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3-D Imaging of Partly Concealed Targets by Laser Radar

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ABSTRACT

Imaging laser radar can provide the capability of high resolution 3-D imaging at long ranges. In contrast to conventional passive imaging systems, such as CCD and infrared (IR) techniques, laser radar provides both intensity and range information which adds an extra dimension to the image. Furthermore, laser radar has the ability to penetrate sparse obstructions, such as foliage and camouflage nets, which enables detection and recognition of partly concealed objects.

3-D laser radar can also be employed to "see through" windows and to create 3-D images of objects inside a building. We demonstrate that this is possible even through curtains or with Venetian blinds down. Also, disturbing reflexes, particularly in shaded glass, that can reduce the performance of passive sensors, presents no obstacle for the laser radar to image through windows. This capacity can, e.g., be of use in urban applications.

Although we use a commercial scanning 3-D laser radar (ILRIS 3-D from Optech Inc.), with a rather low data rate, the collected data indicate the type of information that can be obtained with a staring 3-D flash imaging laser radar. Such systems will provide the capability of high resolution 3-D imaging at long ranges with cm-resolution at full video rate. This will also make it possible to image dynamic scenes.

In this paper we will give examples of 3-D data from targets that are partly concealed in vegetation or under camouflage nets, as well as behind windows, and discuss how the data can be used.

1.0 INTRODUCTION

With 3-D laser radar a new dimension is added to active imaging. In addition to intensity and angular coordinates, also range is included in the image. Range resolved imaging gives the ability to recognize and identify objects and people based on 3-D geometrical shape, as well as other parameters such as reflection and contrast. It also adds the ability to "see" what is hidden behind partly obscuring objects, such as vegetation, camouflage nets, curtains, and Venetian blinds. This ability can be used, e.g., in surveillance, and for reconnaissance and recognition. The high resolution and accuracy of 3-D laser radar makes it possible to make accurate measurements in a 3-D image, e.g., to identify a person or to make a complete 3-D model of a scene. In this paper we present techniques that are used for active imaging with laser radar and give examples of how this technology can be of use.

One can think of many applications where it is of interest to observe objects and areas that are more or less obscured by, e.g., vegetation, camouflage nets, curtains, Venetian blinds, or shaded windows. Visible and near infrared (NIR) wavelengths penetrate windows in buildings and vehicles. This can be used for

Letalick, D; Chevalier, T.; Larsson, H. (2005) 3-D Imaging of Partly Concealed Targets by Laser Radar. In *Emerging EO henomenology* (pp. 11-1 – 11-12). Meeting Proceedings RTO-MP-SET-094, Paper 11. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

reconnaissance purposes to detect if humans are present in a building or a vehicle. Other applications are terrain mapping, where, e.g., trees, roads, and buildings can be classified [1, 2]. Object recognition is facilitated by 3-D information in comparison to a 2-D image, but also more complex.

2.0 3-D IMAGING LASER RADAR

There are several principles for 3-D imaging laser radar, time-of-flight (TOF) systems are perhaps the most common ones. Here, a pulsed laser is used for illumination and the time-resolved reflected radiation from the scene is recorded by a fast detector. The active illumination with a laser results in complete independence of ambient light conditions (such as day or night), and hence the image contrast is very robust in that respect.

If an illuminating laser pulse hits some partly transmitting material, or some concealing object with gaps in, and is reflected from a target surface behind the concealment, this can be detected by the sensor as depicted in Figure 1.

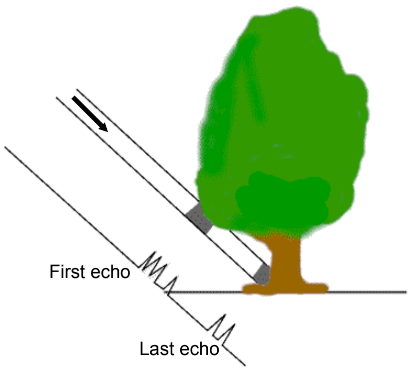


Figure 1. The illuminating laser pulse first hits the canopy of the tree, which results in the first echo. Part of the laser pulse penetrates the canopy and is finally reflected by the stem, giving the last echo.

