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Development and construction of a camera system for landmine detection

Final Report

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Ontwikkeling en vervaardiging van een camera systeem voor landmijn detectie

Eindrapport

Probleemstelling

Het project "Ontwikkeling en vervaardiging camerasysteem voor mijndetectie" heeft als doelstelling de ontwikkeling van een camerasysteem dat als tool gebruikt kan worden bij 'mechanical mine clearance' en 'area reduction'. De opdrachtgever voor dit project is het Ministerie van Defensie, waarbij Defensie Research & Development verantwoordelijk is voor de projectbegeleiding. The HALO Trust, een NGO die gespecialiseerd is in humanitair mijnenruimen, is als mogelijke eindgebruiker nauw bij de uitvoering van de eerste twee fasen van het project betrokken geweest. Het opsporen en onschadelijk maken van landmijnen die achterblijven na een conflict, het zogenaamd humanitair ontmijnen, is tijdrovend. Om een gebied sneller te kunnen ontmijnen heeft The HALO Trust voor het deelproces van area reduction een shovel ontwikkeld die voorzien is van minerollers. Na een detonatie van een antitankmijn (AT-mijn) onder de roller is de roller vaak zozeer beschadigd dat hij gerepareerd moet worden, wat relatief veel tijd en geld kost.

Een automatisch detectiesysteem op deze shovel, dat de chauffeur vroegtijdig waarschuwt voor AT-mijnen, kan detonaties onder de roller voorkomen en daarmee tijdwinst geven. De kwaliteit van de area reduction wordt niet minder als dit detectiesysteem een mijn niet detecteert, omdat de roller deze mijn dan alsnog laat ontploffen. Een dergelijk automatisch detectiesysteem kan gerealiseerd worden door middel van een camerasysteem dat gebruik maakt van de polarisatie-eigenschappen van licht.

Beschrijving van de werkzaamheden

TNO Defensie en Veiligheid heeft voor bovengenoemd doel een demonstrator-polarisatiecamerasysteem ontwikkeld. Het ontwikkeltraject van dit demonstrator-camerasysteem bestaat uit drie fasen die zijn uitgevoerd in het project waarvan dit rapport de eindrapportage is.
Fase 1, de 'inventarisatiefase' heeft geresulteerd in een scenariobeschrijving en een beperkt programma van eisen. In fase 2, de 'haalbaarheidsfase' is de haalbaarheid van verschillende concepten onderzocht en is een keuze gemaakt voor een definitief concept. De resultaten van de eerste twee fasen van het project zijn uitvoerig beschreven in een tussenrapportage (FEL-04-B152; juli 2004).
Van het definitieve concept waarvoor in fase 2 is gekozen, is in fase 3 een demonstratiesysteem gebouwd. Dit demonstratiesysteem bestaat uit een polarisatiecamera die speciaal voor dit doel is ontwikkeld en vervaardigd. Daarnaast is software ontwikkeld voor de automatische detectie van landmijnen en de visualisatie van de detectieresultaten.

Om de werking van het systeem te demonstreren is het systeem op een shovel van de Genie gemonteerd. Op een testterrein van het OTCGenie zijn twee demonstraties gegeven. De demonstraties hebben plaatsgevonden op een zandweg die deels begroeid was en op een graspad. Tijdens deze demonstraties zijn met het demonstratiesysteem opnamen gemaakt van landmijnen die niet begraven zijn. Na afloop van de demonstratie zijn de opgenomen beelden door de ontwikkelde software geanalyseerd en heeft automatische detectie van de landmijnen plaatsgevonden. De gedetecteerde mijnen zijn gemarkeerd in de originele opgenomen beelden.

Resultaten en conclusies

Aan het eind van het project zijn de volgende resultaten bereikt:

1. Er is een polarisatiecamera gebouwd zonder bewegende delen. Deze is daardoor robuust en geschikt voor montage op een bewegend platform.
2. Er is software ontwikkeld waarmee automatisch landmijnen gedetecteerd zijn in de beelden van de

polarisatiecamera. De detectieresultaten zijn gevisualiseerd.

