A

Phase 2
Scanner

For

Study of Optronics

(W7701-135588/A)

Presented to

Philips Laou, Ph.D.
Scientific authority

Public works and government Services Canada
601-1550, Avenue d'Estimauville
Québec , Québec
G1J 0C7

By

Side by Side Optics Inc.

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Introduction

In Phase 1 of this contract, we did a literature search for the different methods that can be used for single-point and area (2D) range measurement (see report REP_PWGSC_W7701-135588_PHASE1.pdf) [1]. Commercially available ranging devices were identified. This research concluded that simultanious 2D range measurement devices meeting the 600m ranging distance and the man portable requirements were not commercially available and are still under development. 2D ranging devices of resonable size were for distance of only few meters. 2D longer ranging devices (>600m), were bulky, energy-hungry and could not be considered as man portable devices.

The single-point LRF on the other hand are commercially available, compact and find applications in many fields (recreative sports, construction, defence, etc.). Since that technology is mature, we determined that the single-point LRF combined with a scanning technology could provide a reasonable solution to build a 2D range measurement system of acceptable size.

In this second phase, we analyse the different approaches that could be used to extend the capability of existing single point laser range finder (LRF) in order to perform a 2D range measurement. We also review few of the recent technologies that could be used to design a man portable 2D range finder but still need further development. Finally, we suggest different approaches to convert a single-point LRF into a 2D scanning LRF.

1 2D scanning single point LRF

In recent years, the single point LRF technology was used in many fields of application. The military industry is certainly a large user of LRF technology but we can also add the sport and hunting industry, the construction industry, the mining and gas industry, and the aerospace industry, etc. The list is constantly increasing as the price for LRF devices are going down. Most of the long-range LRFs are based on time of flight (ToF) method for measuring the distance. Other devices use laser Phase-Shift technique and the Frequency Modulated Continuous Wave (FMCW) technique. The last two techniques are mostly used for short distance measurement [1].

In this section, we review the various scanning systems that could be added to commercial available LRF in order to perform 2D ranging.

1.1 Scanning mirrors combined with single point LRF

The must obvious approach to build a 2D LRF is to add two scanning mirrors in front of the single point LRF device. The mirrors need to be large enough to cover the exit and entrance ports of the LRF simultaneously. This is an important characteristic of the assembly in order to ensure that the collecting channel of the LRF is looking in the same direction as the projected laser beam. Since the collection apertures of commercial single-point LRFs are between 20 to 50mm, the scanning mirrors have to be at least that size and obviously cannot be considered as micro-mirrors. Figure 1 shows an example of a two mirror scanning arrangement and Figure 2 is an example of a commercially available scanning mirror assembly.

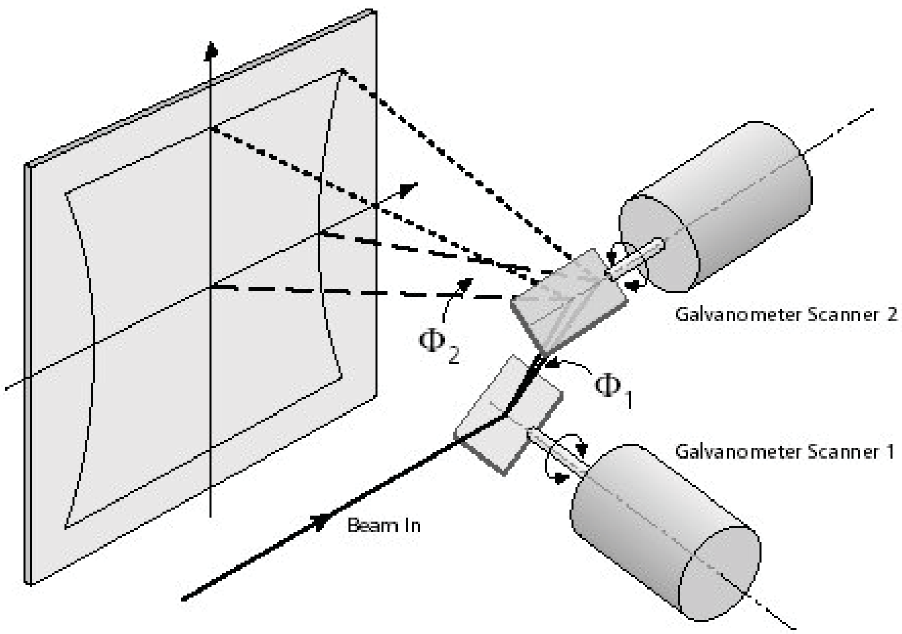

Figure 1 Two mirrors (2D) scanner.

Figure 2 Galvanometer dual axis scanner from Thorlabs.

The advantage of the 2 mirrors system is its simplicity [2]. The moving pattern can be easily programmed and fast (60 Hz). However, if the mirrors are large, in order to cover the two channels of the LRF (>50 mm), the scanning speed can be affected by the mirror inertia and the settling time. Also, depending on the type of motors used (DC, stepper, etc.), it might be difficult to point the LRF precisely in a particular direction within the region of interest. Mirror scanning system can also be affected by vibration and sudden acceleration.

Variations of the two mirrors system can use polygon mirrors for faster speed or PZT mirrors for reliability (see figure 3). Since commercial single-point LRF are typically slow devices with a time per measurement of about 1 second, polygon scanners are considered to be too fast for building a 2D LRF.

