Polarized Light Camera; a Tool in the Counter-IED Toolbox

Wim de Jong PhD, John G.M. Schavemaker PhD and Arnold J. Schoolderman, PhD
TNO Defence, Security and Safety
Business Unit Observation Systems
P.O. Box 96864
2509 JG The Hague
The Netherlands

wim.dejong@tno.nl / john.schavemaker@tno.nl / arnold.schoolderman@tno.nl

ABSTRACT

It is well known that smooth surfaces polarize visible light that is reflected by that surface. This phenomenon can be used to discriminate between relatively smooth man-made objects, such as landmines, UXO and IEDs, and the rough natural background.

This paper shows real-time detection results obtained with a static polarization camera and a polarization camera mounted on a moving vehicle. For the tests anti-vehicle and anti-personnel mines were placed on a stony background, a gravel road and between vegetation, and were both surface laid and partly buried. With the camera mounted on a moving platform the automatic detection processing was performed in real-time and visualized in real-time. The detection rate is very high, together with a very low false alarm rate.

It is demonstrated that the polarized light camera can be a valuable sensor for the discrimination of man-made objects from their surroundings, and thus can have an added value for the detection of certain types of IEDs. An operational concept for the use of the camera is the support of surveillance of the road side by military from an armored vehicle.

1.0 INTRODUCTION

Improvised Explosive Devices (IED) are responsible for many casualties in Afghanistan and Iraq and pose a major problem for military operations. IEDs are often used against convoys or patrols. Finding a reliable way to detect IEDs has become a priority for the military. And this detection is a very difficult task as IEDs can be hidden in any object one can think of.

In recent years a lot of attention has been paid to the detection of landmines that are placed on or besides a road. Several tools have been developed for this purpose. Some of them can be useful for the detection of IEDs. This paper describes the development and demonstration of a polarised light camera. This camera has been developed for the detection of surface laid and flush buried mines on a road or alongside a road. A very high detection capability with a low false alarm rate has been demonstrated in a road clearance scenario. Also for IED detection this camera could be a tool in the toolbox.

The paper is organised as follows. Section 2.0 describes the use of camera systems in landmine detection and more specific the use of InfraRed and visible light polarization cameras. In section 3.0 the detection methods are very briefly described. Results of both static and dynamic tests are given in section 4.0.

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2.0 LANDMINE DETECTION WITH CAMERA SYSTEMS

Landmines as left behind after military or civil conflicts are a huge problem. The main current practice to detect mines is by prodding and by use of a metal detector. Prodding is very time consuming, dangerous and demands a lot of concentration from the deminer. The metal detector is used to find all metal objects. However landmines that contain little or no metal also exist and moreover, in former battle zones a lot of metal shrapnel is left behind. The lack of other reliable tools makes the process of demining very slow. To improve the clearance speed in the future, many nations have put effort in landmine-detection research. The research on sensor systems focuses on three main topics [[1],[2]]. Firstly, the development of new sensors. Secondly, the improvement of existing sensors. The third research topic is the integration of these sensors into a sensorfusion system. The use of one sensor is generally believed to be insufficient for landmine detection meeting the requirements of humanitarian demining (100% detection) for the reason that a single sensor has a false-alarm rate which is too high or a detection rate which is too low. The goals of sensorfusion are to reduce the probability of false alarms P(fa), to increase the probability of detection P(d), or to improve a combination of both.

2.1 Polarization of light

One of the sensors that is considered for a multi-sensor landmine detection system is the thermal infrared (TIR) camera [[3]]. TIR cameras are able to detect small temperature differences (as low as 15 milli Kelvin). Landmines often have different heat conductivity and heat capacity compared to the soil and the vegetation around them. Due to these differences in thermal properties, differences in temperature between a landmine and the background may develop when the soil is heated or cooled down. However, TIR images of landmines in natural scenes contain clutter, since other (natural) objects like trunks, holes, and rocks also may have different thermal properties compared to the background. In the visual spectrum it is well known that unpolarized light reflected from a smooth surface becomes polarized [[4]].

Figure 1 shows an example of the polarisation effect of visible light from a dummy PMN mine placed in a natural background. This mine has a black rubber top that is not shiny, but still polarises the reflected ambient light. This polarization effect also exists when the colour of target and background, or the TIR intensity of ttarget and background are identical. The polarization contrast can thus be very useful in a cluttered environment.

