Development and implementation of a camera system for faster area reduction

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ABSTRACT

This paper describes the development and implementation of a low cost camera system that uses polarisation features of visible light for faster area reduction. The camera system will be mounted on a mechanical minefield area reduction asset, namely an AT mine roller of The HALO Trust. The automatic detection system will give an audible alarm in order to stop the AT mine roller before the rollers detonate a mine.

Keywords: Mechanical Demining Equipment, Anomaly detection, EO polarisation, imaging sensor, features, processing, real time

1. INTRODUCTION

In mine clearance operations reduction of the suspected area, before close-in detection is started, is very important. A recent study that has been performed by the Geneva International Centre for Humanitarian Demining (GICHD),[1] identified 12 tasks, activities and procedures (referred to as capabilities) that provide opportunities for improved equipment and information management systems. Determination of the outer edge of mined areas is one of the capabilities where very significant benefits are expected from improvements by investment in new and improved equipment, in processes or procedures.

Area reduction is the process through which the initial area indicated as contaminated (during a general survey) is reduced to a smaller area. Area reduction consists mainly of collecting more reliable information on the extent of the hazardous area. Area reduction is sometimes done as part of the clearance operation.

Mechanical methods to reduce the area for mine clearance are among others rollers and flails. Since better and faster area reduction methods are needed, several (research) projects are running that exploit airborne techniques. Examples are the Mineseeker, ARC and SMART projects. The last two are EU sponsored projects. Sometimes dogs are used to determine the boundaries of a minefield.

This paper describes the development of a camera system that will be used on a mechanical area reduction system. Section 2 describes the current procedure of The HALO Trust for the reduction of areas that are contaminated with only AP mines. In section 3 the new Anti Tank mine roller unit is described that has been developed by The HALO Trust for areas with AT mines. Section 4 discusses the development of a camera system and the detection algorithms that will be used with the new AT mine roller unit to increase the speed of the area reduction process. In section 5 the results of static tests are presented.

2. THE HALO TRUST AREA REDUCTION PROCEDURE

Front-end loaders are built in numerous forms by a multitude of companies worldwide. A feature common to most of them is that they are robust and can be put to work to perform a variety of tasks. They are simple to

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Figure 1. A Pearson Roller attached to a CASE front-end loader.

operate and maintain. Unlike most purpose-built mine action machinery, commercial vehicles are versatile and can perform tasks beyond mine action alone. After the close of a working day in the minefield, a front-end loader for example can be set to work for the local community building or improving roads, digging water ditches for drinking and agriculture, or digging sanitation trenches.

The HALO Trust uses so called Pearson rollers,[2] mounted on an armoured commercial front-end loader to rapidly reduce areas adjacent to locations where anti personnel landmines are suspected.

Rollers typically consist of segmented, weighted plates, each turning separately on a central axle. With the Pearson roller (see figure 1) for example, each individually floating disc exerts a ground pressure of 50 kg. The weight of the roller is designed to activate sub surface AP mines. As the attached vehicle moves forward, the roller contacts the ground. The roller follows uneven ground, bumps and rises with each independently rolling wheel. The roller is capable of withstanding multiple AP mine blasts. It is not designed to withstand AT mine blasts.

The HALO Trust has approximately ten rollers in service between Abkhazia, Mozambique, Somaliland, Georgia, Kosovo, Cambodia and Afghanistan. They have been using the rollers since 1998. The rollers are not used as a specific clearance device, but in an area reduction and verification role. The rollers are used in minefields where the definition of mine location and patterns is not clear. By using the rollers in set patterns as visualised in figure 2, large areas of ground are verified for the presence and location of mines by their deliberate detonation. Once the presence of mines has been verified, direct clearance assets can be brought to bear in the smaller area where mines are actually laid. This inevitably speeds up clearance rates by enabling fast deployment of manual or further mechanical methods directly onto mined areas.

3. THE HALO TRUST ANTI TANK MINE ROLLER UNIT

Since the AP mine rollers have proven to be successful within humanitarian mine clearance, The HALO Trust has been developing an AT mine roller system. Military AT mine rollers that are mounted in front of a main battle tank do exist, but have not yet been used in the scenarios as described above. The HALO Trust has developed an AT mine roller unit to be mounted on a front-end loader like the AP mine roller, see figure 3.

