ARC

IST–2000-25300

Airborne Minefield Area Reduction

ARC Final Public Report

WP100 Deliverable D56a

Report Version:	1.0.0
Report Preparation Date:	20/02/2004
Classification:	Restricted
Contract Start Date:	1st January 2001
Duration:	30 Months
Project Co-ordinator:	SCHIEBEL
Partners:	GTD, GEOSPACE, CROMAC, FOI, TNO, IMEC
Responsible for Report:	GTD

Project funded by the European Community under the "Information Society Technology" Programme (1998-2002)

Project	ARC	**Contract**	IST-2000-25300
Client	European Commission		
Reference	ARC_FinalReportPublic_D56a_1.0.0.doc		
Issue	1.0.0	**Date**	February 20th, 2004
Status	Final	**Nature**	
Author(s)	Mehrdad Khalili, Markus Eisl	**Organisation**	Schiebel, GEOSPACE

Financial / Administrative co-ordinator	
Name	Schiebel Elektronische Geräte GmbH
Address	Margaretenstrasse 112 A-1050 Wien, Austria
Phone Numbers	+43 1 54626
Fax Numbers	+43 1 5452339
E-mail	mehrdad.khalili@schiebel.net
Project web-sites & other access points	http://www.arc.vub.ac.be

Executive Summary

This report summarizes the achievements of the ARC consortium during the lifetime of the ARC project, which lasted from January 2001 to December 2003.

Humanitarian demining is an important task to support the population of a region affected by a conflict to return to the normal use of the country, e.g. for agriculture or the construction of infrastructure facilities. In this context the ARC project aimed at supporting Mine Actions by providing a tool for the fast, accurate and cost efficient mapping of a mine suspected area as well as for minefield area reduction.

The document gives an introduction to the project background of humanitarian demining as well as the conceptual ideas behind the project, followed by an overview of the work done with respect to the development and application of the system. This is followed by a section providing more detailed information on results achieved with this work, comprising the concept of the system as well as its implementation and integration, as well as the evaluation of the Minefield test results. The report closes with short overviews on exploitation and dissemination activities.

Version Management

Software Used		Microsoft Word	Filename	ARC_FinalReportPublic_D56a_1.0.0.doc
Edition	Date	Modification		
1.0.0	20/02/04	Final Version		

Table of Contents

1 INTRODUCTION

This document represents the public part of the final report summarising the work carried out during the three years of the lifetime of the **ARC** project.

The document gives a short overview of the background to the **ARC** project, giving an understanding of the end-user based approach for the project. Work progress during the project lifetime is discussed and results and conclusions of results of the project are presented. The report is public and therefore fairly brief and general in nature, but further details on the methods and results generated are documented in the project deliverables as well as in internal technical reports, and can in part be obtained by contacting the project co-ordinator, or by consulting the **ARC** web site at

http://www.arc.vub.ac.be.

1.1 ABBREVIATIONS AND TERMS OF REFERENCE

1.1.1 ABBREVIATIONS AND ACRONYMS

The following table lists the main acronyms used in this document:

Acronym	Description
DAU	Data Acquisition Unit
GIS	Geographic Information System
MIS	Mine Information System
MAGIS	MIS+GIS
UAV	Unmanned Aerial Vehicle
IP	Image Processing
II	Image Interpretation
DF	Data Fusion
DFE	Data Fusion Engine
ATR	Automatic Target Recognition
AGM	Automated Georeferencing and Mosaicking
MAC	Mine Action Centre
GPS	Global Positioning System
INS	Inertial Navigation System
MFR	Mine Field Records

Acronym	Description
USB	Universal Serial Bus
GCS	Geographic Coordinate System
PCS	Projected Coordinate System
DI	Data Interface
EI	Electrical Interface
MI	Mechanical Interface
SI	Software Interface
CI	Configuration Item
TBD	To Be Defined
TBC	To Be Confirmed
TBI	To Be Identified

Table 1-1 General Abbreviations and Acronyms of reference.