3. Met het demonstratiesysteem, gemonteerd op een bewegend platform van de Koninklijke Landmacht, zijn twee demonstraties gegeven waarbij landmijnen en andere objecten op de weg en in de wegberm zijn gedetecteerd.

Toepasbaarheid

De unieke polarisatiecamera die is vervaardigd, is toepasbaar in landmijndetectiescenario's, maar ook in andere detectiescenario's zoals 'bermdetectie' tijdens het 'prooven' van routes of het opsporen van Improvised Explosive Devices. Het proces van 'prooven' wordt momenteel met behulp van veldkijkers uitgevoerd door de pantsergenie. In plaats daarvan kunnen één of meerdere camerasystemen op een pantservoertuig of op een onbemand voertuig gemonteerd worden. De camerabeelden kunnen worden gebruikt voor automatische detectie, maar ook als hulpmiddel voor een menselijke waarnemer. Voor de toekomst kan deze polarisatiecamera met name in de actieve zoekfase van het 'Search'-concept een belangrijke aanvullende rol spelen. Mogelijke toepassingen die niet gerelateerd zijn aan landmijndetectie, zijn de detectie van gecamoufleerde voertuigen, of de onderdrukking van reflecties van autoruiten waardoor gemakkelijker in een auto kan worden gekeken.

PROGRAMMA	**PROJECT**
Programmabegeleider -	Projectbegeleider Lkol A.F. Keijzer, DMO/DR&D
Programmaleider -	Projectleider Dr. ir. W. de Jong, TNO
Programmatitel -	Projecttitel Ontwikkeling en vervaardiging camerasysteem voor mijndetectie
Programmanummer -	Projectnummer 015.31831
Programmaplanning -	Projectplanning Start 01-07-2002 Gereed 31-10-2005
Frequentie van overleg Met de projectbegeleider werd 8 maal gesproken over de invulling en de voortgang van het onderzoek.	Projectteam Dr. ir. W. de Jong Dr. J.G.M. Schavemaker Ir. M.G.J. Breuers Ir. J. Baan Dr. ir. J. Dijk Ir. R.A.W. Kemp Ing. R. de Rooy P.J. Fritz

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Development and construction of a camera system for landmine detection

Final Report

Problem definition

The project "Development and construction of a camera system for land mine detection" aims at the development of a camera system to aid in mechanical mine clearance and mine area reduction. The sponsor of this project is the Dutch Ministry of Defence. Defence Research & Development is responsible for project supervision. The HALO Trust is an NGO that specialises in humanitarian demining. As a possible end-user they are closely involved in the execution of the first two phases of the project.
Humanitarian demining, the detection and removal of land mines when a conflict has ended, is extremely time consuming. The HALO Trust has developed an AT mine roller system in order to demine an area faster. This roller system, which is mounted on a wheel loader, is used for area reduction. A detonation of an AT mine will cause damage on the rollers. Repairing a damaged roller costs time and money. An automatic detection system on the wheel loader, that gives an early warning to the driver, can avoid detonations and gains time. Such an automatic detection system can be realised with a camera system that utilises the polarisation properties of light. The quality of the area reduction remains the same, even when the detection system misses a mine. In this case the roller will detonate the mine as it will do without a detection system.

Description of activities

TNO Defence, Security and Safety has developed a polarisation camera for the above mentioned purpose. The development process of this camera system was split in three phases. This report is the final report of the project.
Phase 1, the inventory phase, has resulted in a scenario description and a first set of requirements. In phase 2, the feasibility phase, the feasibility of different concepts has been studied. The results of these first two phases are extensively reported in an interim report (FEL-04-B152; july 2004).
In phase 3 a demonstrator system has been built of the most promising concept of phase 2. This demonstrator system consists of a polarisation camera that has been developed and constructed for this purpose. In addition to this camera, software has been developed for automatic detection of land mines and the visualisation of the results.