The roller system is designed to detonate anti-tank mines, but each detonation of an AT mine will incur a down time for repair of the rollers, since some damage is expected on an AT mine detonation. To build a fully survivable system is not feasible.

First tests have been performed with the AT mine roller in Somaliland, Africa.

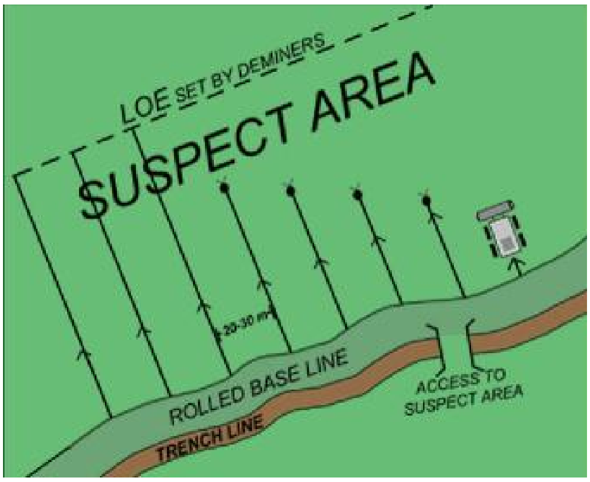


Figure 2. Rolling in perpendicular lines from a baseline out to a pre-determined limit of exploitation (LOE) in an area where AP mines are suspected. Once the roller has established the presence of AP mines, and the approximate pattern of AP mines, (manual) clearance assets are deployed.

Figure 3. Anti-Tank Mine Roller unit as developed by and constructed for The HALO Trust.

4. CAMERA SYSTEM DEVELOPMENT

Research performed by TNO-FEL has shown that using polarization features of light (both infrared and visual light) improves the detection capabilities of a camera system for landmine detection.[3] In order to minimize the amount of physical AT mine detonations for the AT mine roller of HALO trust, a camera system is developed that uses polarization properties of visual light to reach a high-detection rate of AT mines, combined with a low false-alarm rate. The camera system is fitted to the roof of the vehicle and is forward looking. The goal is to detect as many surface-laid AT mines as possible and to stop the vehicle before the roller detonates the mine.

The development project consists of six phases. In the first phase preliminary information was gathered, that resulted in a scenario description and a first set of requirements as given in Section 4.1. Currently, the project is at the end of the second phase where concepts have been developed and test models were acquired. The current status of concept development is described in Section 4.2. Tests with a static set up have been performed in the summer of 2003. The results of these tests are reported in Section 5. The feasibility of the concepts is studied and a full set of requirements is being formulated. At the end of the second phase a proposal for further development will be written. In the third phase, a demonstrator of the camera system for landmine detection will be built. Field tests of the system will be performed in 2004 with a moving vehicle at a Royal Netherlands Army test site in The Netherlands. This phase concludes with a description of a raw prototype of the camera system. In the engineering phase, tests will be performed in one of the areas where the HALO Trust is active with their AT mine roller. In the prototype phase a final prototype is developed, and in the sixth phase, production of the camera system is foreseen.

4.1. User requirements

According to the HALO Trust, the camera system should meet the following criteria to be able to work successfully:

1. The equipment should be simple to install on to the vehicle. Mounting of the camera and the processing unit will be done in the country of operation. Main components should be pre-assembled prior to shipping to allow a simple plug-together assembly, and should be accompanied with a set of clear and concise fitting instructions.
2. Operation of the camera should be as simple as is possible. It will be operated by non-technical personnel. If the system is too difficult for the operator to use and understand, then it is likely that he will not use it. Simple operation must also include a simple to understand readout, be it visual or audio.
3. Maintenance of the system should be possible within its country of operation. The easiest way to achieve this is to have the system built with changeable components. This would make repair simpler and also allow the return/exchange of light weight parts which could be air freighted back for repair. HALO has trained radio and detector technicians in all countries of operation.
4. The unit must be robust and able to withstand temperatures of 45 degrees centigrade. Also external components will need to be dust and water resistant.
5. Signal processing is required in real time. A delay of not more than one second for the processing of the signal should be allowed. The camera will be mounted on a moving platform operating at a speed of around 3-4 m/sec, over rough terrain. The area of ground viewed will be approximately 9-10 m from the camera lens, covering a width of around 4 m.
6. The number of false alarms by the system should be very low. For each 100 m in the forward direction a maximum of 3 false alarms is allowed.