1.1.2 TERMS OF REFERENCE

Term	Description
Component	Generic term to refer to any the ARC system building block, either hardware, software or documental –e.g., a procedure specification-. In general in the descriptive text in the document, the term *component* is a generalisation of the terms: *station*, *workstation*, *unit*, *module*, and therefore it may be used instead. Although, these different terms have been used consistently in the reference naming of the different system components, in order to enhanced some particularities, as described below in this table.
Station	Like *Component*, but enhancing the shade of a computer system that provides an HMI to control an equipment.
Workstation	Like *Component*, but enhancing the shade of a computer system that provides HMI to perform a set of complex software processes, and data interpretation operatives.
Unit	Like *Component*, but enhancing the shade of a computer system that does not have HMI, but is controlled via an Station component.
Module	Like *Component*, but enhancing the shade of being mainly software component.

Term	Description
Customisation	Development of a functionality based on a COTS software platform.
Blackboard	The Blackboard concept is the implementation of philosophy of sharing data between different *knowledge sources.* A Blackboard Data Structure is a hierarchically organized global memory or database which saves the solutions generated by the knowledge sources;
Virtual Scene	Virtual Scene is a representation of the mission area, in terms of the features about the Scene gathered by the sensors.
Co-registration	Association of the extracted spatial data to a point in space and time Co-registration is the process of lining up two images, a so-called master image and a slave image, covering the same area in a way that they fit exactly on top of each other.
Feature	The term feature is used in several contexts. In a Data Fusion theory context, a feature is a piece of information with discriminating capacity for a given purpose. In a GIS context, feature is a piece of geocoded information. When the purpose is minefield “recognition”, then feature is synonym of Minefield *Indicator*.
Feature Selection	Selection from the catalogue of features provided by Features Dissection, with the following criteria: a) discriminating capacity; b) features independence.
Features Dissection	Taxonomy of characteristics provided by sensors that can become features.
Features Objects	Instance of a features, geo-referenced in the GIS.
Feature Type	Refers to the description of an specific type of feature. Refer to Feature Type Catalog in [D22.A], for a detailed description of the feature types, and the underlying semantics.
Indicator	An indicator is an object present in the scene, whose represents something for the final purpose of the system
Minefield indicator	An indicator that have the purpose of Minefield recognition.

Table 1-2 General System Concept Terms.

1.2 Documents of Application and Reference

1.2.1 Applicable Documents

The following table lists the main documents relevant for the project.

[DoW]	Description of Work . EC IST, **ARC - Airborne Minefield Area Reduction**, Description of Work, 15.10.2000, Contract no.: IST-2000-25300.
[DoW2]	Description of Work, version 2 (after Annual Review 1).
[D02]	ARC Website
[D04]	ARC End User Requirements
[D06]	ARC Dissemination and Use Plan
[D07]	ARC Trial I Evaluation Report
[D09]	ARC System Requirements
[D10]	ARC Data Fusion Concept
[D11]	ARC Operational Requirements
[D13]	ARC System Concept
[D15]	ARC Trial II §valuation Report
[D22]	ARC System Design
[D22A]	ARC System Design Annex
[D24]	ARC First Annual Report
[D28]	ARC Trial III Evaluation Report
[D31]	ARC Intermediate Exploitation Report
[D36]	ARC Implementation Report
[D40]	ARC Trial IV Evaluation Report
[D41]	ARC Second Annual Report
[D46]	ARC Integration Report
[D49]	ARC Minefield Test Evaluation Report
[D53]	ARC System Report
[D55]	ARC Exploitation Perspective
[D56a]	ARC Public Final Project Report
[D56b]	ARC Administrative Final Project Report

2 AIRBORNE MINEFIELD AREA REDUCTION

2.1 BACKGROUND

The area affected with antipersonnel land mines in 56 infested countries is estimated to be 1 Mio km², with 60 to 200 million landmines in the ground (Source: Landmine Monitor Report 1999, edited by The International Campaign to Ban Landmines, Human Rights Watch 1999). This represents a serious threat to the human lives and a major obstacle for the development of the polluted region. Humanitarian mine action is of global concern. It is a comprehensive, structured approach to deal with mine and unexploded ordnance contamination, including survey assessment, mine clearance, mine awareness and victim assistance.