In the last few years there has been a fast development of new sensors and sensor capabilities. 3-D imaging laser radars have generally been scanning systems, usually with mechanical scanners. Hence, data collection has been quite time consuming. Furthermore, capturing moving objects has not been possible. A new generation staring systems (sometimes called "flash laser radar") is now being developed, where a complete rangefinder in included in each detector element in the form of a time-resolved receiver and read-out integrated circuit (ROIC). This enables the capture of a complete 3-D image with just one transmitted laser pulse. Although the range accuracy and resolution of staring detectors are improving, still the scanning systems give better performance for high resolution 3-D imaging.

2.1 Laser scanner

A straight-forward method to acquire 3-D information about a scene is to scan the object with a single element detector laser radar. With every laser pulse a very small part of the object is illuminated and the time-of-flight is stored. Some detectors give a time-resolved pulse response (full waveform), whereas other detectors only give the time for the pulse return (above a certain threshold). With some systems it is possible to store first and last echo, or even more returns, each echo representing a different target range. An advantage of a scanning system is the possibility to achieve high angular resolution. The main disadvantage is the long data acquisition time, which prevents the capture of moving objects. Scanning laser radar systems can be ground based laser, see Figure 2 [3, 4], or airborne, see Figure 3 [5].Ground based systems can be used for 3-D modelling and recognition of small objects, whereas airborne systems are mainly used for terrain mapping.

Figure 2. Two ground based scanners that are used at FOI. Optech ILRIS 3-D (left) and Riegl LMS-Z210 (right).

At FOI we have used the ILRIS 3-D scanner for ground based recordings, the specifications for that system are summarized in Table 1. For airborne data acquisition we have used TopEye Mark II, which has the ability of full waveform recording.

Table 1. Specifications for ILRIS-3D.

Parameter	Data
Wavelength	1.5 µm
Maximum range	350 m (4% reflectance); 800m (20% reflectance)
Accuracy	X-Y @ 100 m ±10 mm Z @ 50 m ±10 mm, Z @ 100 m ±10 mm
Field of view	40º (±20 º, programmable, horizontal and vertical)
Divergence	0.2 mrad
Range Resolution	1 cm
Angle Resolution	0.2 mrad
Sampling Frequency	2000 points/s
Working Temperature	0°C -- +40 °C
Size	30 x 30 x 20 cm
Weight	12 kg

With a laser radar that can record the full waveform of each pulse return it is possible to improve the information about a target [6, 7]. Waveform processing can contribute to reveal more information about the target shape and reflectivity distribution [8, 9] and help to discriminate the target from the background and partly concealing objects in the foreground. The resolution may also be improved above that obtained from simple peak detection or leading edge thresholding systems.

Waveform processing to improve classification and visualization is of interest not only for mapping and terrain visualization but also for reconnaissance and complete scene analysis as well as for targeting applications. We have used an airborne down looking laser radar but the technique should be of interest also for horizontal and slant views in a ground vehicle or a low flying application.

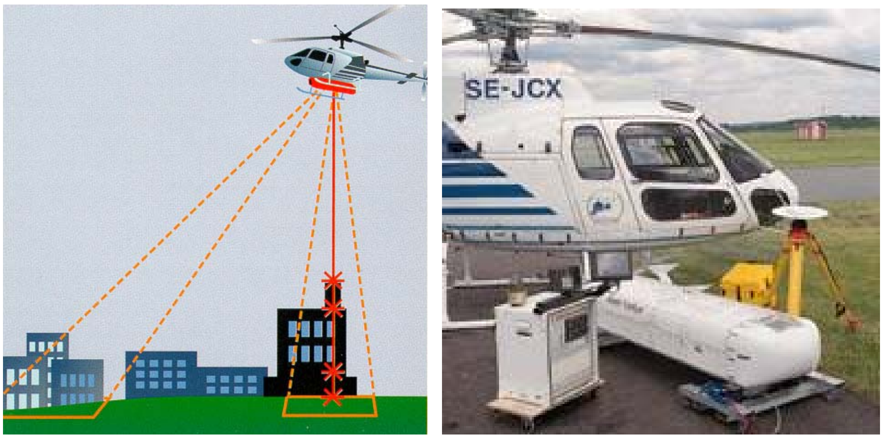


Figure 3. TopEye is an airborne laser radar system for airborne laser mapping. The new Top Eye Mark II also has full waveform recording capability. (From [5])