4.2. Camera system concepts

In order to meet the above-mentioned requirements a visual-light camera system is foreseen. A forward looking camera system mounted on top of the mine area reduction vehicle can warn the driver of the vehicle that an (AT) mine is in front of the vehicle. At that point, the driver can decide to stop the vehicle and investigate the situation. The acceptance of such a system depends on the detection and false-alarm rate of the system. The HALO trust has stated that a very low false-alarm rate combined with a moderate detection rate would be a valuable system. The following list presents some possible camera system concepts and the assumptions they have on the camera image modality:

Monochrome, visual-light camera : Landmines have intensity values that are different from local surroundings.

Color, visual-light camera : Landmines have distinctive colors or have a color contrast with the background.

Monochrome, visual-light camera with polarization : Landmines have a smooth (artificial) surface and / or have intensity values that are different from local surroundings.

Color, visual light camera with polarization : Landmines have a smooth (artificial) surface and / or have distinctive colors or have a color contrast with the background.

The above-mentioned camera concepts of a visual-light camera with or without polarization have different mine-detection capabilities. Besides the conventional way of detecting mines using image intensity[4] and 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] 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. For example, position of the sun (both azimuth and elevation), viewing angle with respect to the sun position, and weather conditions (daylight, clouds) have impact on the use of polarization. The static tests that have been conducted have given some insights into the application of polarization and its effect on the system characteristics.

Contrary to the IR polarization setup that has been developed by TNO-FEL,[3] the visual-light camera of the system is intended to have no moving parts; but fixed polarizers. An optical prism assembly, mounted behind the camera lens, will 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 orientation is mounted. Using this configuration the polarization state (expressed in the Stokes components I, Q and U) of each pixel in the image can be measured in one snap shot, which is important when the camera is mounted on a moving vehicle over rough terrain.

For the static tests in Section 5, however, a different polarization setup is used because the visual-light camera with fixed polarizers was not available at the time of the tests. For these tests the original polarization setup with one visual-light camera and a rotating polarizer in front of the lens is used. This setup is comparable to the one that has been developed by TNO-FEL for IR polarization measurements.[3]

4.3. Mine-detection concepts

The above-mentioned camera concept of a visual-light camera with fixed polarizers opens the way to extended mine-detection capabilities based on cameras. The proposed mine-detection concept combines features and cues from different image-processing techniques:

Color and intensity analysis : Detection is based on object color or intensity contrast with the surrounding background. The contrast threshold is defined by local image statistics (mean and standard deviation) of the image.

Edge detection and grouping : Straight or (partly) circular edges are extracted because they can indicate artificial objects. The subsequent grouping step groups edges into hypothetical artificial objects.

Polarization analysis : Objects are detected based on their polarization contrast with the surrounding background.

Each image-processing technique results in a set of possible object detections with computed color, edge or polarization features for which additional features (e.g. morphological) can be calculated. The resulting set of objects is put into a pattern-recognition classifier that makes the final mine detection based on all computed features and previously learned examples. In order to ensure robustness of this classifier it is important that the image-processing techniques deliver *invariant* features. Scale invariance[6] can be found with proper camera calibration, and color invariance[7] is obtained by choosing the right (normalized) color space. Furthermore, invariant morphological features exist, but invariant polarization features are still a research issue.

4.4. Mine-detection implementation

For the static tests of Section 5 we have made a first partial implementation of the mine-detection concepts as described in the previous sections. Not all of the concepts showed the expected performance. For example, when detecting mines by color features, color proved not to be a very discriminative feature because most of the surrounding background clutter has similar colors. Besides color features we have looked at edge detection and grouping and using morphological features based on a modified Hough transformation on intensity and polarization.[8] It proved to work reasonably well, but only on a subset of the mines. However, it requires camera calibration and is computational expensive, which limits a real-time implementation.

Hence we have implemented the intensity and polarization features, and a blob analysis on size as final implementation for the static tests.