Figure 1 Example of the polarization effect on a dummy PMN mine in the visible light. The leftmost image is taken with a horizontal polarizer in front of the camera. The centre image is taken with a vertical polarizer and the third image is the difference between the two images. This last image clearly shows the polarization contrast between the mine and the background.

The polarization of reflected light occurs also with Thermal Infra Red (TIR) radiation. However, for TIR radiation not only the reflection, but also the emission is polarized. Since in general the surfaces of landmines are smoother than the surfaces found in a natural background, the presence of significantly polarized TIR radiation is an extra indication for landmines (or other non-natural objects). Using a polarization setup, the performance of the TIR camera can be improved and thus have a larger contribution to the multi-sensor system [[5],[6],[7]]. Research performed by TNO has shown that using the polarisation features of light (both infra red and visual light) improves the detection capabilities of a camera system [[8]]

When compared to a TIR polarization camera a visible light (VIS) polarization camera is in general much cheaper and more robust. The drawback that buried land mines can not be detected with a VIS polarization camera is in some applications less important. This paper only deals with the automatic detection of landmines using a VIS polarization camera.

2.2 Polarization measurement

Generally there are two different approaches used for the measurement of (infrared or visual) passive polarization. Either time division or spatial division is necessary to measure up to four elements of the Stokes vector using only one focal plane.

With time division, different polarization images are measured sequentially. This is usually performed by mounting a polarization filter in front of the camera and taking a sequence of images with different polarization directions. For measurements of the full (four elements) Stokes vector, a retarder (for instance a quarter wave plate) is rotated followed by a fixed linear polarization filter. This common approach of either rotating a polarizer or a retarder is reported by the majority of literature [[9],[10],[11]]. Time division becomes very complicated when the camera and/or the scene is moving. Advanced image processing is required when the camera is mounted on a moving platform.

Using spatial division, the different polarization states are measured simultaneously at the cost of reduced spatial resolution. For example, every 4 adjacent pixels of a focal plane array (FPA) are grouped. In front of each of these 4 pixels a different polarization filter is mounted, each with a different orientation [[12],[13],[14]]. A recent development in Quantum Well Infrared Photodectectors (QWIPs) makes the polarizer part of the FPA, leading to simpler and robust imaging systems. Using appropriate designs of the optical coupling (e.g. lamellar gratings), QWIPs can be turned into polarization sensitive detectors [[14]]. However the polarization sensitivity of these systems is still too small for landmine detection.

When more than one focal plane is available, an optical prism assembly, mounted behind the camera lens can be used to separate an image into three equal components. Each image is captured with a CCD. In front of each CCD element a polarization filter with a different, fixed orientation is mounted. This solution is only known for visible light since visible light CCDs are much cheaper than IR FPAs.

TNO first used rotating filters in front of both VIS and IR cameras [[5],[6],[7],[8]], but has moved to the 3 CCD solution. TNO has modified an existing 3 CCD camera design by developing and realising new beam splitter coatings. These coatings have been optimised to measure linear polarisation with a high sensitivity. A polarisation camera, using these coatings, has been constructed. This camera, which has no moving parts, is robust and can be mounted on a moving platform and no complicated signal processing is required to determine the polarisation information from the scene [[15]].

Figure 2 shows from left to right an TIR system with a rotating polarizer, a VIS system with a rotating polarizer, and the layout of a VIS 3CCD system.

Figure 2 Different polarization measurement systems. From left to right a TIR system with a rotating polarizer, a VIS system with a rotating polarizer, and the layout of a VIS 3CCD system.

3.0 DETECTION OF LANDMINES FROM POLARIZATION IMAGERY

In addition to the conventional way of detecting mines using image intensity [[16]] and/or color features, an additional way is created by the use of polarizers. Polarization can add significantly to the systems robustness and its detection performance [[5],[6],[7]], especially in the case of detecting artificial objects within a natural background. However, the performance of polarization features depends more on the operating conditions than the color or intensity features, which are more invariant to those conditions. For example, the position of the sun (both azimuth and elevation), viewing angle with respect to the sun position, and weather conditions (daylight, clouds) have an impact on the use of polarization. Extensive tests have given some insights into the application of polarization system and its effect on the system characteristics.

3.1 Detection methods

For the tests that are described in section 4.1 we have implemented a threshold on intensity and polarization, and a blob analysis scheme as pattern-recognition classifier.

