ADVANCED LASER SENSORS

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ABSTRACT

The paper presents the status of laser sensors based on direct and coherent detection technology. Potential and limitations of 3D- laser radar, laser vibrometer, and gated viewing systems will be described.

1. INTRODUCTION

Sixty years after the invention of the laser there are only few types of laser sensors introduced in the military and security area. Mainly laser range finders, designators and beam riders play the major role with respect to opto-electronic active sensors. But there is now a number of laser imaging devices which show a high level of maturity and reliability and we will see more and more smart laser imaging sensors in the field of reconnaissance, navigation, target classification and targeting. One example of those new sensors types is HELLAS [1] from EADS which is an active laser radar–based obstacle warning system and is fielded by the German Federal Border Guard. In September 2007 the full military variant, known as the Military Obstacle Warning System (MilOWS), demonstrated successfully its functionality on board of an NH90 helicopter.

Laser imaging sensors are going from the research and demonstrator level into service – especially driven by the development of transmitters and receivers operating at the eye safe wavelength regime (particularly at the wavelength of 1.5 µm).

This presentation will summarize the potential and status of the active imaging sensors like 3D-laser radar, gated viewing and laser vibrometer.

There is a great progress in 3D focal plane array (FPA) techniques in the last years. With these devices a full range and intensity image can be captured with one laser shot. Because of this feature no pixel registration is needed and also data of moving targets can be captured. Compared to present single detector element systems no scanning device is needed or is much reduced – which ends up to a more robust and less weighted system [2]

The basic advantage of laser radar is that object recognition can be reliably automated, even for non-controlled environments such as outdoor scenes with variable background, illumination, and clutter. Since image discontinuities are in fact object boundaries, the problem of object/background segmentation, which is extremely difficult for passive imagery, can readily be resolved. Subsequent shape and pose analysis can be restricted to the extracted objects, facilitating object detection, classification and tracking. Finally, range data can be directly matched to 3D model surfaces, allowing efficient object differentiation and identification [3],[4].

Gated viewing is a well known technology for many years. Recent developments of cameras sensitive in the eye safe wavelength range (1.5 µm) make this technique very attractive for target detection and recognition in the recent time [5],[6],[7].

The quality of range gated laser images suffers from severe degradations caused by speckle effects due to atmospheric turbulence and target surface roughness. This is important for a human observer having to interpret the image or for applying 3D reconstruction algorithms. While turbulence induced speckles can help to improve the image quality by temporal averaging a sufficient number of images, the target induced speckle are still present and lower the range resolution with 3D reconstruction of an object or a scene. There are different techniques for 3D reconstruction, i.e. using a number of many sliding gates [8] or techniques where only two images are necessary [9].

Combinations with thermal cameras result in systems with longer recognition ranges for the same optical aperture and often provide better target-background contrast (by range gating using silhouettes etc.) and images which are easier to interpret than pure thermal ones. New dual-mode detectors from SELEX S&AS, based on HgCdTe technology offer both capabilities. The same FPA can be switched to operate as a passive sensor in MWIR or as a GV sensor in the SWIR [10].

Laser vibrometry based on coherent detection technique allows non-contact measurements of small-amplitude vibration characteristics of objects by using the Doppler effect. This technique offers an extensive potential for short-range civil applications [11][12] and for long-range applications [13][14] in the defense and security area. For close distance (up to few meters distance) measurements the laser vibration sensing technique is well-established in the field of testing all kind of mechanical structures in the automotive, aerospace, and medical areas. A very specific application for short range measurements is the Doppler based acoustic-to-seismic detection of buried mines [15][16]. The laser vibrometer used for these applications are based on a HeNe laser source (λ = 632 nm). For long range applications (in the order of several kilometers) which may be relevant in the field of defense and security higher laser output power is necessary. To meet the laser safety regulations laser wavelengths in the "eye-safe" region are essential.