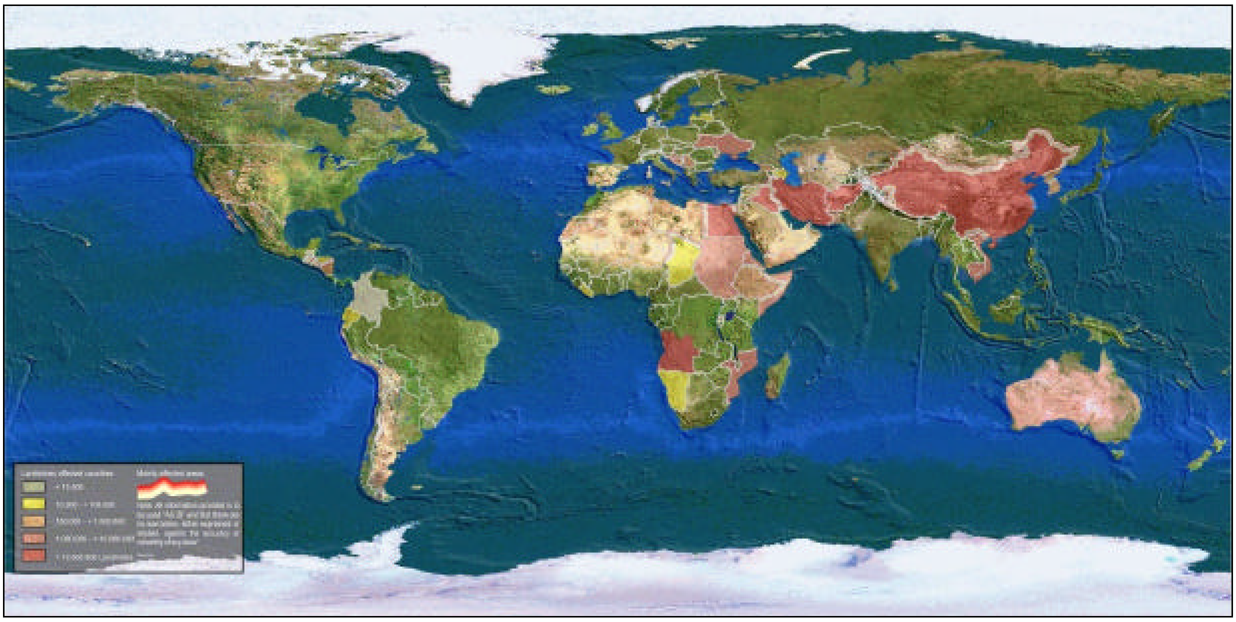


Figure 2-1: Map of mine affected countries in the world

The economic side of humanitarian demining may be illustrated by two examples:

- The cost of mine clearance in Kuwait was estimated to be US$ 960.000 per km² (4000 deminers involved, 84 of them killed)
- After 1990 US$ 90 Mio. were spent for demining in Afghanistan, at costs of US$ 620.000 per km²

A mine action project cycle can be divided into three phases, and all three must be fulfilled to ensure that the overall objectives of the program are reached:

1. pre-mine clearance - identifying beneficiaries and clearing all legal entitlement aspects,
2. mine clearance which starts after all issues in the first phase are resolved, and finally

3. the post mine clearance to ensure that the initial objectives of the project have been reached.

A major problem connected with all phases of mine actions all over the world is the severe lack of baseline information. To respond to this in a rapid way, cost-efficient data acquisition methods are a key issue. This is the point where **ARC** aims at contributing to a relief of this global problem by increasing speed and reducing costs of mine actions.