To demonstrate the capabilities of the polarisation camera system it has been mounted on a wheel loader of the Corps of Engineers. Two field demonstrations have been given at the Engineer Training Centre. These demonstrations took place on a sand road partly covered with vegetation and on a grass road. During the demonstrations, recordings have been made of surface-laid landmines. The mines were detected automatically in off-line processing of these recordings. The detection results have been visualised in the recorded images.

Results and conclusions

The following project results have been accomplished:

1. A polarisation camera, without any moving parts, has been constructed. This camera is robust and can be mounted on a moving platform. The camera is a unique polarisation measurement system.
2. Detection software has been developed. With this software, landmines can be detected automatically in images that are recorded with the polarisation camera. The detection results can be visualised in the recorded images.
3. Two field demonstrations have been given with the camera system mounted on a wheel loader of the Corps of Engineers of the RNlA. At these demonstrations, recordings have been made of surface laid mines. Enhanced polarisation contrast has been shown in real time. Mines have been detected automatically in off-line processing.

Applicability

The constructed polarisation camera is applicable in landmine detection scenarios, but also in other detection scenarios. For example road proving, road-side inspection and detection of improvised explosive devices can also benefit from the possibilities of a polarisation camera. At the moment road-side inspection is done with only binoculars. As a better alternative, one or more polarisation cameras can be placed on an armoured manned or unmanned vehicle. The polarisation images can be used for automatic detection, but also as an image enhancement tool for the human observer. In the future, this polarisation camera can be an important additional technique in the active search phase of the 'Search' concept. Applications not related to landmine detection are the detection of camouflaged vehicles or the suppression of reflections from car windows in order to look inside the cars.

Programme	**PROJECT**
Programme supervisor -	Project supervisor Ltcol A.F. Keijzer, DMO/DR&D
Programme manager -	Project manager Dr W. de Jong, TNO
Programme title -	Project title Development and construction of a camera system for landmine detection
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Frequency of consultation The interpretation and the progress of the research have been discussed with the project supervisor 8 times.	Project team Dr W. de Jong Dr J.G.M. Schavemaker M.G.J. Breuers, M Sc J. Baan, M Sc Dr J. Dijk R.A.W. Kemp, M Sc R. de Rooy, B Sc P.J. Fritz

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Abbreviations

AP	Anti-personnel
AR	Area reduction
AT	Anti-tank
CCD	Charge-coupled device
EU	European Union
HALO	The HALO Trust
RNlA	Royal Netherlands Army
TNO	Netherlands Organisation for Applied Scientific Research

1 Introduction

In mine-clearance operations, it is very important to reduce the suspected area, before close-in detection is started. Area Reduction (AR) is the process through which the initial area indicated as contaminated (during a general survey) is reduced to a smaller area. AR consists mainly of collecting more reliable information of the extent of the hazardous area and it is sometimes done as part of the clearance operation.

Mechanical methods to reduce the area for mine clearance include rollers and flails. Since better and faster area reduction methods are needed, several research projects investigate the use of airborne techniques; for example, Mineseeker, ARC and SMART projects (last two are EU-sponsored projects). Dogs are sometimes used to find explosives (mines) in order to determine the boundaries of a minefield.

The HALO Trust (HALO) is an NGO that specialises in humanitarian demining. HALO has developed an AT mine roller system in order to demine an area faster. This roller system, which is mounted on a wheel loader, is used for area reduction. A detonation of an AT mine will cause damage on the rollers. Repairing a damaged roller costs time and money. An automatic detection system on the wheel loader, that gives an early warning to the driver, can avoid detonations and gains time. Such an automatic detection system can be realised with a camera system that utilises the polarisation properties of light. The quality of the area reduction remains the same, even when the detection system misses a mine. In this case the roller will detonate the mine as it will do without a detection system.

