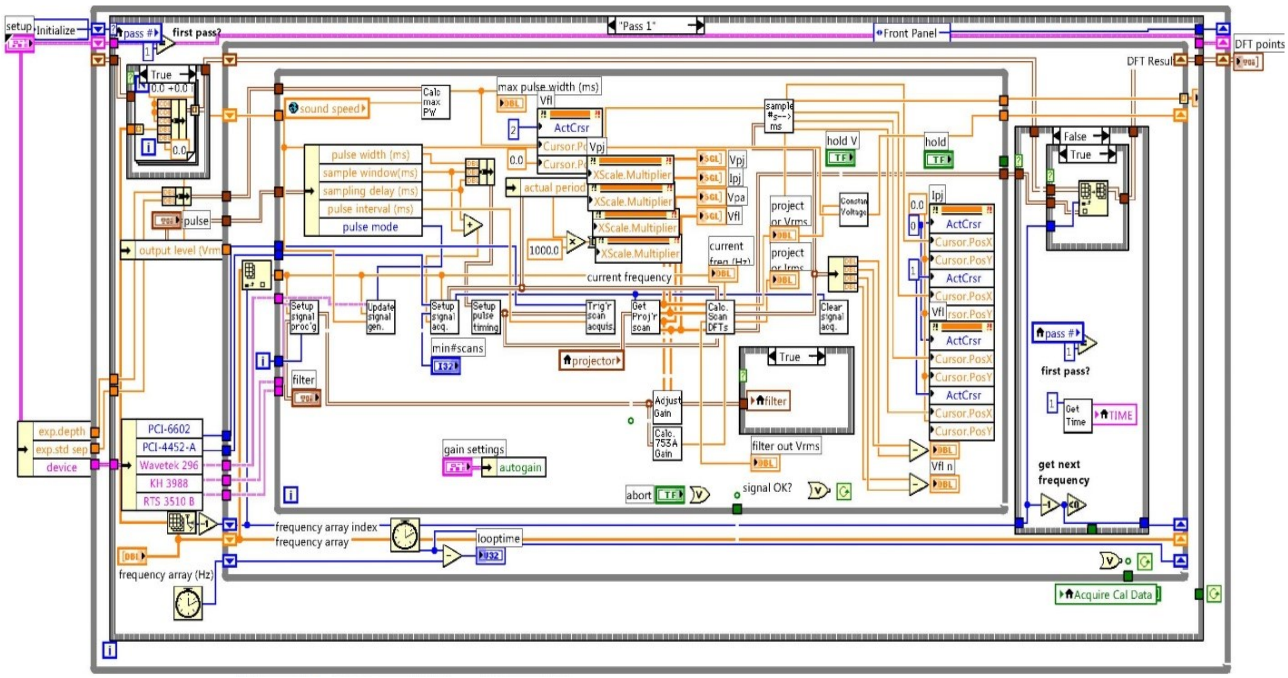

Figure 1: *Section of code in existing LabVIEW based calibration software version 1.*

Each subVI in this figure that communicates with NI-DAQ equipment contains errors that would need to be fixed for the program to run. The majority of these errors occur due to the use of old architecture within the program that is incompatible with the new system, most notably the NI-DAQ driver, now known as Traditional NI-DAQ (Legacy). A DAQ, or data acquisition, driver is required in order to configure and reset National Instruments devices, as well as generate and acquire data from them. The Traditional NI-DAQ driver was continued until version 6.9.3, at which point it was replaced by NI-DAQmx. This new NI-DAQmx driver contains an entirely new architecture that increases the ease of usability and enhances performance over the Traditional NI-DAQ driver [6]. Traditional NI-DAQ is not compatible with 64-bit operating systems; however, all new devices and operating systems support NI-DAQmx. As the new system is 64-bit, updates to the NI-DAQmx are required in order to operate the calibration system with the new hardware.

A cursory analysis of the code identified significant barriers to what had been initially thought to be a relatively simple update. Assessed against the areas outlined in the LabVIEW development guidelines, the program's front panel was found to be challenging to navigate (Figure 2), and the block diagrams were overcomplicated and difficult to follow [7]. As shown in Figure 1, wires are overlapping and structures of code are hidden. Documentation explaining to a user how to operate the software was limited to manuals from 1997 and demonstration files were unusable because they had never been upgraded from LabVIEW 3.1.1. The code had little to no comments or external documentation that described its functions and flow.