Landmines that have a smooth artificial surface (and/or have intensity values that are different from local surroundings) can be detected using polarization contrast. Polarization contrast can be defined using the Stokes vector [[4]], which is a mathematical representation of polarization. Combination of the intensity and polarization threshold results in a binary image with blobs. These blobs are extracted by means of a connected-component algorithm. Blobs are groups of connected pixels that represent possible landmine detections. Blobs with a size smaller than a certain threshold are removed from image. As such, the complete detection procedure has three parameters: thresholds on intensity, polarisation contrast and size [[17]].

For the tests described in section 4.2 the intensity contrast is no longer used.

4.0 EXAMPLES OF POLARIZATION IMAGES FOR LANDMINE DETECTION

This section describes the results of automatic detection in two different scenarios. The first paragraph shows results from static tests were we used a rotating filter. In this test the ground truth was available and ROC curves could be calculated. In the second paragraph results obtained with the new 3 CCD polarization camera are shown. The automatic detection was performed real time.

4.1 Static Tests

This section presents detection results on recordings made during August and September 2003 on a test field near TNO-FEL, The Hague, The Netherlands. The data sets were recorded with a VIS camera system, mounted on a tripod. There were four measurement areas, that all four had the same lay-out. Each measurement area contains three samples of four different mine types and six special false alarms. These six false alarms are stones that are selected to have the same size and/or color as the mines. The mines and the stones are placed on a 1 m square grid. During the data collections, the camera made recordings of the different measurement areas by rotating the camera on the tripod to view the different areas. From the camera viewpoint, the four areas faced the north, south, east, and west directions [[8],[17]]. Figure 3 shows an example recording.

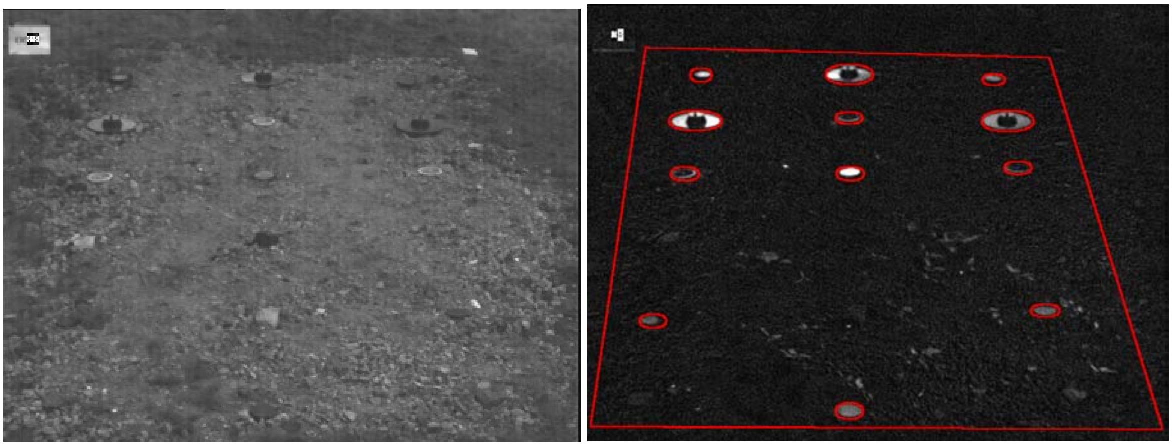

Figure 3 Normal BW intensity image on the left and polarisation contrast image on the right. The red circles in the last image indicate the ground truth.

4.1.1 Performance evaluation of landmine detection

The performance of the camera system is evaluated using the Receiver Operator Characteristics (ROC) curve. In a ROC curve the detection rate is plotted against the false-alarm rate for adjustable (optimization) parameters. Each working point on the ROC corresponds with a set of values for the thresholds used. The detection rate is defined as the fraction of detected landmines. The corresponding number of false alarms per unit area is calculated using the following method. The camera system will be fitted on top of the vehicle that moves forward, as such, we count multiple false alarms that are on the same horizontal line of the measurement area as one. This is because the vehicle has to stop only once if one or more false alarms are detected at the same distance in front of the vehicle. Each measurement area consists of six horizontal lines that are 3 m wide and 1 m deep.

The graph in Figure 4 shows results from the four areas in four different wind directions (influences the illumination of the mines) The data gathered between 9:00 and 13:00 has been processed with one set of thresholds. The ROC graph shows two curves. The blue curve gives the detection results without using the polarisation contrast. Only intensity contrast is used. The red curve shows the results using only the polarization contrast [[8],[17]].