3.0 GATED VIEWING OR BURST ILLUMINATION

With the technique of gated viewing (GV), also called burst illumination, the sensor can be a simple camera constructed for the laser wavelength, but the shutter is connected to and synchronized with a short illuminating pulsed laser. With an adjustable a delay setting, corresponding to the time-of-flight back and forth to a desired range, the opening of the camera shutter is controlled. This exposes the camera only for a desired range slice, with the slice as deep as the laser pulse length plus the shutter open time. The delay can be changed through a predefined program, resulting in a number of slices representing different ranges, i.e., a 3-D volume. The set-back of this system is the power inefficiency, since every range slice image requires a total scene illumination. The advantage is the low cost and robustness, since rather simple components can be used. As active illumination is used, GV systems have night capability

With appropriate gate control, we can use multiple images from a gated viewing system for making a 3D reconstruction of an imaged scene. By taking the depth information into account, the 3-D volume of an object can be constructed by a few gated images [10].

4.0 EXAMPLES OF PENETRATION THROUGH OBSCURING OBJECTS

The ability to penetrate partly obscuring objects, such as camouflage nets, vegetation and Venetian blinds, with the scanning 3-D laser radar ILRIS-3D has been investigated. The use of last echo recording makes it possible to image objects that are only hit by a small fraction of the illuminating laser pulses. The examples below illustrate the power of multiple echo recording capability, since such results cannot be obtained with a laser radar that only records the first echo. The visualization of such 3-D images is greatly enhanced by rotating the 3-dimensional point-cloud and observing it from different directions.

4.1 Camouflage nets

In Figure 4 an example from a recording of a camouflage net covering a person is shown. The body, covered by the clothes, is clearly visible, but the face has not been captured in the image. This is caused by the low reflectivity of the skin, in comparison with the clothes [11]. The pulse return form the face is below the detection threshold, hence the last echo above the threshold in these image points are from the net. Good results of camouflage penetration have been reported [12]. Another example of penetration of a camouflage net is shown in Figure 5, where a truck is hidden under a camouflage net.

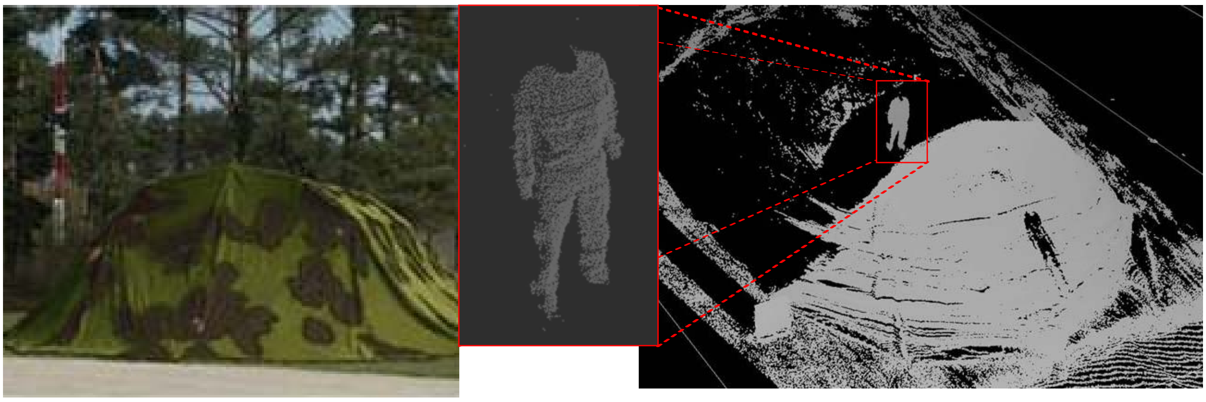
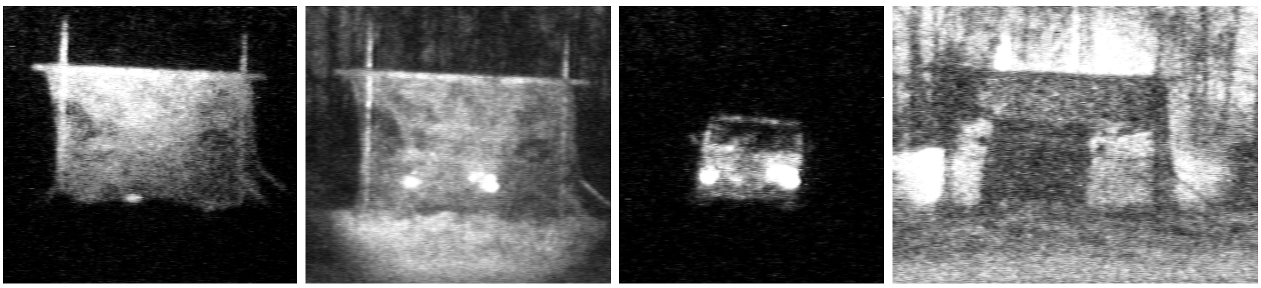


Figure 4. To the left is a photo of a camouflage net, covering a man inside. To the right is the corresponding laser radar image revealing the person under the net. Note that no echo from the man´s face is captured due to the low reflectivity of the face. As the last echo is recorded, the person also appears as a "shadow" on the front of the net.