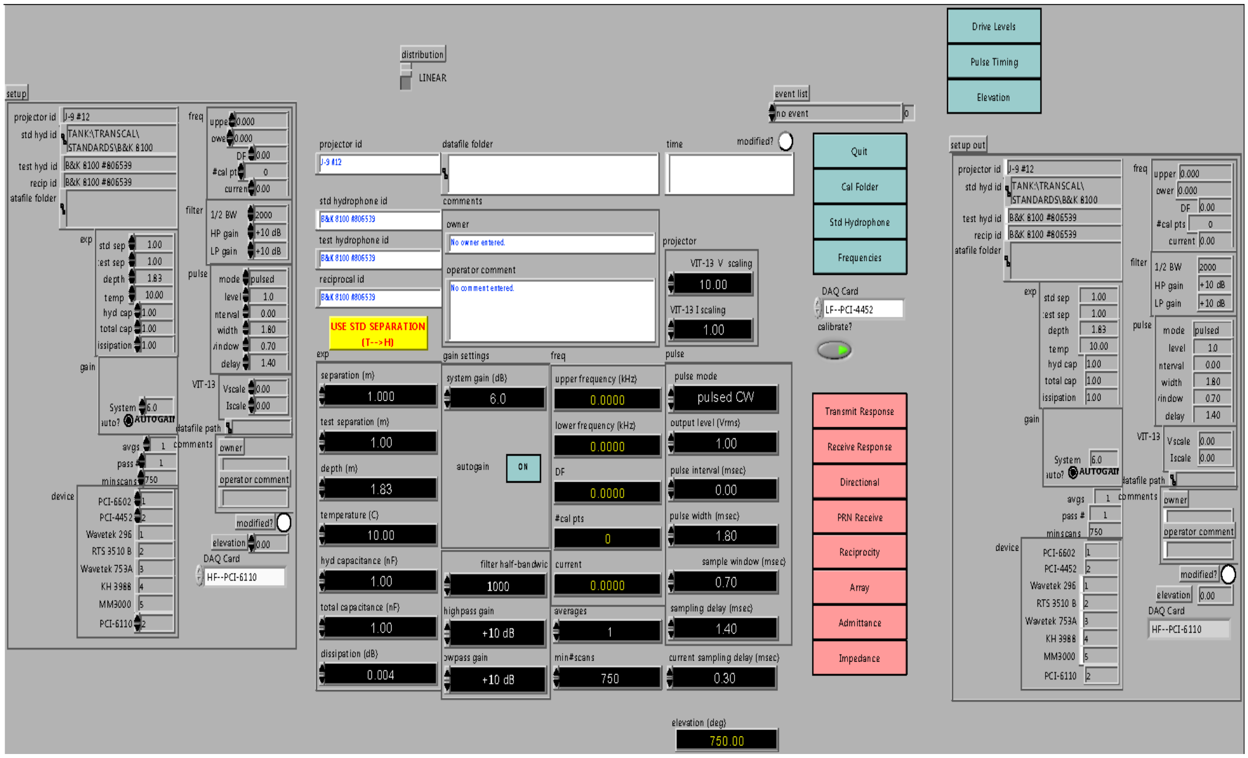

Figure 2: *Graphical User Interface for existing software.*

Using LabVIEW error checking and search tools, the code was then searched to identify areas for NI-DAQmx updates. Traditional NI-DAQ VI's were located across the program, often buried within subVI's. This is largely due to the architecture of Traditional NI-DAQ VI's and the limitations placed on the developer for implementing the steps of configuration, acquiring, generation, stop/clear/reset for a given device. In NI-DAQmx, these processes have been simplified and contained within a much smaller set of polymorphic VI's [6].

During the code analysis, a number of additional issues with the existing code were identified. These included missing libraries, disconnected or misconnected pieces of code, and portions of code that had been started, but never completed. Further compatibility issues arose where functions such as file dialog VI's were no longer supported by LabVIEW 2014.