4.4.1. Intensity contrast

The assumption that landmines have intensity values that are different from local surroundings can be exploited with intensity contrast. As mines can be brighter or darker than the background, the intensity contrast can be a so-called positive or negative contrast with the background. The normalized positive intensity contrast image is defined as:

$$I_{pos}(x) = \frac{I(x) - min(I)}{max(I) - min(I)} \tag{1}$$

The normalized negative intensity contrast image is defined as:

$$I_{neg}(x) = 1 - \frac{I(x) - min(I)}{max(I) - min(I)} \tag{2}$$

On both contrast images a threshold is applied to obtain an image with binary values indicating the detection of landmines. The applied threshold is a parameter of the detection method, and its choice of value depends on the scenario of application and required performance. The positive and negative contrast detections are defined as:

$$D_{I_{pos}}(x) = \{I_{pos}(x)\}_t, D_{I_{neg}}(x) = \{I_{neg}(x)\}_t \tag{3}$$

where $\{f(x)\}_t$ is the threshold operator.

4.4.2. Polarization contrast

Landmines that have a smooth (artificial) surface can be detected by polarization. The amount of linear polarization is in the implementation for the static tests taken as the polarization feature. The amount of linear polarization is defined as:

$$LP = \sqrt{Q^2 + U^2} \tag{4}$$

With Q and U the Stokes components that are determined for each pixel. The normalized polarization contrast image is defined as:

$$LP(x) = \frac{LP(x) - min(LP)}{max(LP) - min(LP)} \tag{5}$$

The polarization detections are defined as:

$$D_{LP}(x) = \{LP(x)\}_t \tag{6}$$

4.4.3. Combination of intensity and polarization contrast

For the implementation for the static tests, we have combined the intensity and polarization contrast detection in the following way:

$$F(x) = \{I_{pos}(x)\}_{t_1} \vee \{I_{neg}(x) \cdot LP(x)\}_{t_2} \tag{7}$$

The blobs in the resulting binary image $F(x)$ are extracted by means of a connected-component algorithm. Blobs with a size smaller than threshold t_3 are removed from image $F(x)$. As such, the complete detection procedure has three parameters: thresholds t_1, t_2, and t_3.

5. RESULTS OF 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, see Figure 4 for examples, that all four had the same lay-out. Table 1 shows the lay-out of the measurement areas. 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.

Figure 4. Two examples of the four measurement areas (facing north, south, east, and west). The example on the left is the west measurement area that has grass as background. The other three measurement areas have debris as background clutter as shown in the example on the right.

	column 1	column 2	column 3
row 1	PRBM-3	TM62P-3	PRBM-3
row 2	TM62P-3	P2	TM62P-3
row 3	P2	PRBM-3	P2
row 4	false alarm	false alarm	false alarm
row 5	PMN	false alarm	PMN
row 6	false alarm	PMN	false alarm

Table 1. Lay-out of all four measurement areas. The objects are placed on a 1 m grid. The six special false alarms mentioned in this table have sizes and/or colors that are comparable to the mines that are used.

5.1. 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 t_1, t_2, and t_3. 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 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 in front of the vehicle. Each measurement area consists of six horizontal lines that are 3 m wide and 1 m deep.

5.2. Measurement setup

The measurement setup consisted of a VIS camera system, with a frame rate of 25 Hz. The images of the VIS are grabbed from the analog video output of the camera. Two different VIS cameras have been used alternately, a 3CCD Hitachi color camera and a B/W Sony camera. A rotating polarization filter (polaroid sheet) has been mounted in front of the camera lens (Zoom lens 12.5-75mm). The filter was rotating at a constant speed. A trigger pulse from the rotation setup started the acquisition of the frame grabber in the computer. Since the camera is running at a fixed frame rate, the time between the frames and thus the rotation of the polarization filter between the different frames is fixed. A complete sequence consists of 56 images for the VIS. The sequences contain at least one full rotation of the filter, which had a rotation time of just over 2 seconds.

The measured intensity I_p as a function of the angle φ, where φ is the angle between the principal axis of