2. 3D-LASER RADAR

During takeoff and landing as well as during rescue and surveillance operations, helicopters are often required to fly close to dangerous obstacles such as power lines, masts, cables and other high, narrow structures. Such obstacles are difficult to detect, not only during adverse weather or visibility conditions, or during night flight using image intensifier or infrared vision aids. Many helicopter collisions have occurred during daytime operations with obstacles which were within the pilot's visibility range, but which nevertheless were not seen by the pilot. During one such collision with a cable lift traversing a valley in the German Alps, the pilot was unable to locate the cable although explicitly looking for it, and knowing its approximate position. Apparently the human visual system has difficulties separating narrow structures from a highly cluttered background, particularly if the search time is restricted to a few seconds. Since human vision is an extremely efficient pattern recognition system, it is highly unlikely that automatic processing of visual, IIT or IR data will ever be able to detect wires reliably enough to help pilots avoid these obstacles [17].

In range imagery, on the other hand, foreground and background can easily be separated by analyzing range discontinuities.

One technique, which has successfully been tested in helicopter flight tests using a scanning laser radar (Fig.1).

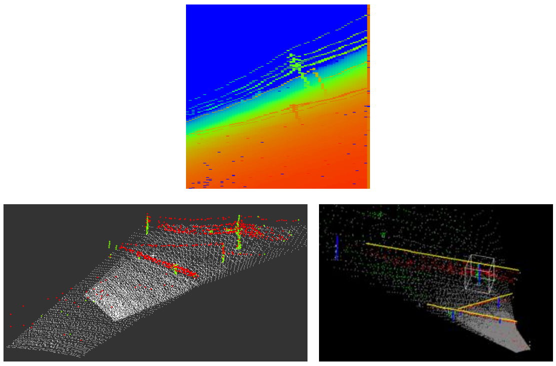

Figure 1. Range image processing for helicopter obstacle warning; top: laser radar image (color coded), below left: point cloud generation and classification, below right: recognition of masts and wires.

Practically no applications exist for which automatic processing of 2D intensity imagery can equal human visual perception. This is not the case for range imagery. 3D laser radar applications relying on automatic data processing can exceed human visual cognition capabilities.

If an accurate 3D surface model such as a CAD-model of the object being searched is known, then model based object recognition may be used rather than feature based classification. In this case automatic object recognition typically exceeds human visual capabilities, particularly for objects at high range, low contrast, or viewed with night vision sensors. For example the human observer has difficulties determining which object in the infrared image of Fig. 2b corresponds to the target model of Fig. 2a, while range image processing of the same scene (fig. 2c) uniquely identifies the target (Fig. 6d). The resolution of the range image (128 x 128) is much lower than that of the intensity image (640 x 486), which is typical for such results.

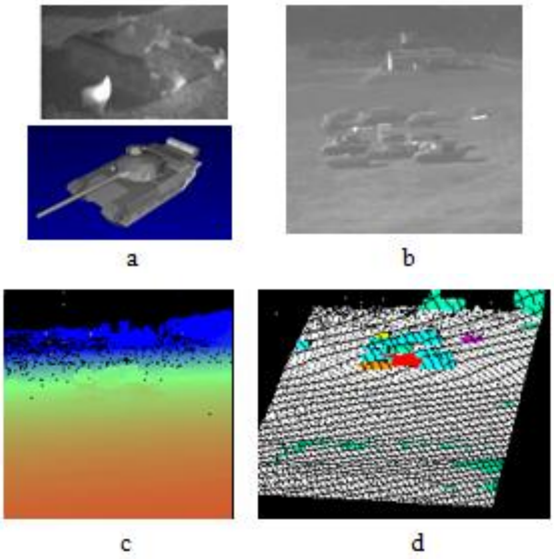

Figure 2. Comparison of object recognition in intensity vs. range data: the human observer fails to recognize model a in intensity image b, while automatic processing of the range image c correctly identifies the target (red in d). Human performance is not improved if an intensity model (a, top) is used.

In general, object recognition attempts to answer “what is where”: given a model library and a scene containing several objects, determine the model and pose of each object in the scene (Fig. 3).