3 Discussion of results

3.1 Hardware upgrades

The new hardware offers significant benefits over the previous PCI based platform and modules. As shown in Table 1 in the Statement of results, a new counter/timer will need to be acquired to control the carefully timed sequence of events required in the calibrations, as this was not included in the 2014 hardware purchase. NI-PXIe-6612 and NI-PXIe-6614 are both examples of PXI Express counter/timers available that are compatible with the new system, where the PXIe-6614 is capable of more precise timing. To provide additional timing accuracy and calibration, the acquisition of a GPS component should be considered. As the current filter for signal processing is connected via GPIB, an upgrade in this area should be considered as options become available.

During this assessment, it became apparent that many environmental conditions for calibrations are not being measured and none of the existing measurements are integrated into the software system. Table 3 outlines recommendations for a number of sensors to add to the system in order to track environmental conditions. Knowledge of the speed of sound in water is crucial to the calibration of transducers in underwater sound. Since the speed of sound is dependent on temperature, depth and conductivity, it is recommended that at least one dedicated CTD (conductivity, temperature, depth) sensor be added to the system [8]. If these measurements were to be incorporated into the software system, it would assist in the ease of use and in the logging of collected data. A measurement of the speed of sound at the time of every calibration will result in a more accurate value for the separation distance between the projector and hydrophone; this second value is currently calculated based on a measurement of time between output and input and the inputted speed of sound. An integrated temperature sensor in the CTD would replace the existing temperature sensor that cannot be connected to the software system. A continuously run, moored CTD profiler would also assist in identifying thermoclines, indicating ideal depths for conducting calibrations over time.

Adding meteorological sensors would be of benefit, since air temperature, wind direction, wave height, and water current can all affect the results of a calibration. These weather and water conditions are known to affect temperature gradients of the water as well as ambient noise levels [3]. Sensors to provide information on barge dynamics would also support users in understanding the environment for calibrations.

To provide accurate information on the orientation of the transducer, one potential solution would be to use depth sensors and an echo finder that could be mounted on the transducer. The depth sensors would act as a horizontal level and the echo finder, when installed in the direction of interest, would assist the operator in aligning the projector in the desired orientation. A challenge not addressed here is that the station does not rotate the mounted transducer in the horizontal plane. The proposed depth sensors would provide information regarding the transducers orientation, but in the current setup it would still need to be raised out of the water and manually adjusted. To simplify this adjustment for the operator, a mechanical solution would need to be considered.

__Table 3:__ Sensor recommendations.

Function		Sensor Recommendation
Speed of sound, identifying thermocline, determining test separation distance		CTD: conductivity, temperature, depth sensors
Barge dynamics		x-y accelerometer placed on corner of barge
Water conditions		Turbidity sensor
		Current meter
		Wave height sensor
Air conditions		Air temperature sensor
		Wind speed sensor
Orientation, depth and alignment of transducers	Depth and z-axis alignment of projector	2 depth sensors
	Depth of hydrophone	1 depth sensor
	X,y-axis alignment of projector	Echo finder

3.2 Software upgrades

The current calibration software was installed on the PXIe-8135 controller in LabVIEW 2014. Since it is a 64-bit operating system, it is unable to use the Traditional NI-DAQ driver and modifications to update the code to use NI-DAQmx are necessary. The first step for a developer to update the code is to understand its flow and function, which has proven to be a much more challenging than originally anticipated. The program is of significant size and with many of the block diagrams disorganized and difficult to follow. A contributing factor is that at the time of its initial design, there was limited availability of tools to build well simple structured, concise programs for complex purposes in LabVIEW. LabVIEW's compatibility updates may have also inserted unnecessary complexity in the form of compatibility VI's and reorganization of diagrams. Furthermore, no type of code packaging had been used to transfer code between machines, which resulted in numerous versions with no clear record to distinguish between them. Figure 2 shows code from the same VI as shown in Figure 1, but from a different version. It was only through examining the code that the differences in the program became apparent. Due to these factors, combined with the overall lack of documentation to describe the code, a considerable amount of time would be required for a developer to simply understand the existing code.