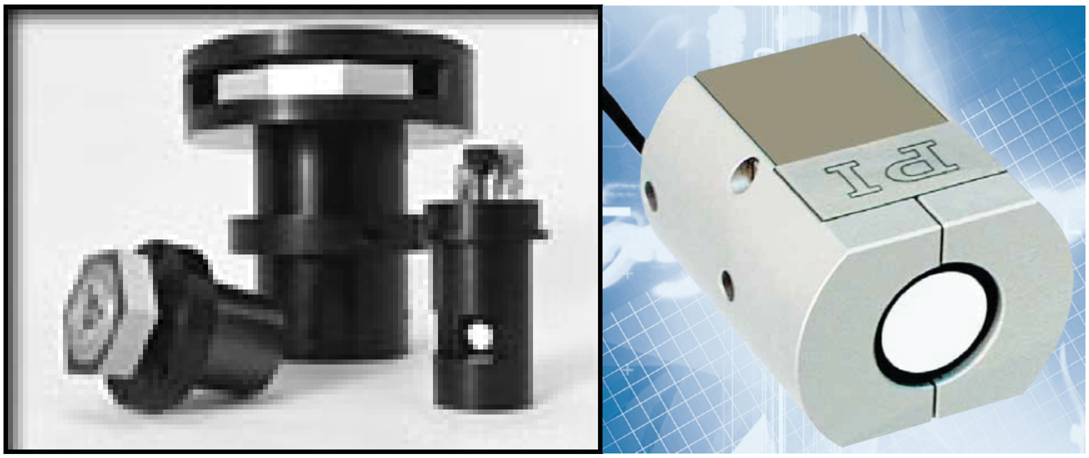

Figure 3 Polygone (left) and PZT (right) mirrors.

1.2 Risley-Prism scanner combined with single point LRF

Risley-Prism scanners are relatively simple devices [3]. The scanner is composed of two prisms with a common rotation axis. As the laser and the return beam passes through the prisms, they are angularly stirred. Figure 4 shows a cross section of a commercial Risley-Prism assembly from Optra.

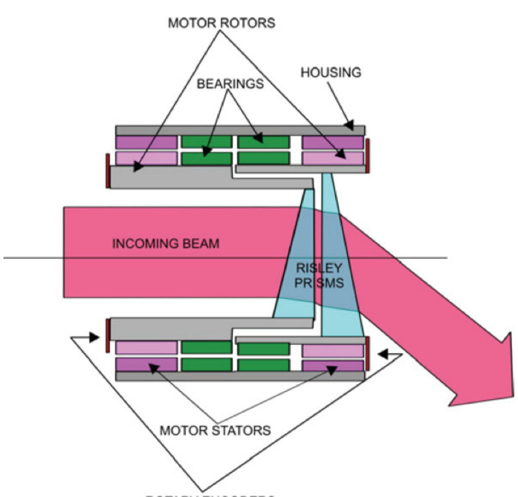

Figure 4 Risley-Prisms layout from Optra, inc. [3].

The prisms can be achromatized to minimize the pointing accuracy error due to laser wavelength shift from the source. The prisms can be quite large in comparison to a two mirrors scanning system. The inertia to rotate the prisms is also manageable and independent of the prism thickness. The advantages of the prisms assembly are the beam deviation stability over a large temperature range and vibration, the scanning speed and its simplicity. The scanning patterns can have very complex form. Figure 5 shows rosette scanning patterns that the company Neptec uses in their commercial LRF instrument. These particular patterns can have some advantages but are also more mathematically complex to manage.

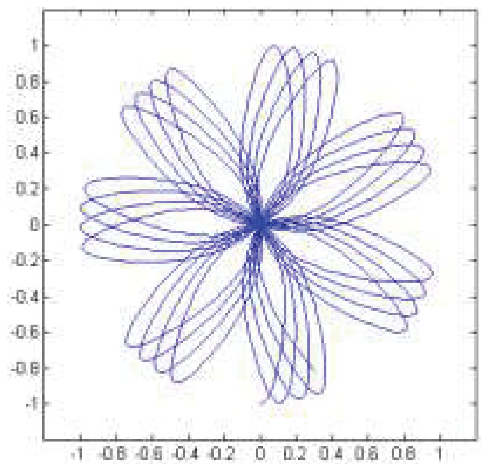

Figure 5 Risley-Prisms scan patterns (from Neptec Tech. corp.).

The commercially available Risley-Prism assembly from Optra Inc. (see figure 6) is calibrated to offer simple programming of the devices.

Figure 6 Optra laser scanner assembly.

Potential drawbacks when using the Risley-Prism assembly are the so call Nadir problem and the traveling salesman problem. The Nadir problem is due to a mismatch of the two prisms and the difficulty to obtain zero deviation of the beam. At near zero deviation you may need a very large rotation to steer the beam by a small angle. The traveling salesman problem is related to the efficiency of the algorithm to set the prisms orientation and steer the beam in a particular direction. This is a mathematical problem that has been solved but is a challenge since the solution depends on the starting orientation of the prisms.

The company Nectec commercializes a 360° 3D imager based on a Risley-Prism assembly combined with an additional rotating prism/fold mirror. This system is not man portable due to its size and weight but it demonstrates the efficiency and the feasibility of using the Risley-Prism for this application (see figure 7) [5].