The overall goal of the project ***ARC*** (Airborne Minefield Area Reduction) is the design, implementation and testing of a prototype system which allows the reduction of mine suspected areas. The approach selected by the project consortium comprises

- the use of optronic sensor systems (cameras in the visual and IR spectral range)
- mounted on a UAV (unmanned air vehicle)
- with subsequent analysis (image processing),
- combination with other contextual information (data fusion), and
- visualisation of the results in a GIS based ground station.

The demonstrator system has been developed in close co-operation with an end-user organisation, and was accompanied by a series of Trials allowing the assessment of the proposed approach in a "real world" problem.

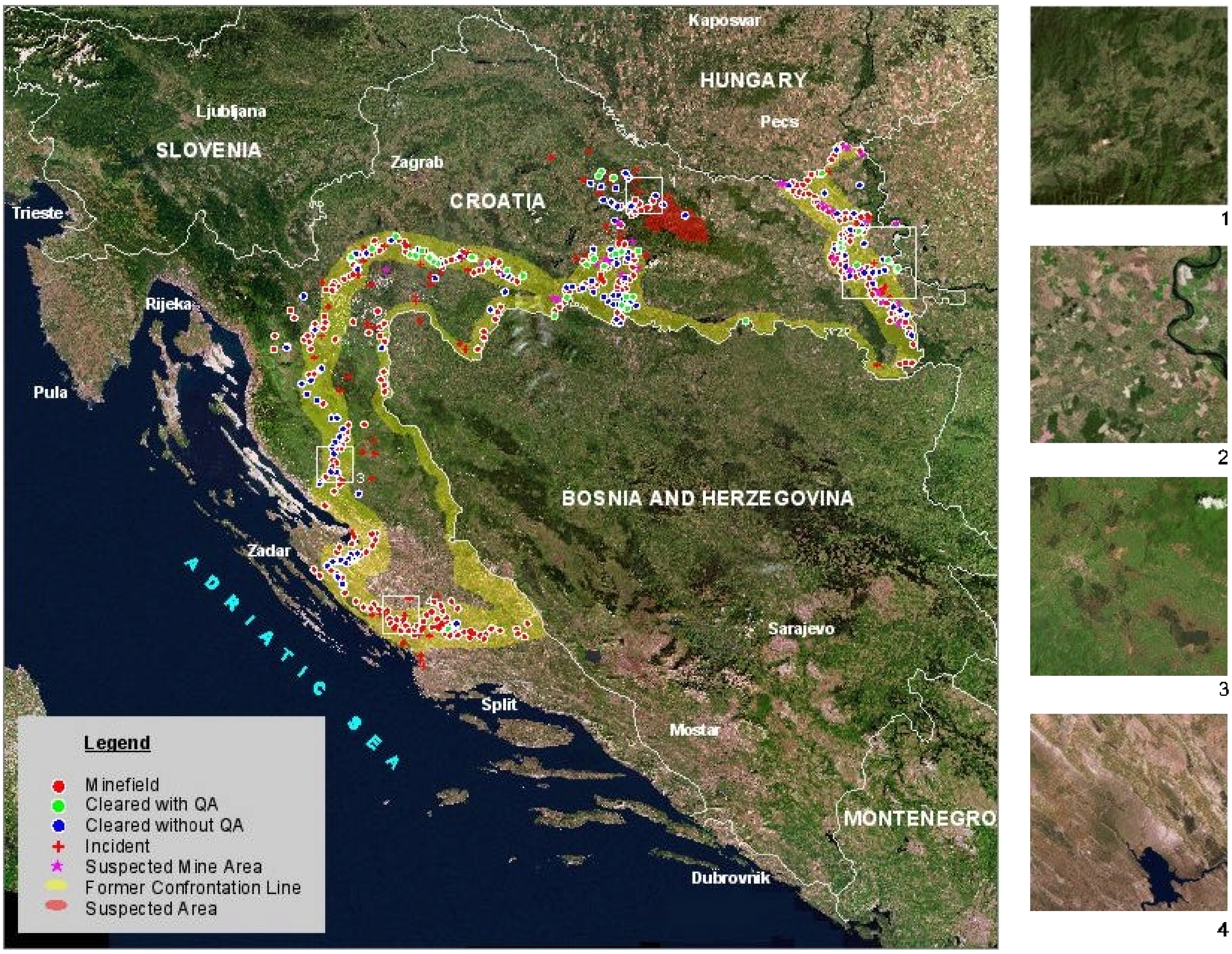


Figure 2-2: The mine situation in Croatia (Source: CROMAC 2000).