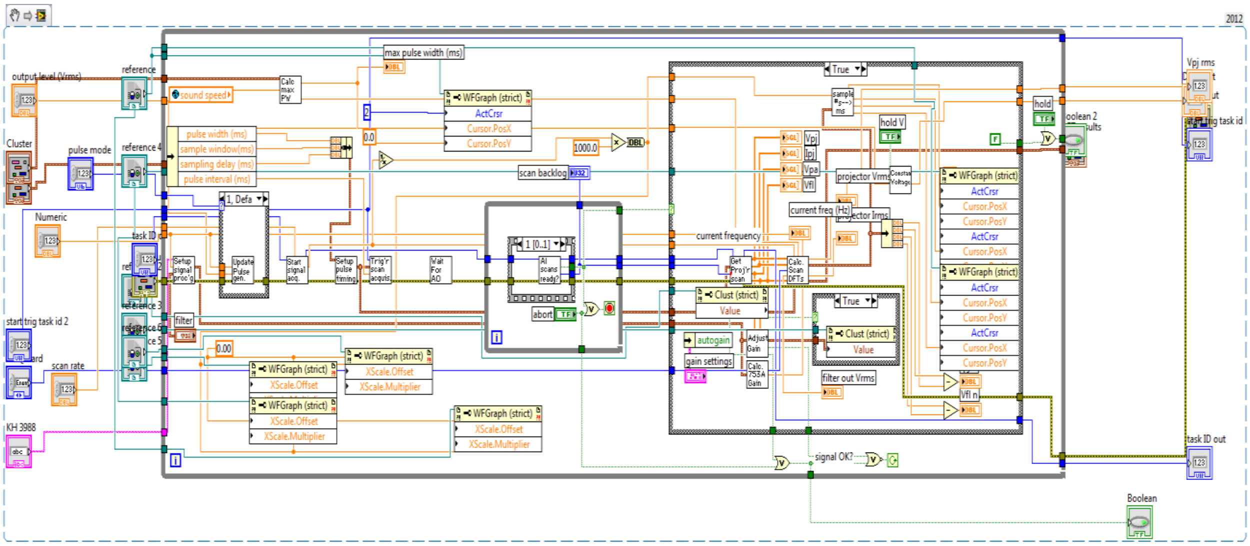

Figure 3: Section of code in existing LabVIEW based calibration software version 2.

The architecture of programming in LabVIEW, specifically with the NI-DAQ driver, has been changed so significantly that no equivalent VI's exist that could easily replace VI's in the existing code. Rather, this process to upgrade from Traditional NI-DAQ to NI-DAQmx would involve a detailed analysis of the code and a complete redesign of all aspects utilizing the NI-DAQ driver. Since this is the primary function of the program, the end result would be modifications to the majority of the code, save VI's that are calculation based. If this option was pursued, the updated version would be nearly impossible to maintain and enhance, since it would continue to use the overarching framework, and not utilize any of the new programming techniques and tools now available.

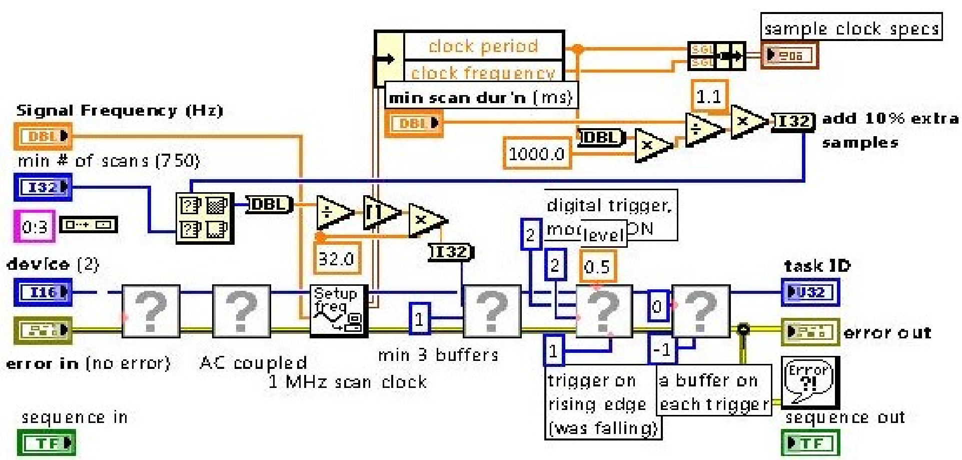

Figure 4: Section of code in calibration software for setting up signal acquisition showing missing traditional NI-DAQ VI's.