Figure 5. To the left is a photo of a camouflage net. In the corresponding 3-D laser radar image to the right the point cloud has been rotated so that it is viewed from an elevated angle, revealing a truck underneath (highlighted in red for clarity).

Imaging through camouflage nets is also possible with range gated "2-D" imaging by stepping through a number of range gates over the target, as illustrated in Figure 6. By using a specially developed processing technique [10] developed at FOI, a sequence of 2-D gated viewing images can be used to construct a 3-D object and to increase the range resolution over that defined by the range gate or laser pulse only.



(a) (b) (c) (d)

Figure 6. Range gated viewing of a command vehicle behind a camouflage net. (a) Camouflage net, (b) Net and front of vehicle, (c) Vehicle, and (d) Net and vehicle in silhouette. From ref. [13].

4.2 Vegetation

Experimental data collected with scanning 3-D laser radar systems show that an illuminating laser pulse can penetrate through several tens of meters into vegetation, and enable imaging of objects that are, e.g., behind a forest line [11]. The range distribution of the laser radar echoes can be described by a histogram, as shown in Figure 7.

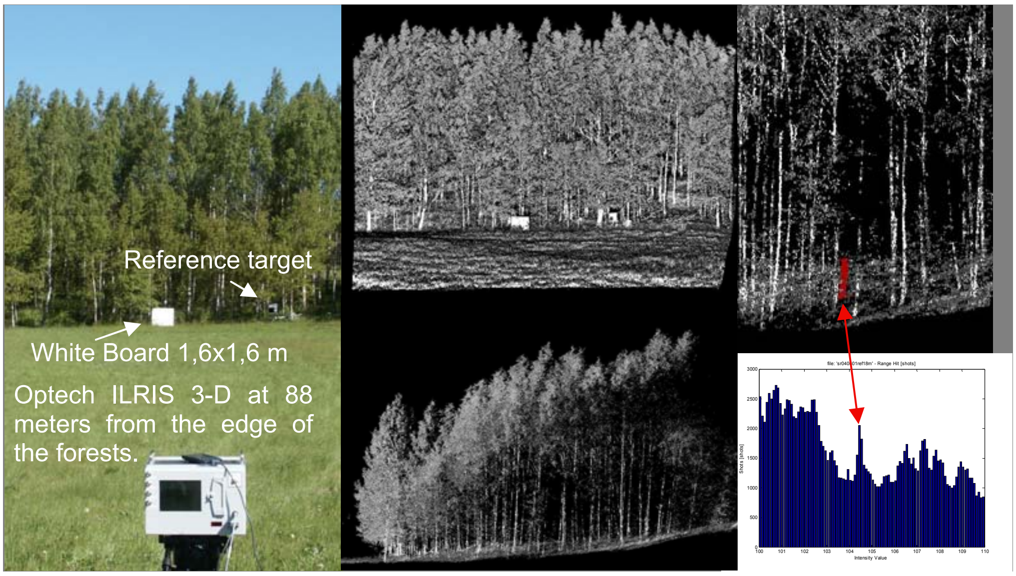


Figure 7. Left shows the measurement scenario with the white board placed at the edge of the forest. Upper middle shows the intensity picture scanned by the laser radar. In the lower left the point cloud has been rotated. Upper right shows the white board zoomed (here coloured in red for clarity) and lower right shows the histogram where the board can be seen as a peak.