Figure 3. Range image matching: the expected range image (left, bottom) generated from the 3D model (centre) is matched with the range image (left, top). Point set matching: segmented on-target 3-D points (red, right) are matched with visible model points (blue, right), generated from the model.

So far, most of the 3D data collection at Fraunhofer IOSB was concentrated on land vehicles. The investigation of 3D laser radar signatures are now extended to maritime targets. Fig. 4 shows the visible and the range profile image of a small boat, taken by the 3D flash laser system from ASC which is operating at 1.5 µm. The signature of target and background (sea surface) is dominated by the absorption and reflection behavior of the transmitter wavelength at 1.5 µm.

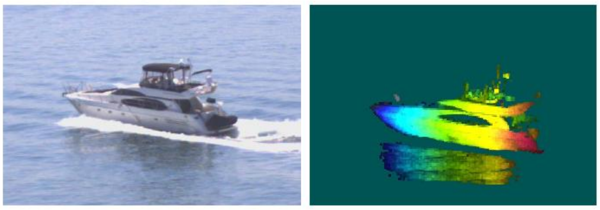

Figure 4. Visible and the color coded range profile image of a small boat, taken by the 3D flash laser system from ASC.

3. GATED VIEWING

The main advantages of range gated imaging include long range target recognition, difficult target recognition by looking through camouflage, vegetation, water, haze and fog, fire and smoke using the range segmentation to separate the target from the background. Another important feature is the reduction of the influence of parasitic light like sun, car lights etc. There are a large number of applications for gated viewing especially in combination with passive EO or radar for target cuing and range gating for target classification.

Fig. 5 shows a typical example of gated viewing images with different gate settings (wide gate, gate on target and gate behind the target). Silhouette images compare to the common reflexion images are able to give more valuable information for perception tasks like recognition or identification. Additionally such silhouettes can be also used for tracking applications. This silhouetting occurs if an object is wholly in front of the gate (as seen by the observer). It will then appear to have zero radiance. The background, if present, consists of reflected and/or backscattered radiation emerging from the gate so that the object appears as a dark silhouette thus representing a higher contrast target. This is especially true for long ranges, if the image resolution will be strongly degraded by the speckle effect – in the silhouette image the shape may be a very typical feature for some perception tasks, whereas in the reflexion image the target could not recognized due to the fuzzy shape.

Figure 5. Different setting of the gate.

Range resolved (3D) images can be reconstructed from several frames using sliding time gates. The range accuracy and resolution for this depends on the single frame noise as well as the image dancing and beam wander. There are different techniques for 3D reconstruction, i.e. using a number of many sliding gates or techniques where only two images are necessary (Fig.6).

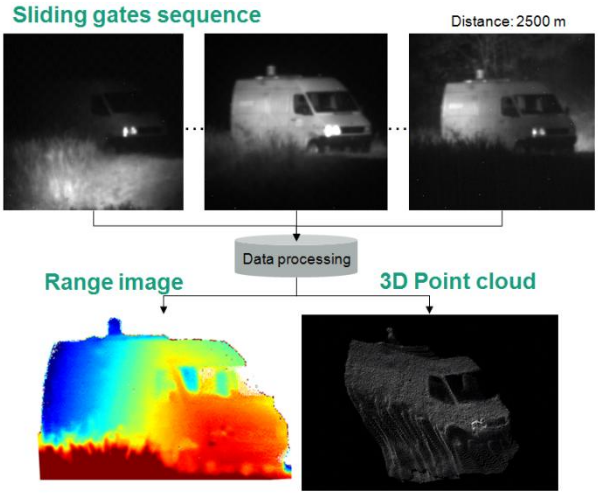

Figure 6. Range resolved image reconstructed from several gates.

The disadvantage with an active system is the reduced covertness by the illuminating laser, which can easily be detected. A conventional gated viewing (GV) system is built as a single unit. In that case the laser and the camera are assembled next to each other. Separating the revealing illuminating laser and the camera offers the great advantage of vulnerability reduction for the camera and the operator. The camera location becomes almost undetectable. There is no technical reason why a GV-system could not be operated in a bi-static configuration. The laser source and the camera can be separated spatially. The separation distance is mainly determined by the application.