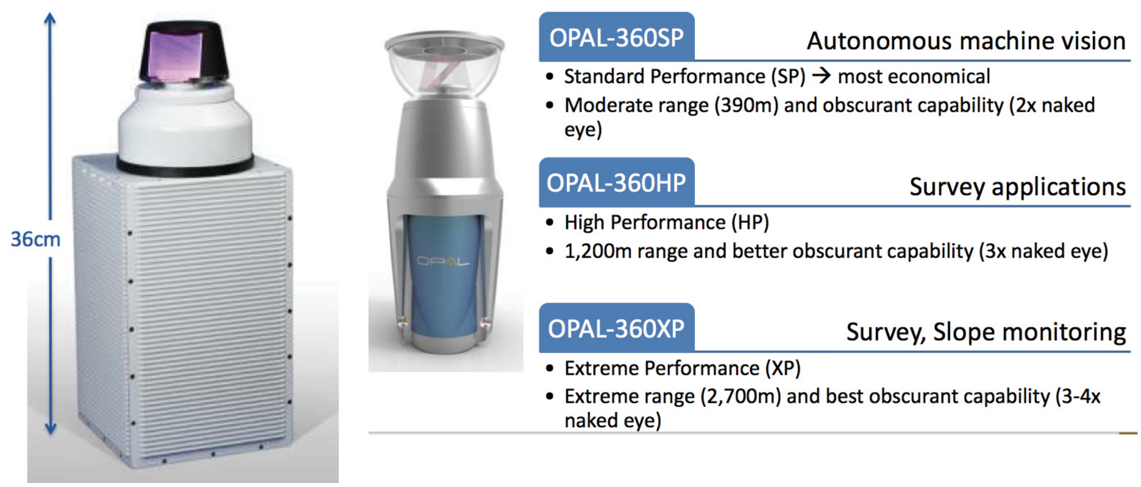

Figure 7 OPAL 3D / 360° surveillance system.

1.3 Auto-synchronized scanner

The auto-synchronized scanner was invented by Marc Rioux at NRC-Canada (see US patent 4627734). In 1999, CSA and NRC presented a paper describing the utilization of time of flight approach combined with auto-synchronized scanning to extend the range of the 3D imaging scanner (SPIE vol. 3707) [9]. The figure 8b shows the proposed configuration by the scientist.

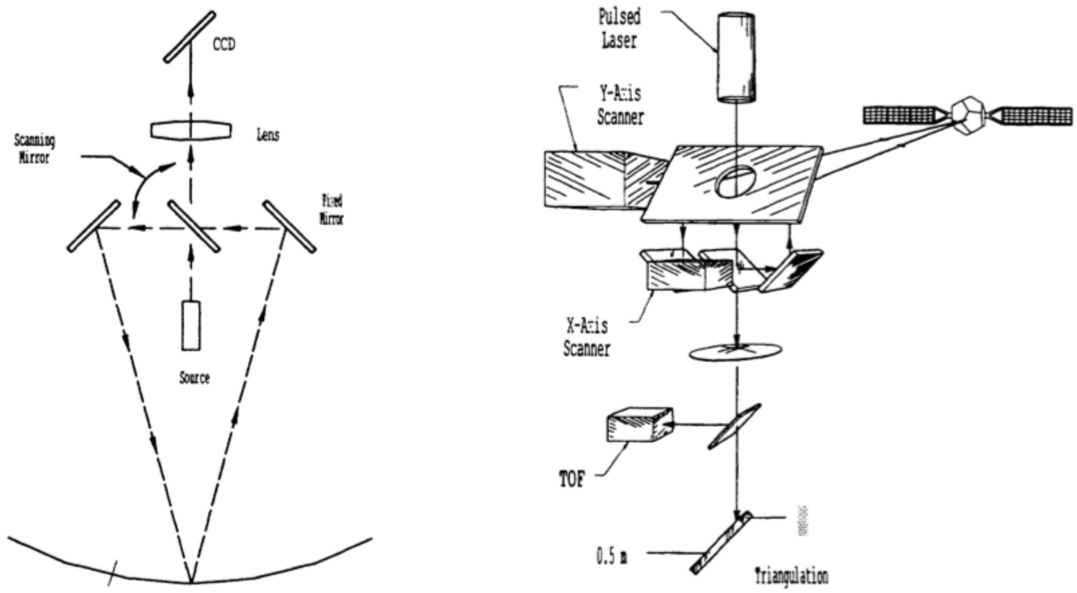

Figure 8 Auto-synchronous scanner: a) single-axis, b) dual-axis.

Based on this principle, the company Optech developed a ranging system that can measure ranges up to 3 km (see figure 9) [10].

Figure 9 Optech's ILRIS-LR Terrestrial Laser Scanner.

The Optech system is not man portable but could possibly be reduced in size and weight (actual weight 13kg) if the field of view is reduced.

2 Scanning technologies not readily adaptable to commercial single-point LRF

2.1 Holographic scanner

Holographic scanners were very common before the laser diode (LD) introduction into the scanner market. Due to the small features of the hologram and their very large optical dispersion properties, holographic elements are not suitable to be used with sources that are unstable in wavelength. Any laser source wavelength change will affect the beam characteristics going through a hologram. Since LDs are not stable in wavelength (mode hopping, temperature), holographic scanners were not widely used for commercial application. Improvement in the fabrication techniques (replica) of HOE and the addition of pre and post scan HOE now allow reduction of this problem (see white papers from Holographix Inc) [6]. In figure 10, we can see a Holographic scanner example from Holographix with the pre and post correcting HOE. The post-scan HOE is not necessary for large distance measurement.