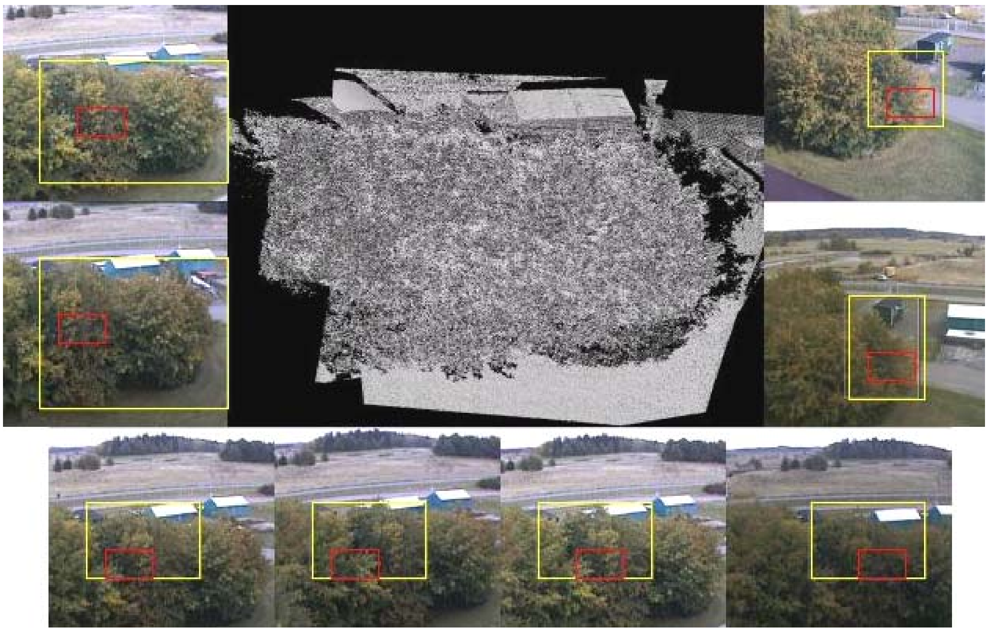


Figure 8. In the middle a 3-D laser radar image of a group of trees stitched together from eight different images. Around is a series of visual views taken from each individual imaging position of the laser scanner. The red rectangles indicate the location of the hidden car.

The capability to "see through" vegetation can be enhanced by imaging the scene from several viewing angles and then stitching the images together. This is illustrated by the scenario in Figure 8, where eight views of a fairly dense group of trees were recorded from various viewing angles. A Volvo V40 is placed behind the trees. In Figure 9 the combined point cloud is rotated, revealing the vehicle that is hidden behind the trees.

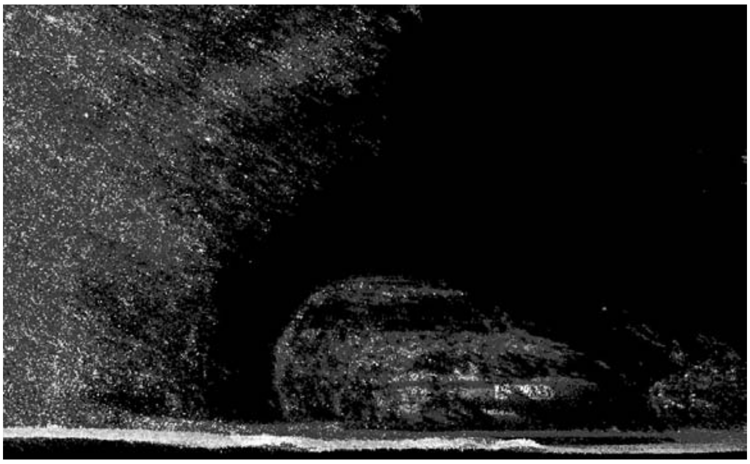


Figure 9. 3-D laser radar images from different viewing angles can be combined to give a well-resolved image of the target. This image, combined from eight views, is re-projected and shows a Volvo V40 hidden behind dense vegetation.

4.3 Imaging through windows

The ability to image objects through windows with curtains and Venetian blinds is illustrated in Figure 10. Indoor measurements of a scene with a mannequin and a person behind blinds revealed a good imaging capability even though the slats were tilted about 60º, resulting in a gap of only 2 mm between the slats. Some artefacts were noted when the distance between the objects was less than the resolution range of the laser radar. This resulted in "ghost images" at intermediate ranges between the objects. Extensive studies and experiments were conducted to clarify this phenomenon [14]. This emphasises the importance of short laser pulses and high dynamic range or high bandwidth receivers (several GHz) and waveform processing to fully take advantage of range imaging through partly occluding material.