Most gated viewing systems are operated in an interactive mode and the captured scene is prepared for display to the operator / observer. Scene interpretation of a natural scene by humans is a complex task. This is true even in the real 3D-world, and is much more difficult if it is based only on 2D-images of a real 3D-scene. The interpretation of 3D scenes can be supported by additional cues due to appearance of shadows. Every active imager illuminates the scene; therefore shadows will always be there. But due to the ‘on-axis’ image capturing, they would be hardly ever seen.

Mainly the lack of observable shadows in the images causes another effect too. A captured scene appears often ‘flat’, if the image was taken from nearly the same location as the scene was illuminated. This is a well-known fact from ‘Facial/Portrait Photography’ and from ‘Computer Graphics’. Missing shadows and weak shading changes (on curved surfaces) are the main reason for that.

We captured a few images from a dynamic scenario in bi-static mode to see some shadow effects. The results are shown in Fig. 7. The acting person was casting shadows on the ambulance vehicle in both situations. In the ‘off-axis’ image (Fig. 7, lower right-hand image) the illuminated person can be seen in front of another shadow, casted by the cabin of the front truck on the ambulance vehicle. In this scene the acting person can be seen much easier in the off-axis images than in the on-axis images. In this particular case this is due to local contrast enhancement between the foreground image (person shape) and the surrounding background image content.

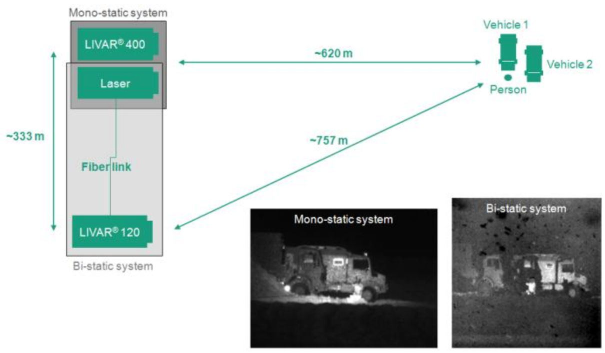

Figure 7. Bi-static configuration: shadow effect.

4. LASER VIBROMETER

In the past the most common laser radar system – for long range applications - operated at 10.6 µm wavelength. Due to the rapid progress in compact solid state and fiber lasers made laser transmitter (heterodyne-capable) at 1.5 or 2 µm available. This offers the possibility to build more compact systems with low- cost components and less power consumption.

With common laser radar systems used over longer ranges, the laser beam is spread across most, if not all, parts of the target. This results in spatially unresolved target vibration signatures, a so-called 1D-vibration signature (Fig. 8). Frequency distributions in the power spectra of such spatially unresolved vibration signatures are dependent on the area covered by the laser beam on target and on target aspect angle. Our aim was to investigate to what extent the target information content of the return signals would be increased by spatially resolving the vibration signature, a so-called 2D-vibration signature (Fig. 8). Spatial resolution may be achieved by using a scan device or a multi-element receiver. With such a 2-dimensional laser vibration sensing approach (vibration imagery) the target will be spatially resolved and one obtains a 'data cube' consisting of a 2D map of vibration amplitudes across the target, one for each vibration frequency (Fig.9).