2.2 SUMMARY OF THE ARC OBJECTIVES

In this section the major objectives of the ARC project, as given in the Description of Work [DoW], are summarized for a better understanding of the overall goals of the project and of the specific approach used for the development of the ARC system. Before doing so, and in order to clarify the context of the ARC developments some definitions taken from IMAS 04.10 Glossary of Mine Action Terms and Abbreviations are given.

2.2.1 DEFINITIONS

General Mine Action Assessment (GMAA)

The process by which a comprehensive inventory can be obtained of all reported and/or suspected locations of mine or UXO contamination, the quantities and types of explosive hazards, and information on local soil characteristics, vegetation and climate; and assessment of the scale and impact of the landmine problem on the individual, community and country. The elements of the GMAA can be conducted concurrently or separately.

Technical Survey (Previously referred to as Level 2 Survey)

The detailed topographical and technical investigation of known or suspected mined areas identified during the planning phase. Such areas may have been identified during the general mine action assessment or have been otherwise reported.

Area Reduction

The process through which the initial area indicated as contaminated (during a general survey) is reduced to a smaller area. Area reduction may involve limited clearance, such as the opening of access routes and the destruction of mines and UXO which represent an immediate and unacceptable risk, but it will mainly be as a consequence of collecting more reliable information on the extent of the hazardous area. Usually it will be appropriate to mark the remaining hazardous area(s) with permanent or temporary marking systems. Area reduction is sometimes done as part of the clearance operation.

2.2.2 ARC OBJECTIVES

The major objectives of ARC are the development of an Information System, including an advanced Geographical Information System, allowing the fusion of (a) measured image data, (b) a priori information (ground truth, Mine Information, Minefield history, …) and (c) geographical information, *to be used for planning of demining activities and as working support during operational process*. Validation in controlled environment and real minefields will allow the ARC project to achieve effective results for the General Mine Action Assessment, the Technical Survey and Area Reduction in a way which is acceptable for Mine Action Centres and Demining Organizations. ARC will contribute to the improvement of the efficiency of the survey by (i) increasing the scanning speed of the suspected area (compared to manual-, dog- or mechanically-based operations), (ii) implementing costly reduced repetitive surveys and (iii) providing accurate and reliable survey data.

The objectives of the project are the development of (a) a remote sensing platform, and (b) an interpretation system for minefield survey, by using (i) a low-cost low maintenance but easy to control and autonomous operating Unmanned Aerial Vehicle (UAV), and (ii) recent developments in high spectral and spatial resolution imaging sensors. The platform shall be an extension of current technology for survey applications; and the ARC system a full new methodology to be smoothly integrated into the pre-(Level 2) and post-(Quality Control) investigation"

Presentation of the results

1) The results of the ARC system can be presented graphically to the end-users to provide a measure of quantifiable success. Detailed large-scale digital geo-coded colour image maps (1:2000 to 1:5000) of each surveyed area, on which the location of every minefield found by the ***ARC*** system have been indicated – in digital form for entry into the ARC GIS. These maps could be used for: planning demining activities, Land use planning and Infrastructure rehabilitation planning (rods, bridges, schools, etc …). The digital maps contain:

- the original suspect minefield area boundary,
- the delineated contour produced by the ARC system, and
- the contour produced by the CROMAC's deminers after a Level-2 survey using current practices.

2) The ARC-GIS contains all the collected data: maps, satellite images, optronic sensors images, results of the image analysis and Data Fusion, and Contextual data including minefield records, historical data (conflict lines, mine laying strategies used, methods used to deploy mines, typical depth, AT/AP mines, minefield patters, trip wires, features that are typically mined (e.g. bush, roads, tracks, agriculture areas, etc…).