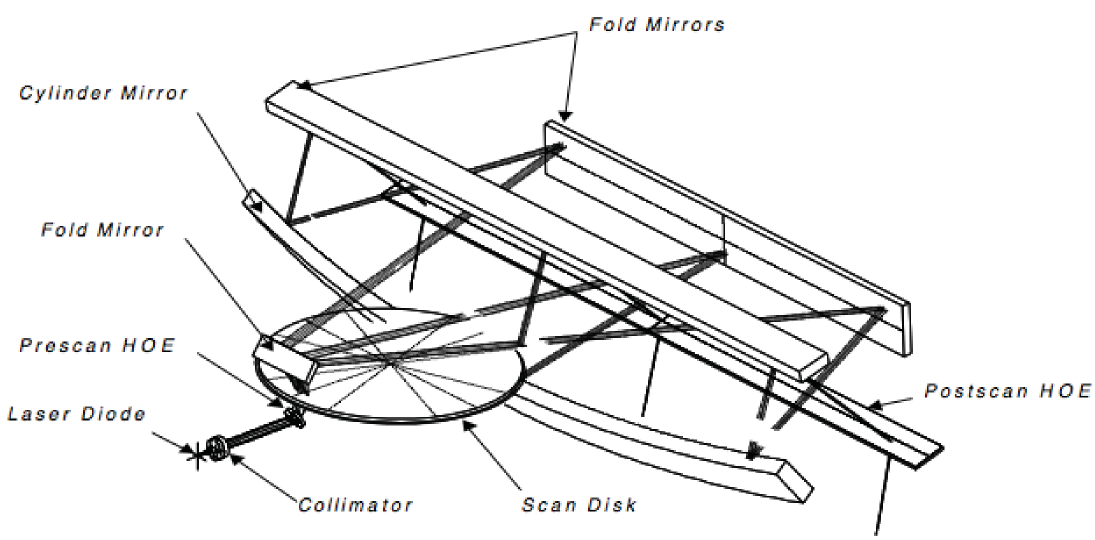

Figure 10 Holographic Scanner system from Holographix Inc.

Northrop Grumman Corp. patented in 1995 (US 5471326) [7] a Holographic laser scanner and rangefinder. The device was applied to an obstacle avoidance system for combat helicopter (see figure 11).

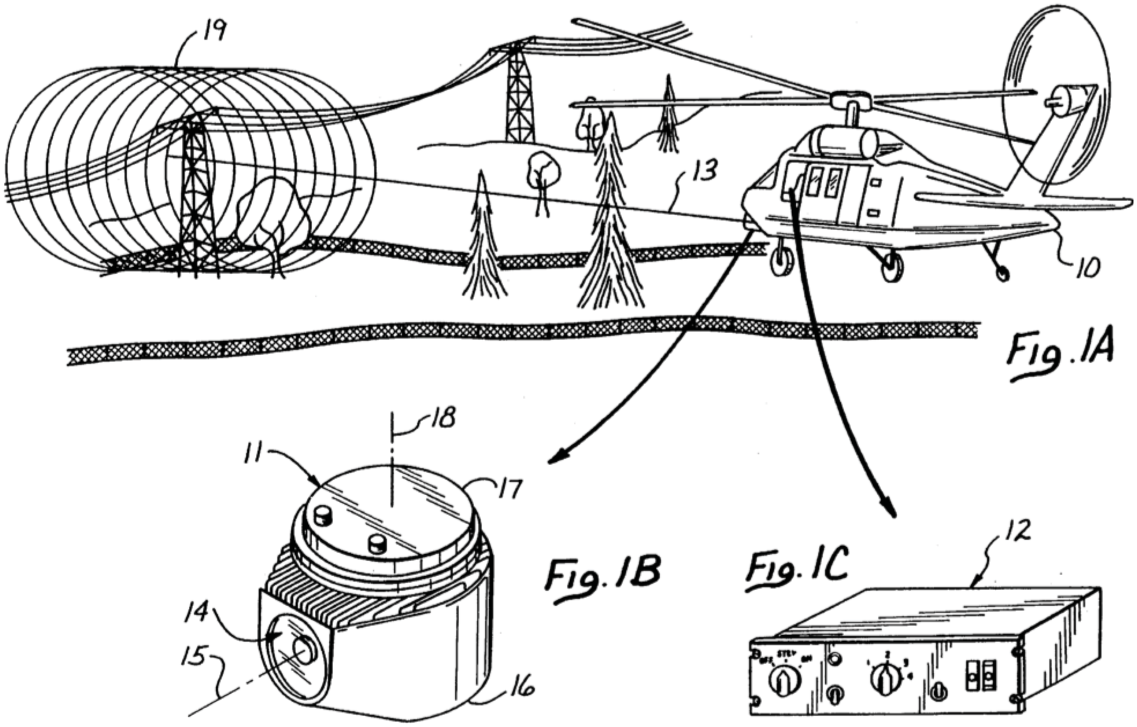

Figure 11 Helicopter obstacle avoidance system.

Even if the technology seems applicable to the problem at hand, we don't know of any commercial HOE scanning system that could be fitted to a single point LRF. However it is a technology that finds application in the military and could potentially lead to the development of man portable 2D LRF devices.

2.2 LCD scanner

A LCD scanner is a very attractive solution when the potential for high acceleration or chock of the device is a high probability. LCD devices can be made quite durable since you do not have any moving parts that can wear out. The company Vescent Photonics developed a 40°x10° Electro-optic laser beam scanner with a full sweep time of 2ms (see figure 12) [8].

Relies on Vescent Photonics' patent pending evanescently coupled liquid crystal waveguide technology

Parameter	Value	Comment
Scan Angle	40° Horiz. × 10° Vert.	Horizontal defined as in plane of the waveguide
Small Angle Transit Time	0.1ms	Small angle defined as 5% of field of regard
Full Sweep Transit Time	2ms	
Insertion loss	3dB	
Pointing Resolution	Analog control voltage	
Available Operational Wavelengths	1500nm $< \lambda <$ 1600nm	

Figure 12 Compact EO-2D laser beam scanner.