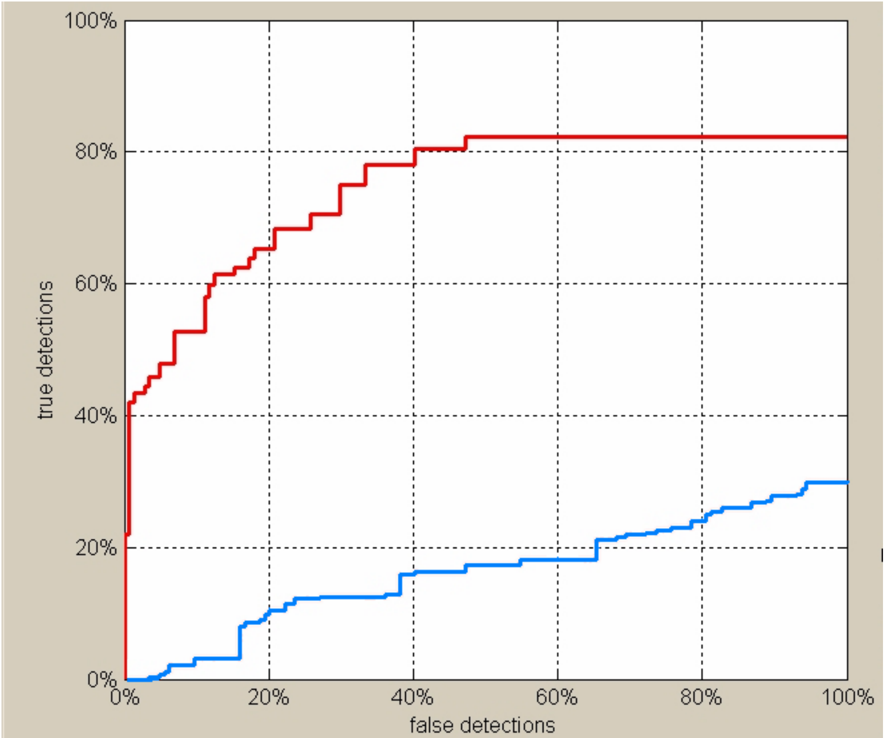

Figure 4 Comparison of detection results. The red curve shows the percentage of true detections verus the percentage of false detections using polarisation contrast. The blue curve shows the same using normal intensity only.

4.2 Moving platform tests

In the moving platform tests, the new developed 3CCD polarisation camera is mounted on a wheeled vehicle. This vehicle moved with a speed of up to 30 km/hr. In this test the data acquisition and the detection processing were done on separate computers to demonstrate the feasibility of the use of a radio link in the real time detection system. Figure 5 gives a schematic drawing of the different hardware components in this setup. The scenario consisted of different backgrounds, namely gravel and light vegetation. Various types of AT and AP mines have been placed. The surface laid mines were camouflaged with twigs, grass, heather etc. Other mines were buried, with only part of the detonator visible.

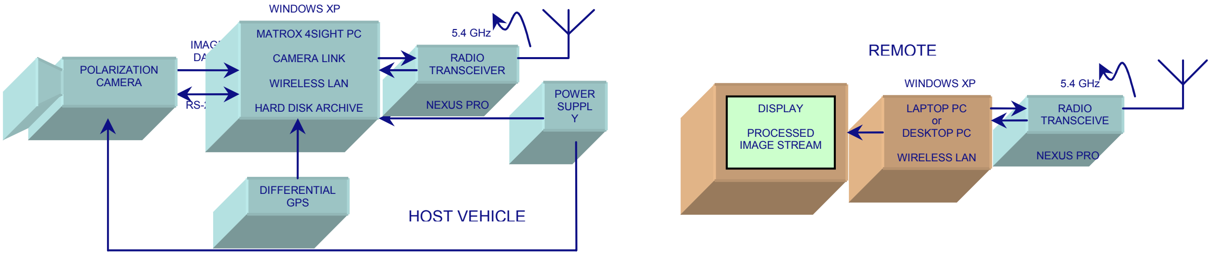

Figure 5 Schematic drawing of the camera system, the data acquisition system, the radio link and the processing computer. In this test the data acquisition and the detection processing were done on separate computers to demonstrate the feasibility of the use of a radio link in the real time detection system.