3) The minefield delineation has been analysed carefully; it is related to the current uncertainty about the accuracy of Level-2 survey. The uncertainty of the system has been analysed by comparing the CROMAC's verification Level-2 Survey and the ***ARC*** detected minefields, which have been classified into three categories:

- Definitely a minefield
- Probable minefields
- Possible minefields

4) Detection and identification of signature (spectral, thermal and spatial – shape-) associated to different objects (mine field indicators, man-made objects, background, mine cues).

2.3 PYRAMIDAL APPROACH

Working on different levels of decision imposes different requirements on the level of detail of geo-information and on the area covered by the data, ranging from e.g. national coverage for political decisions to the coverage of individual fields e.g. for field work. Figure 2-3 gives a schematic view of a hierarchical information model, which takes these different requirements into account.

In the ARC system the pyramidal concept has been implemented by modifying the general view sketched in Figure 2-3 in a way which logically integrates the different information levels available using state-of-the-art remote sensing tools ranging from (coarser) satellite data to very high resolution (cm range) data acquired from the UAV helicopter.

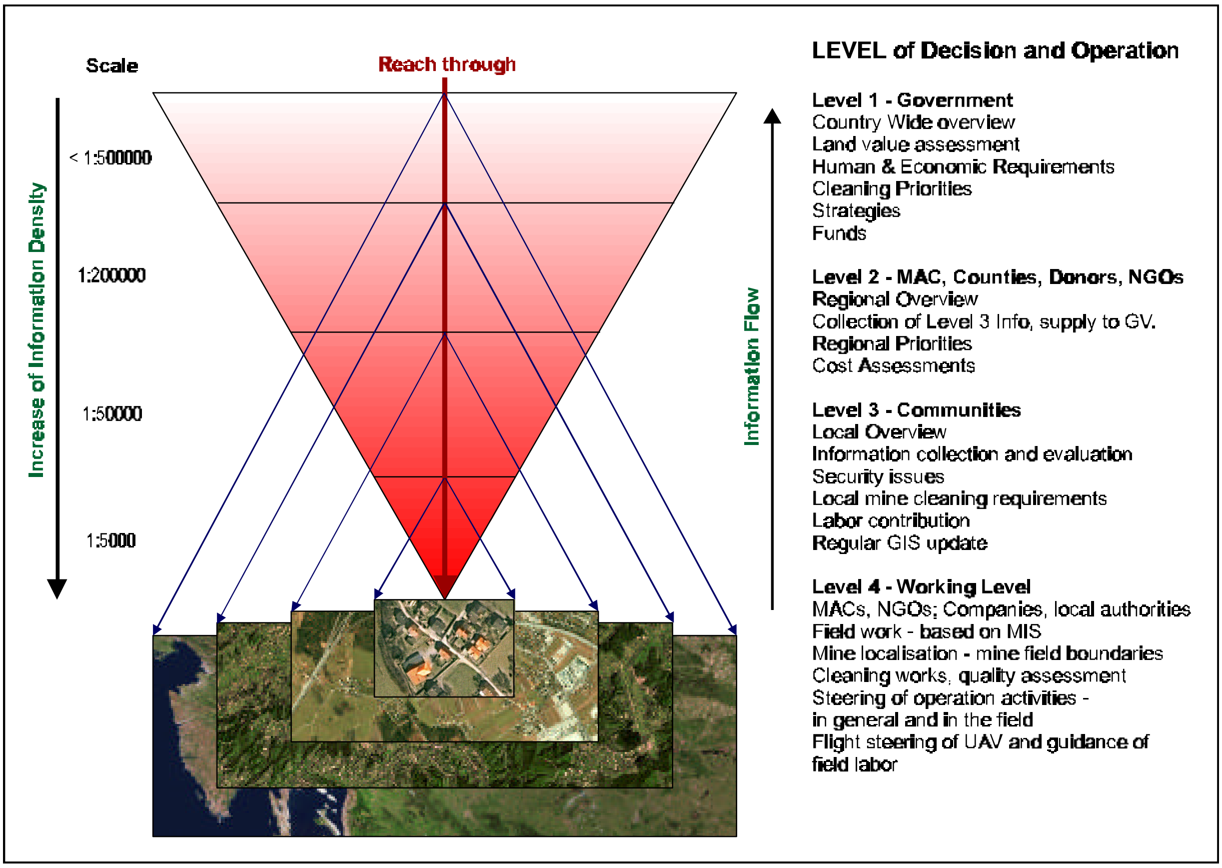


Figure 2-3: Schematic view of data content and information flow in a pyramidal approach.

In this concept the data acquisition from a UAV is an important element, as such platform is fulfils all of the following requirements:

- Small starting/landing area (important within potentially dangerous environment)
- Precise positioning system combining a DGPS, an INS, accelerometers and solid state gyros (important for both exact geo-referencing of the acquired data and for re-visits of areas of interest)
- Offer the possibility to acquire data from altitudes between 30 and 1000m (see pyramidal data acquisition scheme)
- Remotely controlled operation
- Pre-programmed to fly along pre-selected routes
- Autonomously stabilized
- Accurate repetitive scans (flights).

The Information System developed within the ARC project is built up on the base of the existing GIS but it also provides additional information from new satellite data, external sources and the results of the ARC project. This information is restricted to the study areas (Trial and Minefield Test areas), but it clearly demonstrates the developed methodology. Cross merging of maps, image maps and thematic information opens the