1.1 The project "Development and construction of a camera system for land mine detection"

The project "Development and construction of a camera system for land mine detection" aimed at the development of a camera system to aid in mechanical mine clearance and mine area reduction.
The development and construction of a demonstrator version of such a system has been split in the following three phases that are covered in the current project:

1. In the first phase preliminary information was gathered that resulted in a scenario description, a first set of requirements, and a test plan for the tests in the second phase.
2. In the second phase concepts were developed and test models were acquired. Tests with a static set up were performed in the summer of 2003. The feasibility of the concepts has been studied.
3. In the third phase, a demonstrator of the camera system for landmine detection has been built. Field demonstrations of the system have been performed with a moving vehicle at a Royal Netherlands Army test site in The Netherlands.

An interim project report [1] that covers the phases 1 and 2 has been published in July 2004. This report describes an investigation of the use of camera systems to aid in mechanical mine clearance and mine area reduction. The investigation covers different image recording and image processing techniques for landmine detection. The techniques studied are the processing of monochrome and colour visible-light images and the use of polarisation with these modalities. The investigation is directed towards the deployment of a camera system that will be used on a mechanical area-reduction system. This interim project report also describes the procedure of HALO for the reduction of areas that are contaminated with only AP mines. As a possible end-user HALO was closely involved in the execution of the first two phases of the project.

This report describes the results of phase 3 of the project. A demonstrator of the camera system for landmine detection has been built. This demonstrator is described in chapter 2. Demonstrations of the system have been performed in June and October 2005 with a moving vehicle at a Royal Netherlands Army (RNlA) test site in The Netherlands. These demonstrations and the results are described in chapter 3.

2 Polarisation camera demonstrator

The polarisation camera demonstrator consists of hardware and software components that are described in this chapter.

2.1 Demonstrator hardware

2.1.1 *Polarisation camera*

Based on the results of the feasibility tests [1] and the Raw Set of Requirements (see Appendix B of reference [1]) the choice was made to use a camera system without moving parts.
To construct such a polarisation camera without moving parts, an existing 3CCD camera has been modified. The existing beam splitting prisms of this camera have been replaced by prisms with special polarisation splitting coatings. These coatings have been designed and realised by TNO Industry and Technology Delft.
With this prism configuration and the attached linear polarisers the first three elements of the Stokes vector (see paragraph 2.2.2 in [1]) can be measured, which means that the linear polarisation state of the incoming light can be determined.

Figure 2.1 Realised prism assembly (left) and the polarisation camera (right).

2.1.2 *Computer system*

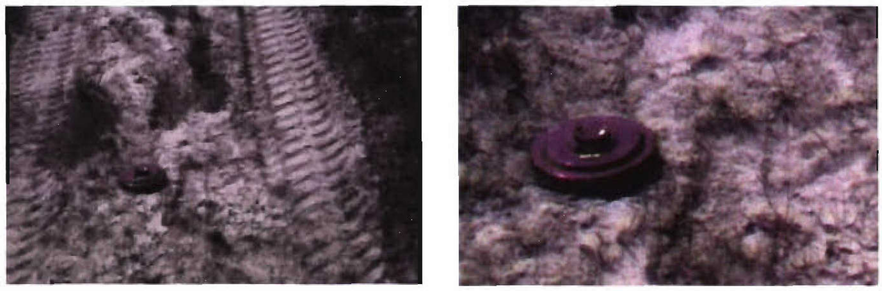
In the demonstrator system several PC's have been used. For camera control (gain and integration time setting) and to store the acquired images a very compact Matrox 4Sight industrial imaging computer has been chosen. In the demonstration this computer is placed close to the camera.
For real time data viewing and data acquisition control a second PC is used. The communication between this PC and the first PC is via a TCP/IP Ethernet wireless link.
For the off-line detection processing on the recorded data any PC platform can be used.

2.2 Demonstrator software

Several software components have been developed for the polarisation camera demonstration.

2.2.1 *Data acquisition software*

This software is running on the computer attached to the camera and on the control PC. With this program the acquisition of polarised images can be started and stopped. Figure 2.2 shows an example of a raw, unprocessed image of a TM62 metal AT mine on a sandy road. In the raw images polarisation contrast appears as colour, while unpolarised parts of the image have a grey value without colour. In this figure the mine has got a purple colour.