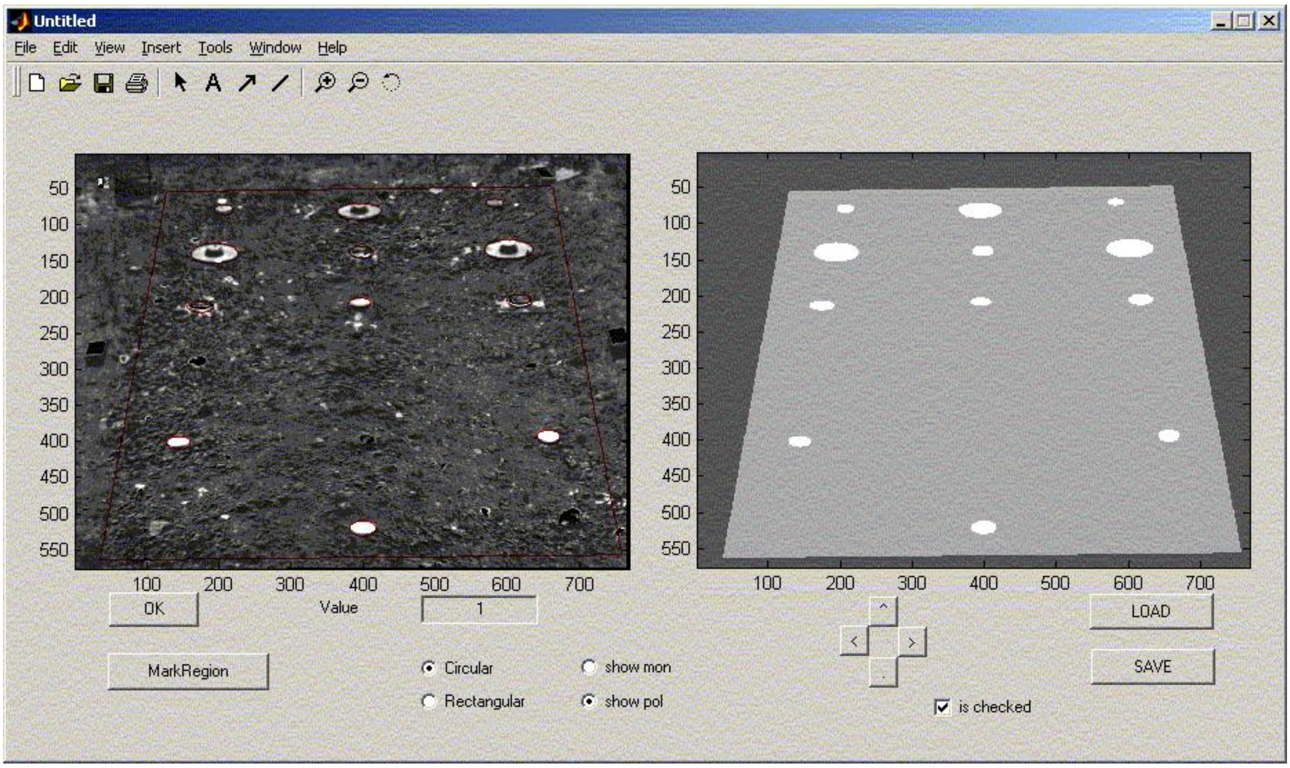


Figure 5. Performance evaluation tool to make ground truth of measurement areas. The left panel shows the calculated LP image (eq. 4). The light-grey area, which is roughly 3 m wide and 6 m deep, in the right panel is used in the detection step. The white circles give the ground truth.

the polarization filter and the horizon, is given by:

$$I_p(\varphi) = I + Q\cos(2\varphi) + U\sin(2\varphi), \tag{8}$$

where $\varphi = 0$ represents the situation that all horizontal polarized light waves pass the linear polarizer. If the intensity is measured for half a period (or $k\pi, k \in \{1, 2, \ldots\}$), then the Stokes-Müller polarization parameters $\tilde{I}$, $\tilde{Q}$ and $\tilde{U}$ are estimated by:

$$\begin{aligned} \tilde{I} &= \frac{1}{N}\sum_{i=1}^{N} I_p(\varphi_i) \\ \tilde{Q} &= \frac{2}{N}\sum_{i=1}^{N} I_p(\varphi_i)\cos(2\varphi_i) \\ \tilde{U} &= \frac{2}{N}\sum_{i=1}^{N} I_p(\varphi_i)\sin(2\varphi_i), \end{aligned} \tag{9}$$

with N the number of frames, i the frame number and $\varphi_i = \frac{ik\pi}{N}$ the angle of the linear polarizer.