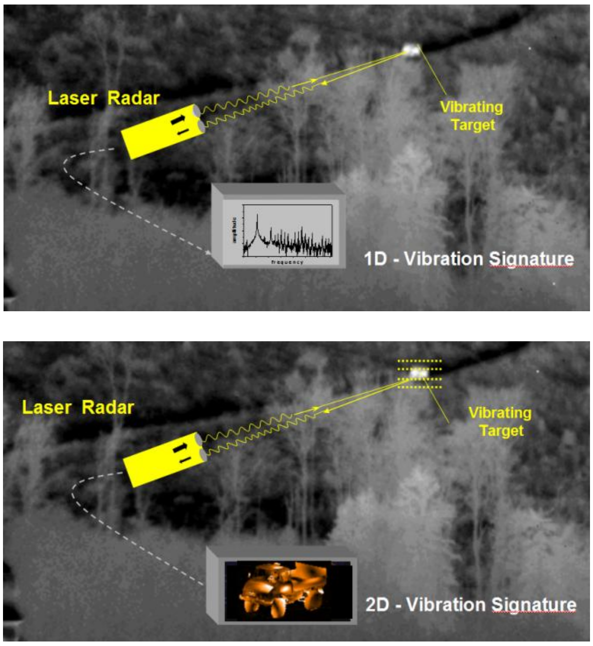

Figure 8. Measurement of 1D-and 2D-vibration signatures.

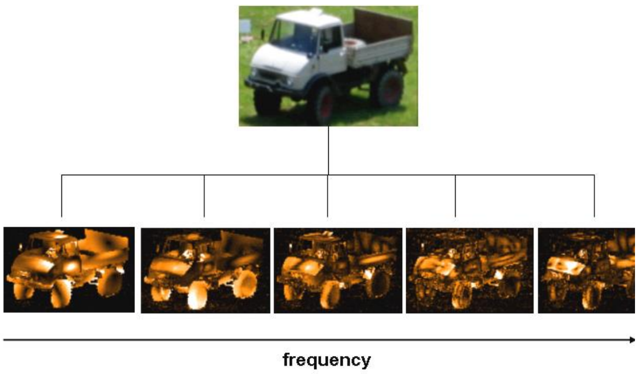

Figure 9. Visible image of a small truck and the 2d- vibration images at five different frequency bands - idling engine condition at different frequencies. Data were recorded using the 1.54 µm - laser radar sensor with a resolution of 90 x 70 pixels at a range of 100 m.

In general, picking up target vibrational features by coherent laser vibrometry techniques requires a direct line-of-sight to the target. However, in the past a couple off-line-of-sight problems were also investigated, including the acousto-optical detection of buried land mines or hidden helicopters.

Depending on how a vibrating target is embedded into its environment, vibration signatures can be transferred via seismic waves to surrounding objects like buildings, walls, traffic signs, containers, posts, etc. In case no direct line-of-sight to the target is given, its vibrational signature could thus probably be picked up from adjacent in-sight objects. In Fig. 10 an example of such an off line-of-sight measurement is depicted.

A truck (type: UNIMOG) was positioned on a paved surface behind a stone wall with its engine running in idle mode. The SAVIS sensor was operated at a distance of 100 m and the laser beam was directed onto the wall. Fig. 10a and Fig. 10b show the vibration signature picked up from the wall when the engine of the truck is idling or turned off respectively. Fig. 10c and Fig. 10d show the corresponding reference spectra but where the truck was measured unhidden, with direct line-of sight.