(a) (b)

Figure 2.2 Example of raw data image. The image on the right shows the metal AT mine in more detail.

2.2.2 *Visualisation software*

When the polarisation contrast is very high, the colour effect is clearly visible in the raw data that is acquired by the camera. The polarisation contrast of the mines is not always that high. Although a significant polarisation contrast between the mine and the surrounding background exists, it is not clearly visible in the raw images. Software has been developed to enhance the visibility of the polarisation contrast in the raw images. This software is running on the control PC and gives the operator the possibility to do a real time inspection of the data that is recorded. Figure 2.3 shows the enhancement result of the raw image that is shown in Figure 2.2(a). Not only the mine in the central part of the image, but also other parts of the scene, including the mine that is partly visible in the top right part of the image show polarisation contrast. The detection software that is described in the next section discriminates between the mines and other parts in the scene that show polarisation contrast.

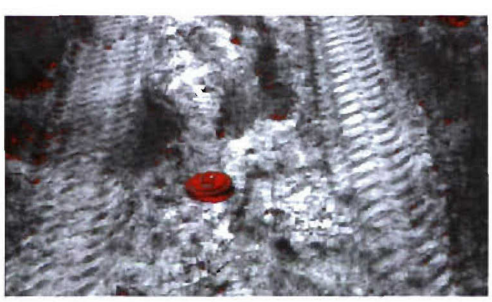


Figure 2.3 Polarisation enhancement of the raw image that is shown in Figure 2.2(a).

2.2.3 *Landmine detection software*

The detection software that has been developed in the second phase of the project [1] has been optimised for the processing of the images from the demonstrator polarisation system. The result of this detection processing is displayed in the normal intensity image that results from the polarisation processing. Figure 2.4 shows the result of this processing for the raw image that is shown in Figure 2.2(a). The 'enhanced polarisation contrast' version of this image was shown in Figure 2.3. In the left side of this last image some spots with polarisation contrast are visible. However the detection software classifies these parts of the image as clutter and only the two mines present in this image are detected, as is displayed in Figure 2.4.

Figure 2.4 Example of detection result.

3 Field demonstration

On 22 June 2005 and 13 October 2005 field demonstrations have been given with the polarisation camera. These demonstrations took place at the Engineer Training Centre in Vught The Netherlands.

3.1 Platform

The polarisation camera, the PC and the wireless link antenna have been mounted on top of a wheel loader of the Corps of Engineers of the RNlA. Figure 3.1 shows the construction.

Figure 3.1 Polarisation camera mounted on the wheel loader. The metal box right of the camera contains the computer.

3.2 Scenario

During the demonstrations recordings were made in two different scenarios, namely a sandy road and a grass road. In both scenarios AT mines and AP mines have been surface laid.

3.3 Demonstration results

In both scenarios recordings were made with the polarisation camera.
The wheel loader moved with a constant speed. While the wheel loader drove slowly the computer on the wheel loader recorded images at a frame rate of 0.5 Hz.

The recorded images of each scenario have been converted to a movie for off-line visualisation. Snapshots from the sandy road are shown in the following figures. First the raw data is shown, then the polarisation contrast enhanced images and finally the detection results.