This device is very attractive since the LD source can be directly coupled to the device via a fiber. The insertion loss is 3dB but using a high power laser can compensate for the loss. However, we are not aware of any device using 2D-EO scanner for laser range finder. Since the device is a waveguide, it is not clear if the ToF sensor using the same or a second 2D-EO could collect enough energy. The device showed in figure 12 will be available in the first quarter of 2014 for about $10K USD.

2.3 2D Micro-mirror scanner

The State Key Laboratory of Precision Measurement Technology and Instruments in China developed a 2D scanning micro-mirror and laser range finder baser on MEMS process and phase-shift ranging technology (Sensors 2012,10,6848-6860;doi:10.3390/s100706848) [11].

The device is very compact but cannot measure range larger than 75m (theoretical). Figure 13 shows a picture of the micro-mirror and the LRF prototype.

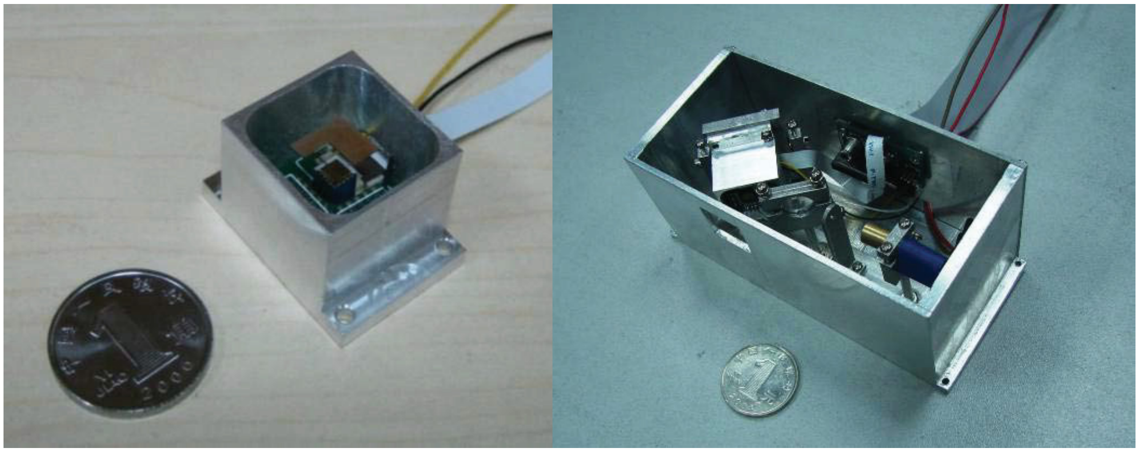

Figure 13 Package of 2D scanning micro-mirror and prototype of MOEMS target detector.

Figure 14 shows the prototype layout.

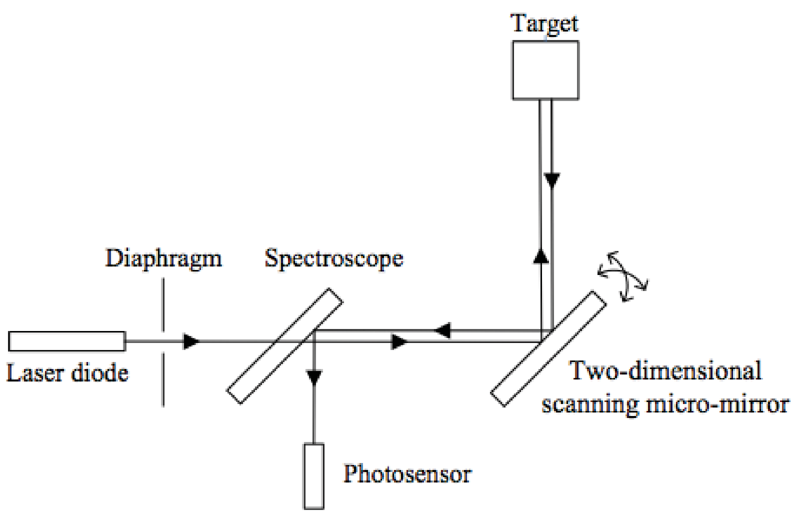

Figure 14 Prototype layout

This experiment demonstrates that micro-mirrors can be used to design a scanning laser range finder at short distance. In order, to use this configuration for larger distance, the collecting optics needs to have a larger diameter and a micro-mirror approach may not be applicable. This approach cannot be utilized to turn a single-point commercial LRF into a 2D scanning LRF. Research development would have to be done to validate if the micro-mirror approach is a viable technology for long range LRFs.

INO also developed a dual-axis micro-mirror that could potentially be used to design a custom 2D LRF (see figure 15). The effort would be considerable and we don't know if enough energy could be collected from the return signal.

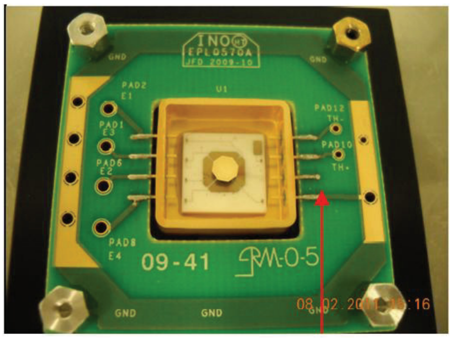

Figure 15 INO dual-axis mirror.

The company Mirrorcle Technologies, Inc. (MTI offer a series of micro-mirror varying in size from 0.8mm to 6.4mm diameter. Figure 16 shows the largest mirrors fabricated.