Whereas thermal imagers can't be used for imaging through windows, due to the wavelength dependent transmission of the glass, the laser radar illumination at 1.5 µm wavelength is transmitted through the window and can be used to image objects inside a building. This is shown in Figure 10, where two people are standing in a room with Venetian blinds covering the window. Range gated techniques also works for looking into windows as shown in Figure 11 (top right), where a short pulse laser in the green wavelength region was used for illumination.

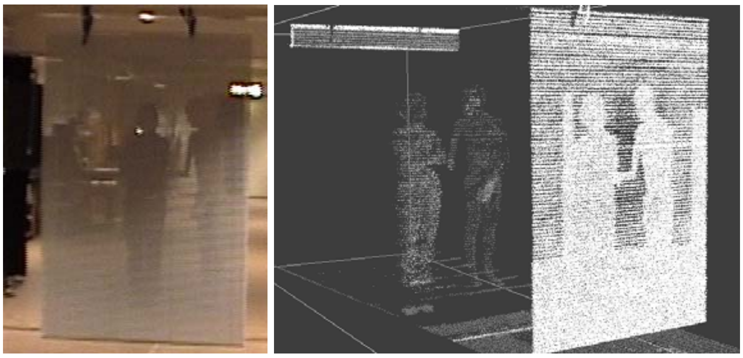


Figure 10. 3-D image of people behind Venetian blinds. To the left a visual photo with the blinds lowered and the slats adjusted to an angle of 45º (gaps of 8 mm between the slats). The scene is illuminated behind the blinds, which gives relative good visibility of the silhouettes; note that the visibility would be substantially worse if the light conditions were different. To the right is a 3-D laser radar image of the same scene. The "silhouettes" on the blinds is an artefact caused by a range separation between the objects that is shorter than the range resolution of the laser radar.

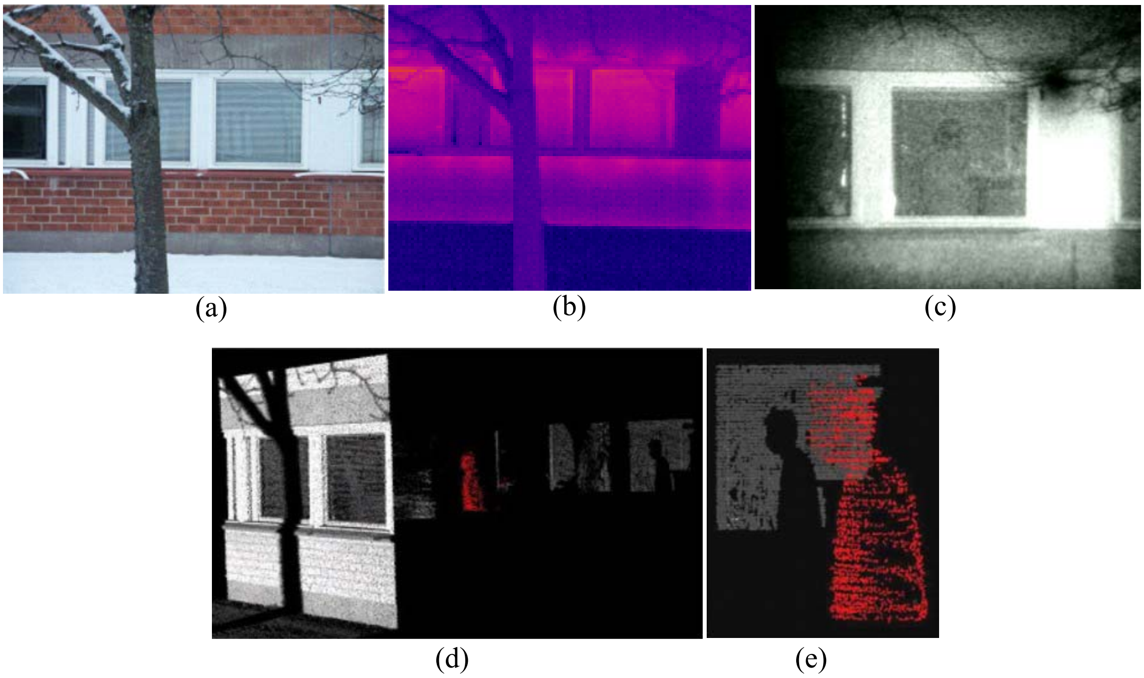


Figure 11. (a) is a photo of a window with the Venetian blinds down (approximately 3 mm gap between the slats), and (b) is an IR image of the same window. In (c) is a range gated image using visible laser radiation looking through the window. In (d) is a 3-D laser radar image (the point cloud is rotated 45º with respect to the viewing angle) showing a man inside the room. (e) shows a section of the 3-D data point cloud (front view) with the person highlighted in red for clarity.