In the experiments of the static tests, the $\tilde{I}$ is used as an estimate of the intensity. The $\tilde{Q}$, and $\tilde{U}$ are used to compute the amount of linear polarization

5.3. Data set 2003-08-07

In this section we look at the detection results for data set 2003-08-07 using only intensity or polarization features. From Figures 6(a), 6(b), and 6(c) we may conclude that polarization is the most important feature for

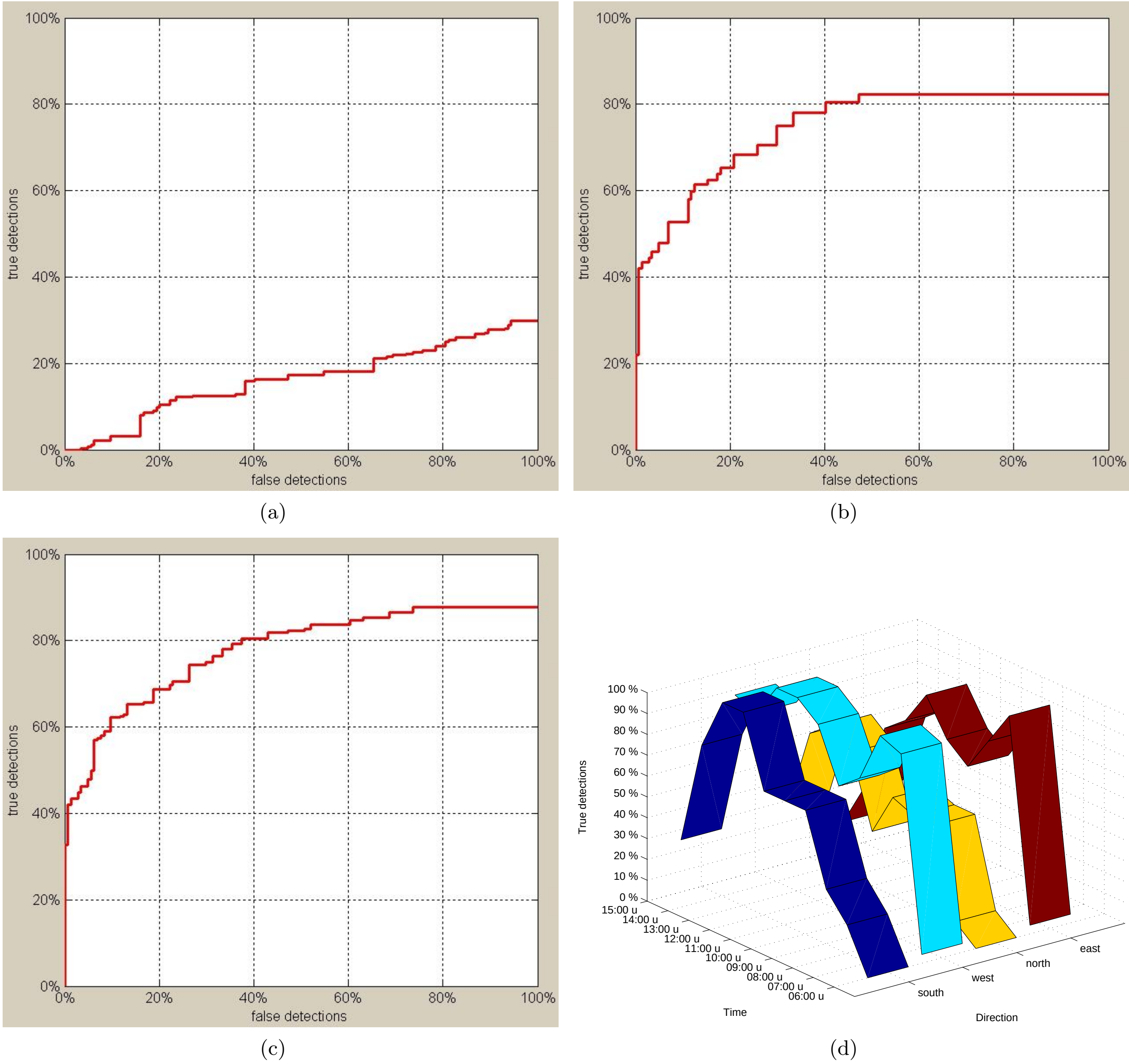
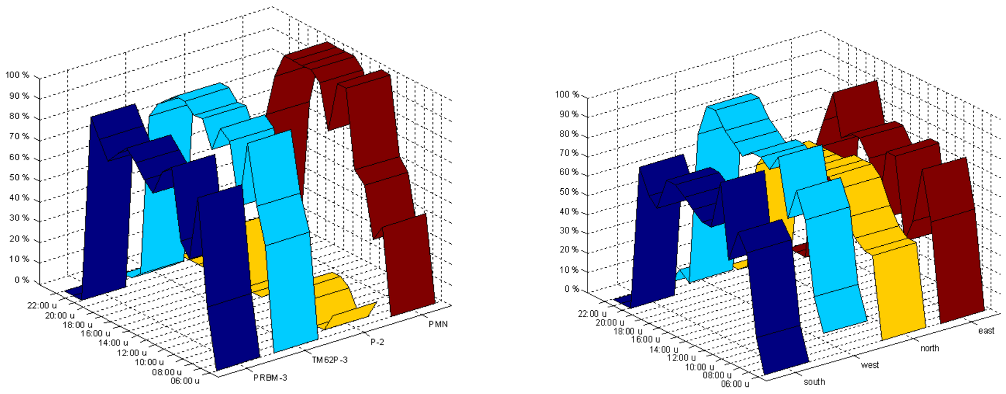