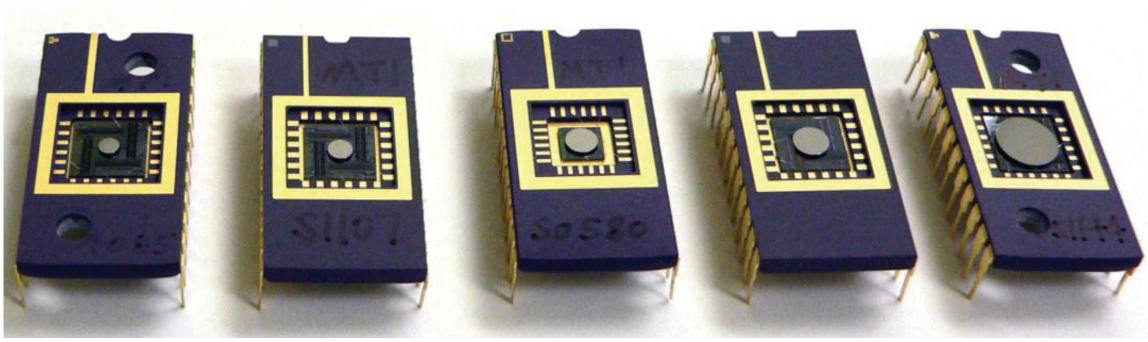

Figure 16 MTI mirror from 2mm to 6.4mm diameter.

An interesting feature for the MIT mirrors are the multiple scanning modes available. In particular, the point-to point mode allows holding the mirror in a DC position. Figure 17 shows three possible modes with the MIT mirror.

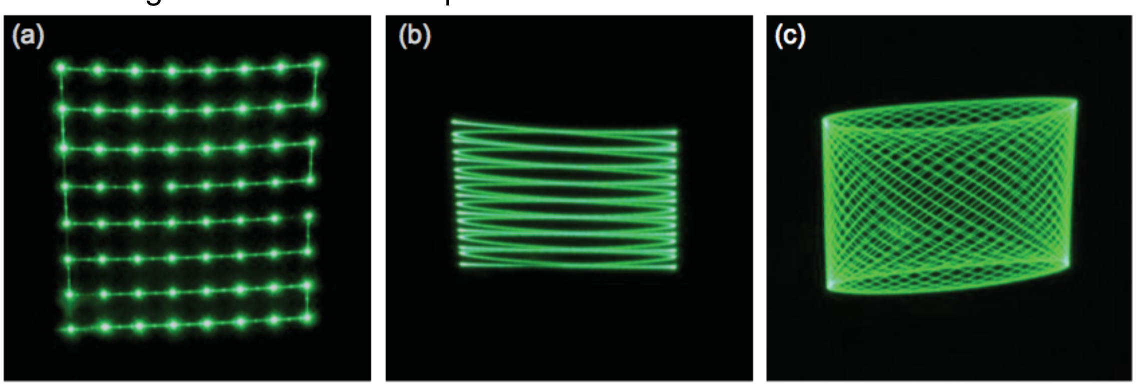

Figure 17 Scanning Mode examples: (a) Point-to-Point, quasi-static; (b) resonant mode in one axis; (c) resonant mode on both axes.

The micro-mirror size available is increasing but it is still too small to be placed in front of a commercially available single-point LRF. The apertures for the long-range LRF devices are still too large.

3 Modifying a commercial LRF

Since long-range single-point LRF are readily available, the fastest approach to test the concept of a 2D LRF is to combine a long-range compact commercial LRF device with a scanning system.

3.1 2D scanning micro-mirror for the laser beam channel

One approach is to scan the laser beam-emitting channel on the target using micro-mirrors or galvanometers and increases the field of view (FOV) of the detection channel to view a fix field of view corresponding to the total scan FOV (figure 18).