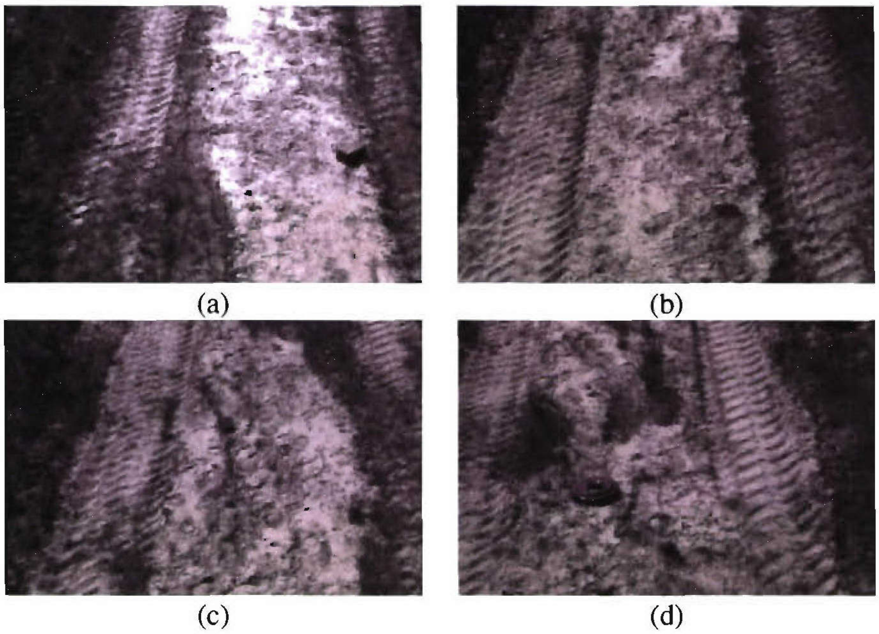


Figure 3.2 Example of raw polarisation data. Figure (a) shows a paving brick in the right part of the image and part of an AT mine in the top left part of the image. Figure (b) contains a PMN AP mine. Figure (c) contains a small 'shoebox' AP mine. Figure (d) contains a TM62 metal AT mine in the central part of the image and a portion of an AT mine top right.

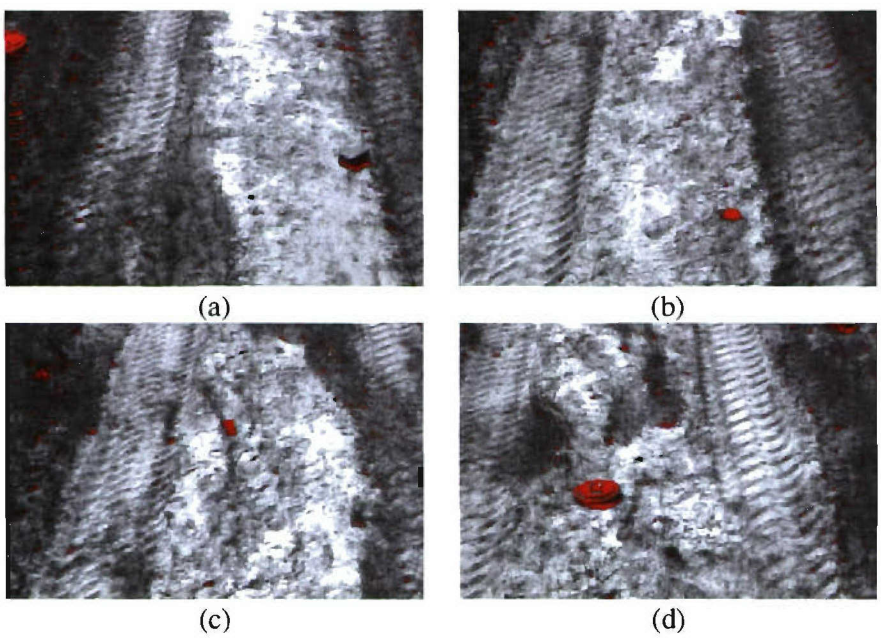


Figure 3.3 Example of enhanced polarisation contrast for real-time visualisation purposes. Figure (a) shows a paving brick in the right part of the image and part of an AT mine in the top left part of the image. Figure (b) contains a PMN AP mine. Figure (c) contains a small 'shoebox' AP mine. Figure (d) contains a TM62 metal AT mine in the central part of the image and a portion of an AT mine top right.