Automatic detection processing, using the algorithms described in the previous sections was performed and the results were displayed real time. For future integration in a multi sensor system, the detected objects were labelled. This label contains the GPS coordinates and the detection confidence level. Figure 6 gives an example of the visualisation of the detection results.

PROCESSING COMPLETED

☑ Scan Area

```
Frame:  20  Object count: 3  Obj1(142,254)C=027.78 Obj2(558,066)C=110.60 Obj3(566,43
Frame:  21  Object count: 2  Obj1(098,318)C=031.54 Obj2(546,102)C=274.07
Frame:  22  Object count: 2  Obj1(042,390)C=043.61 Obj2(530,142)C=341.13
Frame:  23  Object count: 1  Obj1(506,190)C=354.73
Frame:  24  Object count: 2  Obj1(150,010)C=022.94 Obj2(502,238)C=507.84
Frame:  25  Object count: 2  Obj1(134,038)C=049.58 Obj2(502,294)C=259.79
Frame:  26  Object count: 2  Obj1(110,074)C=123.52 Obj2(506,374)C=084.91
Frame:  27  Object count: 2  Obj1(098,110)C=187.86 Obj2(514,454)C=047.34
Frame:  28  Object count: 1  Obj1(070,146)C=335.72
Frame:  29  Object count: 1  Obj1(042,190)C=515.72
Frame:  30  Object count: 1  Obj1(014,242)C=723.48
Frame:  31  Object count: 1  Obj1(078,030)C=001.95
Frame:  32  Object count: 2  Obj1(066,054)C=005.04 Obj2(362,074)C=001.77
Frame:  33  Object count: 2  Obj1(058,086)C=005.89 Obj2(374,114)C=003.93
Frame:  34  Object count: 2  Obj1(046,126)C=013.40 Obj2(378,154)C=010.40
Frame:  35  Object count: 2  Obj1(034,162)C=027.50 Obj2(386,202)C=017.02
Frame:  36  Object count: 3  Obj1(022,210)C=036.02 Obj2(398,254)C=032.36 Obj3(414,07
Frame:  37  Object count: 3  Obj1(006,270)C=019.51 Obj2(414,326)C=082.77 Obj3(434,11
```

Processing DTrpi37

Figure 6 Screen dump from the visualisation of detection results. The top left image shows the raw polarisation data, with red circles drawn around detected mines. The frame below the image displays on each line the detection information per camera frame. For each detected mine the location and the confidence level is printed. The bar on the right shows the tracking of the detected mines.

4.2.1 Examples of detection results

The pictures in Figure 7 show both the visible light pictures of several mines and the visualisation of the detection result.

Figure 7 Examples of automatic detection results from buried mines. The images on the left show normal VIS pictures of the flush buried mines. The images on the right show the raw polarisation images with the visualisation of the detection results.

The results from the automatic detection in both the vegetation and a gravel background are very good. All AT mines, both surface laid, and flush buried, have been detected, and only a few AP mines were missed. Above that the number of false alarms is very low. No false alarms were encountered on the gravel road (even with a speed of 30 km/hr), and very few in the vegetation scenario. Since no ground truth is available for these tests it is not possible to determine ROC curves here.

5.0 CONCLUSION

It is demonstrated that the polarized light camera can be a valuable sensor for the discrimination of man-made objects like land mines from their surroundings, and thus will have an added value for the detection of certain types of IEDs. An operational concept for the use of the camera is the support of surveillance of the road side by military from an armored vehicle.

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REFERENCES

[1] B. Gros and C. Bruschini, “Sensor technologies for the detection of antipersonnel mines: a survey of current research and system developments," in *Proceedings of the International Symposium on Measurement and Control in Robotics (ISMCR'96)*, pp. 509-518, (Brussels, Belgium), May 1996.

[2] F. Cremer, K. Schutte, J. G. M. Schavemaker, and E. den Breejen, “A comparison of decision-level sensor-fusion methods for anti-personnel landmine detection," *Information Fusion* **2**, pp. 187-208, Sept. 2001.

[3] J. G. Schavemaker, E. den Breejen, K. W. Benoist, K. Schutte, P. Tettelaar, M. de Bijl, P. J. Fritz, L. H. Cohen, W. van der Mark, and R. J. Chignell, “LOTUS field demonstration of integrated multisensor mine detection system in Bosnia," in *Proc. SPIE Vol. 5089, Detection and Remediation Technologies for Mines and Minelike Targets VIII*, R. S. Harmon, J. T. Broach, and J. John H. Holloway, eds., pp. 1324-1335, (Bellingham (WA), USA), Sept. 2003.