The alternate option is to develop an entirely new software solution. A new program would be able to take full advantage of the functionality of NI-DAQmx, as well as programming concepts developed over the last decade. The simplification of the NI-DAQ architecture, along with the additional tools now available to developers in LabVIEW and many other programming languages, would allow a newly developed program to have the potential to be significantly more user friendly and easier for future developers to maintain. LabVIEW has made significant changes to improve options for developing graphical user interfaces that are visually appealing, clear and easy to follow. The use of object oriented programming is now commonly used to incorporate structures that allow for future hardware upgrades to be easily implemented. Additionally, events, case structures, and local and global variable have improved the ability of a developer to create programs that are more concise and easier to follow than those developed in 1997.

As with making modification to the existing code, the development of new calibration software requires time and monetary investment. However, the benefits to modifying the existing software are limited to having a system that is functional on the basic level in the short-term with very little, if any, long-term benefits. An investment in developing new software has both long-term and short-term benefits. In the short-term, it would be able to utilize the full extent of the capabilities of the hardware, NI-DAQmx driver and programming tools in the language chosen for design. In the long-term, it would be easier for new users to operate, update and maintain.

4 Conclusion

In order to integrate the new data acquisition hardware into the underwater acoustic calibration system at DRDC, updates to the system software are required. An assessment was carried out to determine if the current software could be modified or if a redesign was necessary. It was determined that there were very few benefits to updating the existing software. If this option was pursued, the resulting product would not take advantage of any of the advanced capabilities of the new hardware or be easily maintained and updated in the future. A full redesign would require an initial investment, but the long term benefits far outweigh that of continuing to work within the framework of the current software. A complete redesign of the calibration software is strongly recommended.

To ensure the new software is easy to use, maintain and update, the following should be considered in its development:

- Users of the existing software should be consulted by the developer before and during the development process to ensure it meets users' needs.
- Other programming languages should be considered for the software design. Options such as a hybrid, with a LabVIEW GUI and alternate programming architecture may offer advantages over a solely LabVIEW based program.
- The user interface and the code should be easy to follow, well labelled and thoroughly documented:
  - Explanations of the function of each calibration technique performed by the software and how to operate the system should be included for the user.
  - The code should be well commented to ensure that new staff unfamiliar with the code have sufficient information for maintenance and updates.
  - Consideration should be given to a requirement to provide both a user's and a programmer's guide to the new software as was provided with the LabVIEW program developed in 1995 [9,10].
- Software must be structured to be easily adaptable to new hardware.
- Software should employ methods to ensure that the software can be easily transferred between work stations and modified versions can be tracked. (Ex. Code packaging).

For this new system to be operable a counter/timer, such as the NI PXIe-6612 or PXIe-6614, will need to be acquired to incorporate into the new PXIe system in order to achieve the timing and triggering functions necessary for calibration.

The following recommendations for additional hardware should also be considered:

- A GPS component for more precise timing.
- A filter that uses a newer system for communication, such as USB, to replace Krohn-Hite dual filter Model 3988.

- A CTD profiler for underwater sound speed measurements. Consideration should be given to acquiring a profiler that can house additional water condition sensors and where sensors can be added over time. A moored profiler would have the added benefit of being able to gather continuous data unmonitored.
- Sensors and devices for positioning of transducers, such as depth sensors and an echo finder.
- Meteorological sensors, including turbidity, water current, wave height, air temperature and wind dynamics.
- Barge dynamics sensors.

These additions to the system will enhance the capabilities of the system, providing additional scientific data for researchers and assisting system operators in conducting more efficient and reliable calibrations.

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DRDC – Atlantic Research Centre
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Scoping study for upgrading the Defence Research and Development Canada (DRDC) underwater acoustic calibration system

4. AUTHORS (last name, followed by initials – ranks, titles, etc., not to be used)

Jantzen, A.B.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
November 2016	24	10

7. DESCRIPTIVE NOTES (The category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g., interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Reference Document

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

DRDC – Atlantic Research Centre
Defence Research and Development Canada
9 Grove Street
P.O. Box 1012
Dartmouth, Nova Scotia B2Y 3Z7
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9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DRDC-RDDC-2016-D058

10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

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