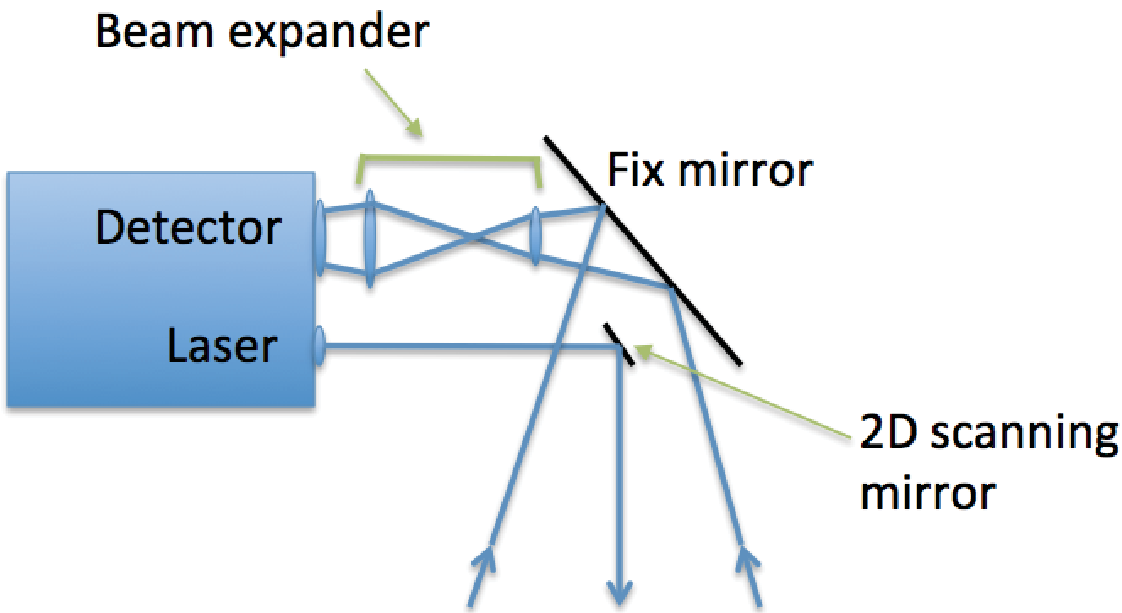

Figure 18 2D scanning laser channel with extended detector field of view

Typically, the field of view of the detection channel is small and ideally matches the laser beam divergence. If we increase the field of view of the detector to see more than the laser beam footprint on the target, we also increase the detector noise and reduce the signal to noise ratio (SNR). Moreover, the addition of a beam expander to increase the detector field of view also increase the F/# of the detection optics by the same ratio. An increase of the F/# translate into a reduction of the energy collected from the portion of the target illuminated by the laser. Back of the envelope computations concluded that the measurement range would be reduced enough that the LRF could not be considered as a long-range LRF anymore and would not be usable for the current application. A reduction of the measurement range of approximately 35 was estimated. For a 4km LRF the range was reduced to 100m. So, the utilization of a micro-mirror approach to scan the laser beam was eliminated as a retrofitting approach to modify a commercial LRF.

3.2 Large 2D scanning mirror for both channels

In the commercially available LRF devices, the collection aperture diameter for the long-range LRF is always larger than 30mm. This is due to the amount of energy that needs to be collected by the detector in order to have enough signals to noise ratio (SNR) for the measurement range. Typically, the field of view of the detector channel is also very small to collect the energy illuminated by laser on the target and very little background around it. If the detector sees more than the emitting laser on the target, the noise will be increased and the range will by reduced. Figure 19 shows the concept using a large 2D scanning mirror or two 1D-scanning mirrors.

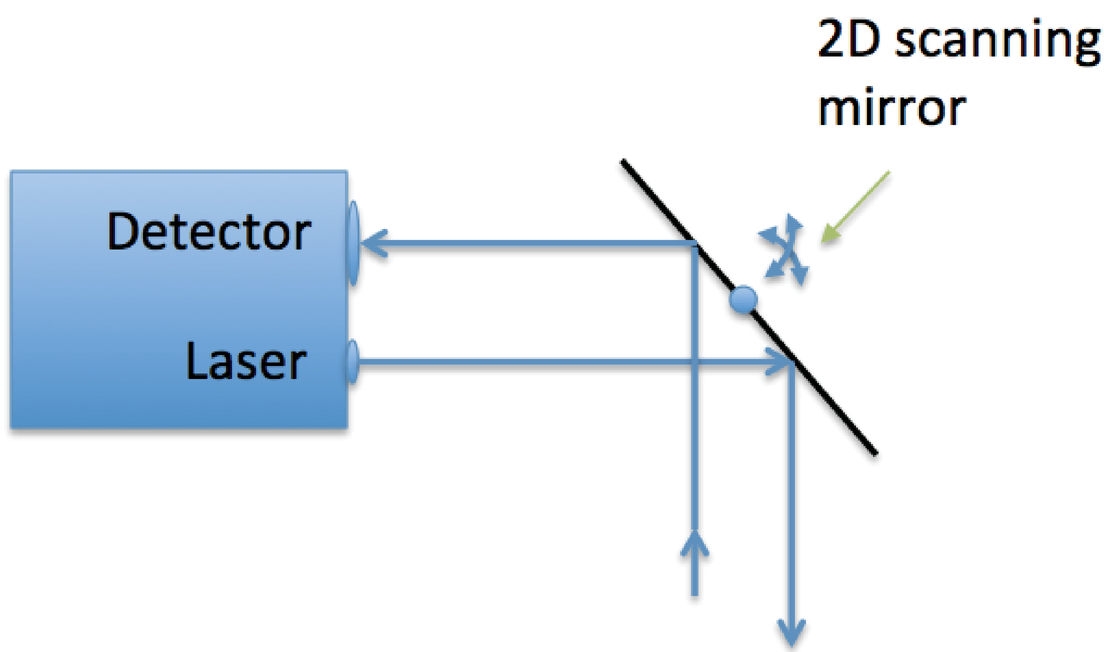

Figure 19 2D large scanning mirror.

A prototype of this concept was realized at Teknova Institute using the Acuity short-range measurement devices [12]. Figure 20 shows a sketch of the setup.

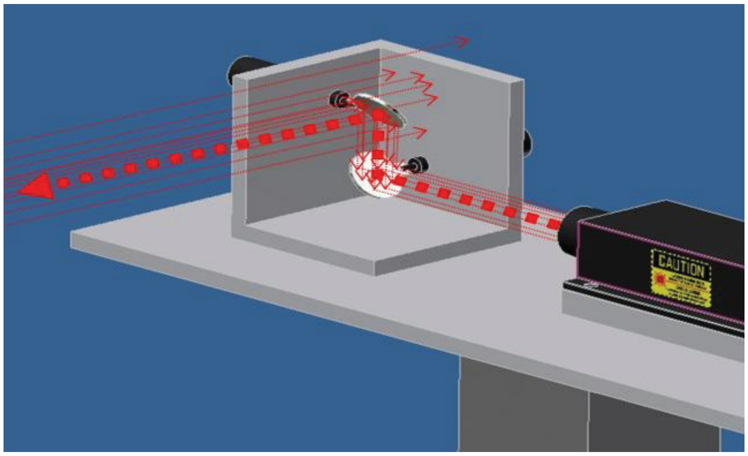

Figure 20 Inexpensive 3D laser scanner.

This arrangement work quite well but could not measure very large range due to the size of the mirrors used in the experiment. The mirrors size limited the amount on energy collected by the detector. Larger mirror could improve the measurement range but may limit the scanning speed due to the mirror inertia.