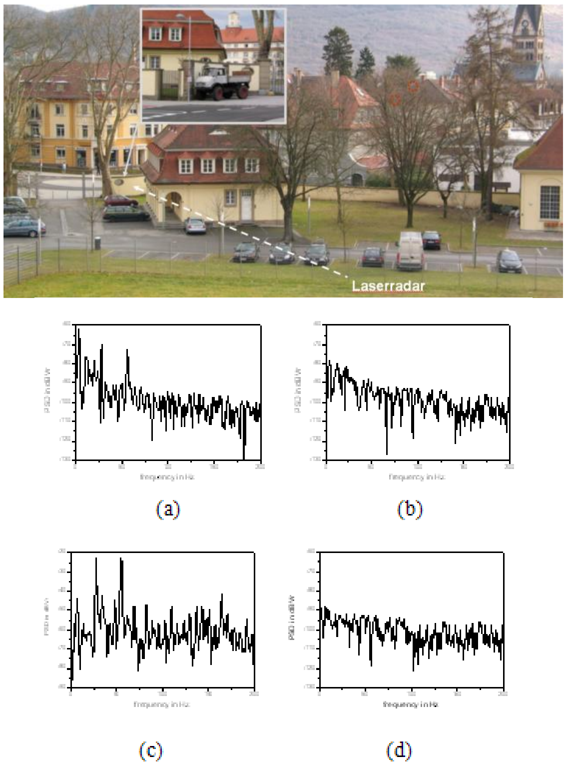

Figure 10. Off line-of-sight vibration measurements of a truck behind a wall. On wall: (a) engine on, (b) engine off. On target (as reference): (c) engine on, (d) engine off.

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6. REFERENCES

1. http://www.eads.com/1024/de/investor/News_and_Events/news_ir/2008/20080115_eads_ds_MilOWS_NH90.html7
2. R. Stettner; H. Bailey; R. D. Richmond, " Eye-safe laser radar 3D imaging", Proc. SPIE, **437,** pp.46-56 (2004)

3. [1] Grönwall, C., Chevalier, T., Persson, A., Elmqvist, M., Ahlberg, S., Klasén, L., and Andersson, P., "Methods for recognition of natural and man-made objects using laser radar data" Proceedings of SPIE, Vol. 5412, 312-319 (2004)

4. [16] Armbruster, W., "Bayesian multi-target tracking and sequential object recognition", Proceedings of SPIE Automatic Target Recognition XVIII, Vol. 6967, 69670S (2008)

5. O. Steinvall, P. Andersson, M. Elmqvist, M. Tulldahl, "Overview of range gated imaging at FOI," Proc. SPIE **6542, 654216** (2007).

6. Deni Bonnier, Sylviane Lelièvre, Louis Demers, "On the safe use of long-range laser active imager in the near-infrared for Homeland Security," Proc. SPIE **6206**, 62060A (2006).

7. E. Repasi; P. Lutzmann, O. Steinvall, M. Elmqvis; B. Göhler, G. Anstett, "Advanced short-wavelength infrared range-gated imaging for ground applications in monostatic and bistatic configurations", Applied Optics, Vol. 48 Issue 31, pp.5956-5969 (2009)

8. P. Andersson, "Long-range three-dimensional imaging using range-gated laser radar images," Opt. Eng. **45 (3)**, 034301, 1- 10 (2006).

9. M. Laurenzis, F. Christnacher, D. Monnin, "Long-range three-dimensional active imaging with superresolution depth mapping," Optics Letters **32**, No. 21 (2007).

10. I. Baker, D. Owton, K. Trundle, P. Thorne, K. Storie, P. Oakley and J. Copley, " Advanced infared detectors for multimode active and passive imaging applications," Proc. SPIE, **6940**, 6902L (2008).

11. http://www.polytec.com

12. C.J: Karlsson, F. Â.A.Olsson, D. Letalick, and M. Harris, "All-fiber multifunction continuous-wave coherent laser radar at 1.55 µm for range, speed, vibration, and wind measurements", Appl. Opt. 39 (2000)

13. R. Ebert, P. Lutzmann, "Vibration imagery of remote objects", Proceedings of SPIE Vol. **4821** (2002)

14. Ning Xiang, James M. Sabatier, "Acoustic-to-seismic landmine detection using continuously scanning laser Doppler vibrometer, Proceedings of SPIE Vol. **5089** (2003)

15. J. C. van den Heuvel, V. Klein, P. Lutzmann, F. J.M. van Putten, M. Hebel, H.M.A. Schleijpen, „Sound wave excitation for acousto-optical landmine detection", Proceedings of SPIE Vol. **5089** (2003)

16. V. Klein, M. Hebel, M. Resch, „SLDV III: the next generation of acousto-optical landmine detection",Proceedings of SPIE Vol. **5794** (2005)

17. W. Armbruster, "Exploiting range imagery: techniques and applications", International Symposium on Photoelectronic Detection and Imaging (2009), Proceedings of SPIE, Vol. **7382** (2009)