Figure 6. Results for data set 2003-08-07 (a) ROC using only the intensity contrast of the mines. (b) ROC using only the polarization contrast of the mines. (c) ROC using a combination of intensity and polarization. (d) Detection rate against time (from 6:00hr till 15:00hr) and viewing direction (at 3% false alarms).



(a) (b)

Figure 7. Results for data set 2003-08-13 (a) Detection rate against time (from 6:00hr till 22:00hr) and mine type (at 3% false alarms). (b) Detection rate against time (from 6:00hr till 22:00hr) and direction (at 3% false alarms).

detection. Although detection based on intensity only has very low performance, the combination of polarization and intensity features results in a better ROC (Figure 6(c)).

Figure 6(d) shows the detection results for data set 2003-08-07 when the detection rate is plotted against the viewing direction of the camera and the local time. The system false-alarm rate is set in this case to 3%. The west direction shows to be the best viewing direction for this data set. This stems from the fact that this measurement has only grass, see figure 4, and not debris as background clutter, resulting in less false alarms, or more detections at a fixed false alarm rate, as is the case in this figure. Time is also of influence and shows large variations, which may be partly due to weather conditions, shadows, and a fixed camera iris.

5.4. Data set 2003-08-13

In this section we look at the detection results for data set 2003-08-13 per direction, per mine type, and per time of day.

Figure 7(a) shows the detection results when the detection rate is plotted against the mine type and the local time, Figure 7(b) shows the detection results when the detection rate is plotted against the viewing direction of the camera and the local time. For both figures the system false-alarm rate is set to 3%. The performance decreases drastically before sunrise (6:00hr) and after sunset (22:00).

From Figure 7, we may conclude that the west direction is the best viewing direction for this data set, as it was for the data set 2003-08-07. Furthermore, detection results per mine type do not differ much with the exception of the P2 mine for which there is a very low performance. This can be explained by the fact that the P2 mine has no flat top surface as the other mines have, and, as such, can not be detected very well by polarization.

6. CONCLUSIONS

In this paper we described the development of a camera system for detection of AT mines. This system uses polarization features of visible light and will be used to increase the speed of area reduction with AT mine rollers. This camera system could also be used in other scenarios, for example road side inspection for mines and unexploded ordnance. Before reaching any conclusions on camera systems and landmine detection methods there are some important caveats to identify beforehand:

- The performance of a landmine detection system based on a camera system heavily depends on the scenario and surroundings in which the system is applied. For example, a landmine detection system that performs well in a Western-European country may fail when applied in an African area near to the equator, even with extensive calibration of the system.

- The only sensible way to evaluate the robustness and performance of a landmine detection system is to test the system under a wide range of circumstances and application areas. Therefore, the conducted experiments in this report provide insufficient base to draw general conclusions, they only give an indication of expected performance.

Notwithstanding above statements we can draw the following conclusions given the results of the conducted experiments:

- Combination of intensity and polarization contrast gives the best performance of the system.
- The performance depends on the viewing direction: the west direction seems to be the best viewing direction for some of the data sets.
- The performance depends on the time of day and shows large variations, which may be partly due to weather conditions, shadows and a fixed camera iris.
- The performance depends on the type of mine: detection results do not differ much with the exception of the P2 mine for which there is a very low performance. This can be explained by the fact that the P2 mine has no flat top surface, and as such, can not be detected very well by polarization.
- The use of color information provides in this case no significant extra information. Most of the used landmines have similar color statistics as the background, which makes color not a discriminative feature. However, when the scenario of application is different (for example, deployment of the system in a sandy environment), color may benefit to the performance of the system.

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