3.3 Auto-synchronized scanner with LRF

The auto-synchronized scanner concept is very similar to the two mirrors scanner presented in the previous section and could be adapted to a commercial single-point LRF. Figure 21 shows this possibility. An additional mirror needs to be added in figure 21 to scan in the orthogonal direction.

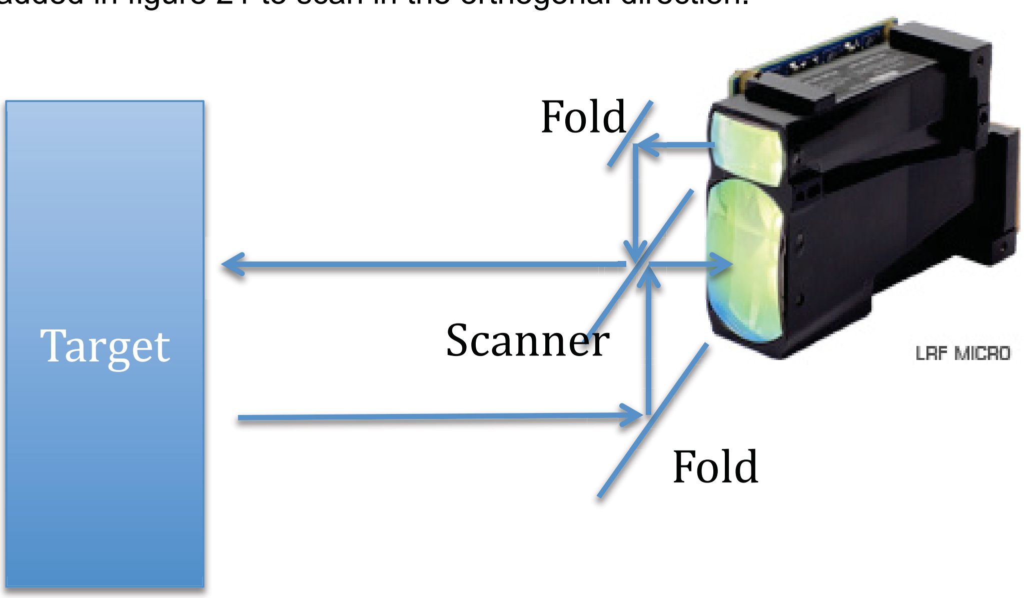

Figure 21 Newcon LRF combined with an auto-synchronized scanner

3.4 Risley-Prism 2D scanner

The 2D scanning mirrors in section 3.2 could be replaced by rotating Risley-Prism to scan simultaneously the emitting and the receiving channel of the LRF. This approach is sketched on figure 22.

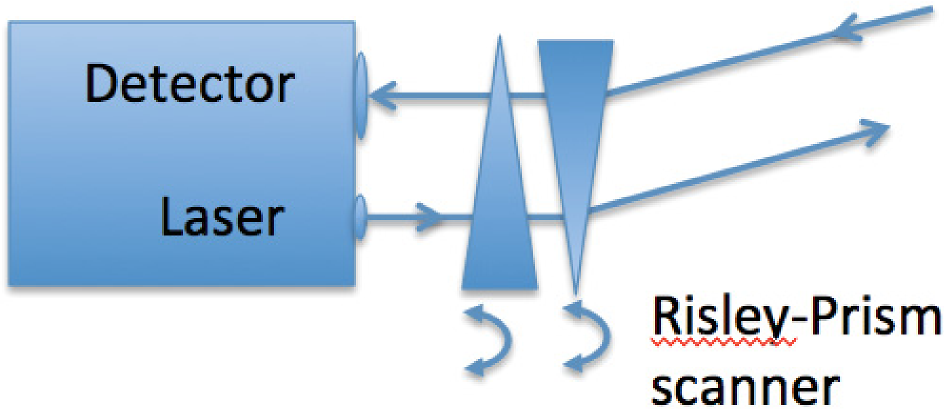

Figure 22 Risley-Prism scanner approach

The advantage of Risley-Prism over the scanning mirrors (galvanometer) is the stability of the arrangement. Chromatic aberration could be a problem if used with multiple wavelengths but the prisms can be achromatized if necessary.

3.5 HOE and LCD

As it was mentioned in sections 2.1 and 2.2, the HOE and the LCD approach could be used to scan the laser beam but there is no obvious solution for the collection optics due to the large aperture necessary for long-range measurement. These approaches are automatically eliminated as a potential quick prototyping due to this difficulty. Also, commercially available HOE or LCD could not be adapted to an off-the shelf LRF easily. Further developments in the technologies would be required.

4 Conclusion

We identify three technics that could work for quick prototyping. The first one is the two mirrors scanner, the second is the Risley-Prism scanner approach and the third one is the Auto-Synchronized scanner. DRDC has two LRF that could be adapted to these scanners. The Burris Eliminator monostatic LRF/sight and the Newcon-Optik LRF micro 1550 (see figure 23).

Figure 23 Burris Eliminator monostatic LRF/sight and Newcon-optik LRF Micro-1550

The two-mirrors scanner and the Risley-prism scanner concept could be adapted to both LRF as long as the mirror or prism clear aperture are large enough to cover the emitting and receiving channel of the LRF. The auto-synchronized scanner could only be adapted to the Newcon LRF since both channels need to be separated to apply the auto-synchronized scanner approach. Because of that we do not consider the auto-synchronous approach for this first attempt to retro fit a commercially available single-point LRF. We suggest keeping the flexibility to adapt different kind of scanners.

As we write this report, DRDC has ordered the Optra Risley-Prism assembly that can be fitted to both commercial LRF presented in figure 23. The next step is to integrate the system and test the ranging performances in a simulated environment (laboratory and outdoor).

5 References

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