[4] E. Hecht, *Optics*, Addison-Wesley Publishing Company, Inc., Reading (MA), USA, second ed., 1987.

[5] F. Cremer, W. de Jong, and K. Schutte, “Infrared polarisation measurements and modelling applied to surface laid anti-personnel landmines," *Optical Engineering* **41**, pp. 1021-1032, May 2002.

[6] F. Cremer, W. de Jong, K. Schutte, A. Yarovoy, V. Kovalenko, and R. Bloemenkamp, “Feature level fusion of polarimetric infrared and gpr data for landmine detection," in *International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, H. Sahli, A. Bottoms, and J. Cornelis, eds., pp. 638-642, (Brussels, Belgium), Sept. 2003.

[7] F. Cremer, *Polarimetric infrared and sensor fusion for the detection of landmines*. Ph.D. dissertation, Technische Universiteit Delft, Delft, Nov. 2003.

[8] W. de Jong, J. G. Schavemaker, M.G.J. Breuers, J. Baan and H.M.A. Schleijpen, “Development and implementation of a camera system for faster area reduction," in *Proc. SPIE Vol. 5415, Detection and Remediation Technologies for Mines and Minelike Targets IX*, R. S. Harmon, J. T. Broach, and J. H. Holloway, Jr., eds., pp. 208-218, (Bellingham (WA), USA), Sept. 2004.

[9] T. Rogne, S. Stewart, and M. Metzler, “Infrared polarimetry: what, why, how and the way ahead," in *Proc. of Third NATO IRIS Joint Symposium*, pp. 357-368, (Quebec, Canada), Oct. 1998.

[10] K. P. Bishop, H. D. McIntire, M. P. Fetrow, and L. McMackin, “Multi-spectral polarimeter imaging in the visible to near IR," in *Proc. SPIE Vol. 3699, Targets and Backgrounds: Characterization and Representation V*, W. R. Watkins, D. Clement, and W. R. Reynolds, eds., pp. 49-57, (Orlando (FL), USA), Apr. 1999.

[11] M. H. Smith, “Optimizing a dual-rotating-retarder Mueller matrix polarimeter," in *Proc. SPIE Vol. 4481, Polarization and Remote Sensing IV*, W. G. Egan and M. J. Duggin, eds., pp. 31-36, (San Diego (CA), USA), July 2001.

[12] F. A. Sadjadi and C. S. L. Chun, “Application of a passive polarimetric infrared sensor in improved detection and classification of targets," *International Journal of Infrared and Millimeter Waves* **19**(11), pp. 1541-1559, 1998.

[13] G. P. Nordin, J. T. Meier, P. C. Deguzman, and M. W. Jones, “Micropolarizer array for infrared imaging polarimetry," *J. Opt. Soc. Am. A* **16**, pp. 1168-1174, May 1999.

[14] A. Nedelcu, E.M. Costard and P.F. Bois, “Small pitch, full-TV format LWIR QWIP FPAs for polarimetric imaging,” in *Proc. SPIE Vol. 6542, Infrared Technology and Applications XXXIII,* B.F. Andresen, G.F. Fulop and P.R. Norton, eds., (Bellingham (WA), USA), To be published 2007.

[15] W. de Jong, “Polarised Camera System for Landmine Detection,” in *Guidebook on Detection Technologies and Systems for Humanitarian Demining*, Jack Glattbach (ed.), Geneva, Geneva International Centre for Humanitarian Demining, 2006, Chp.11.5, pp.180-183.

[16] J. G. M. Schavemaker, F. Cremer, K. Schutte, and E. den Breejen, “Infrared processing and sensor fusion for anti-personnel land-mine detection," in *Proceedings of IEEE Student Branch Eindhoven: Symposium Imaging*, pp. 61-71, (Eindhoven, the Netherlands), May 2000.

[17] W. de Jong, and J.G.M. Schavemaker, “Using Polarization Features of Visible Light for Automatic Landmine Detection” in *Physics of Automatic Target Recognition,* F. Sadjadi and B. Javidi, eds. Springer Science+Business Media, LLC, (New York (NY), USA), 2007.