In order to illustrate the ability of 3-D imaging through windows and Venetian blinds a "kidnapping scenario" was arranged. The scenario included two persons and a mannequin with a baby (puppet) on his arm. The person behind the second window from the left is holding a weapon. Visual photos from inside the room are shown in Figure 12. Even with the blinds lowered in the third and fourth window from the left, the persons in the room are clearly visible, see Figure 13.

Figure 12. The "kidnapping scenario" presented in visual photos. The photo to the left is taken through the second window from the left. The other photos show the interior of the room.

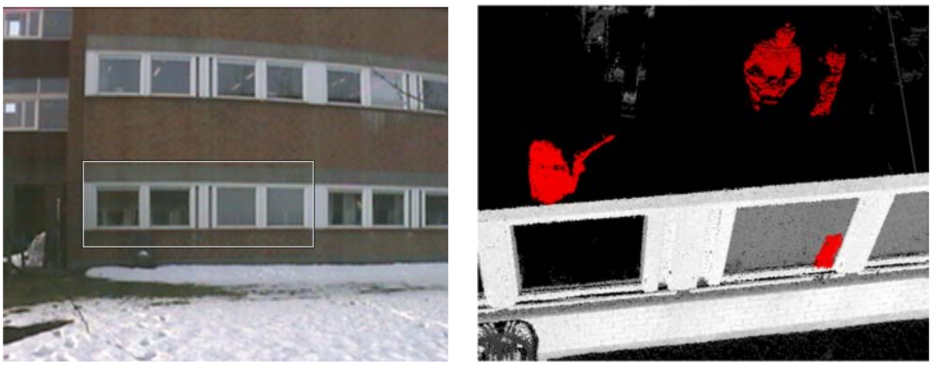


Figure 13. The scene with the "kidnapping scenario". The Venetian blinds in the two windows to the right are lowered and closed. The three persons in the room are clearly visible.

A 3-D laser radar can also be used for looking into vehicles. As an example of this, an experiment was made with a van with driver and one passenger (the mannequin) in the right rear seat. The van had shaded windows, making it very difficult to see through with a passive camera in the visible, especially under unfavourable light conditions that created reflexes in the windows, see Figure 14 and Figure 15. The 3-D laser radar, however, revealed the two people in the van (the driver wearing a bandanna over the lower part of the face).

Figure 14. To the left a visual photo and to the right a laser radar image of two people in a van. The drivers face is covered with a bandanna and a passenger (mannequin) is sitting in the rear seat.

Figure 15. To the left a visual photo of a van. Reflexes in combination with shaded windows makes it difficult to see what is inside the van with a passive sensor. In the laser radar image to the right, both passenger and driver are clearly visible (highlighted in red for clarity).

5.0 DISCUSSION

In this paper we have illustrated the ability to image 3-dimensional objects that are partly obscured by, e.g., camouflage nets, windows and Venetian blinds, using a scanning 3-D laser radar. With the capability to record the last echo it is possible to image objects that are hit only by a small fraction of the illuminating laser pulses. The examples illustrate the power of last echo or multiple echo recording capability, since such results cannot be obtained with a laser radar that only records the first echo. In addition, a laser radar with the ability to record the full waveform opens up possibilities for extracting additional and more detailed information from the data set than what is possible with single or multiple echo detection systems.

Present commercial laser scanners have some drawbacks regarding resolution and data processing and do not reflect the full future potential of 3-D imaging. In order to avoid "ghost images" caused by an object range separation that is less than the range resolution of the laser radar, short laser pulses and fast detectors and digitizers are necessary. Also, scanning 3-D laser radar systems are not functional in real time applications, or for imaging moving objects. However, ongoing development of staring 3-D sensors, such as focal plane arrays with on-chip signal processing, opens up for a number of interesting military applications, not least in urban environments. Although the performance of staring 3-D detectors is improving, high resolution imaging is presently better achieved with scanning systems.

6.0 ACKNOWLEDGEMENTS

We acknowledge Marie Carlsson and Ann Charlotte Gustavsson for their assistance in some of the experiments.

7.0 REFERENCES

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