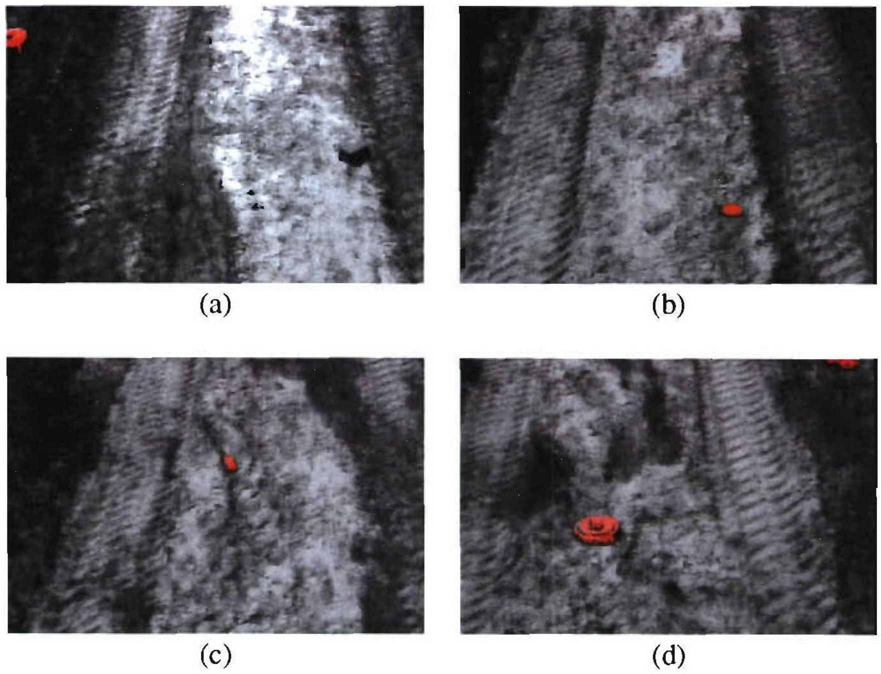


Figure 3.4 Results of the detection algorithm. The paving brick in figure (a) is not detected by the algorithm.

4 Conclusions

This report describes the demonstrator that has been realised in the final phase 3 of the project "Development and Construction of a camera system for land mine detection".

The following project results have been accomplished:

- A polarisation camera, without any moving parts, has been constructed. This camera is robust and can be mounted on a moving platform. The camera is a unique polarisation measurement system.
- Detection software has been developed. With this software, landmines can be detected automatically in images that are recorded with the polarisation camera. The detection results can be visualised in the recorded images.
- Two field demonstrations have been given with the camera system mounted on a wheel loader of the Corps of Engineers of the RNIA. At these demonstrations, recordings have been made of surface laid mines. Enhanced polarisation contrast has been shown in real time. Mines have been detected automatically in off-line processing.

4.1 Future developments

Although the polarisation camera system has been developed in the context of humanitarian demining, the system can also be very useful in military scenarios. For example road proving, road-side inspection and detection of improvised explosive devices can also benefit from the possibilities of a polarisation camera. At the moment road-side inspection is done with only binoculars. As a better alternative, one or more polarisation cameras can be placed on an armoured manned or unmanned vehicle. The polarisation images can be used for automatic detection, but also as an image enhancement tool for the human observer. In the future, this polarisation camera can be an important additional technique in the active search phase of the 'Search' concept. The Corps of Engineers of the RNIA has shown strong interest in these applications.

Since The HALO Trust stopped the development of their AT mine roller they are no longer interested in the further development of the polarisation camera system towards an operational system.

Applications not related to landmine detection are the detection of camouflaged vehicles or the suppression of reflections from car windows in order to look inside the cars.

5 References

[1] J.G.M. Schavemaker, W. de Jong, M.G.J. Breuers, J. Baan; *Development of Camera System for landmine detection*; TNO Physics and Electronics Laboratory; The Hague; FEL-04-B152; July 2004.

6 Signature

Den Haag, november 2005

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The project 'Development and Construction of a camera system for landmine detection' aimed at the development of a camera system to aid in mechanical mine clearance and area reduction. This report describes the results of the last phase of this project. A demonstrator polarisation camera system for landmine detection has been built. Demonstrations of the system have been given at a Royal Netherlands Army test site, with the system mounted on a moving vehicle. In these demonstrations recordings have been made of surface laid mines. The enhanced polarisation contrast has been shown in real time. In off-line processing the mines have been detected automatically.

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