GIS to a multi-user community and provide precise information as a decision support. For instance land-use maps and land-use change maps derived from multi-annual and multi-seasonal data sets are provided which allow a preliminary assessment of possible mine-polluted areas. Up-to-date field maps prepared from 1 meter IKONOS data almost comparable to 0,5 – 1 meter aerial photomaps bring additional improvement for operational purposes.

In its final version the GIS System is an integrated 4-level multifunctional system which fulfils the following tasks:

- Collection and dissemination of all minefield related information, based on the existing GIS and MIS, but implementing additional information material as mine information assessment, ground truth assessment, acquired satellite, aerial surveys and ARC data, and from external sources (statistics, reports, etc.)
- Provide support for decisions about priorities of minefield clearance by specific data evaluation and delivery of information on specific minefield related information.
- To be used as operational tool for selection of strategies, operational decisions and supplier of specific field information.
- Working as a steering instrument for an ARC survey and ground survey.
- Provide base maps for level 3 - quality control works.

Level	Cover-age	Scale	Height	Platform	Instru-ment	Products	Resolution
Global	50 x 50km	1:150.000	700km	Landsat	SAR	Maps Sat imagery	[30-15m]/pixel
Regional	20 x 20km	1:10.000 1:5.000	700km	High-res Iconos Sat	SAR	Ortophoto Maps, frontline maps	1m/pixel (panchromatic)
Local	10 x 5km	1:2.000	3000m 500m	UAV/Bell	Optronic Sensors	Ortophoto, Optronic Imagery	0,5m/pixel
Local	2 x 0,5km		1000m 500m	Camcopter®	Optronic Sensors	Optronic Imagery	20cm/pixel
Minefield	200x200m		500m 30m	Camcopter®	Optronic Sensors	Optronic imagery	10cm/pixel

For this, the system is built up as a four level decision and operation instrument, which consists of the following**:**

1. Level 1 – The government level, which develops strategies and provides funds. Access to country wide overviews of high resolution. With land-value assessment according to human and economic priorities, allowing the observation of mine clearance progress, cost statements and cost assessments for funding requirements. Scale of overview maps 1:500.000 to 1:600.000 with zoom in function to scales 1 : 5.000 and thematic GIS-information superimposition.
2. Level 2 - Regional Level, Scales 1:50.000 to 1:200.000 for detailed information of MAC organisations, country governments, donors, NGO´s etc. providing the same information as on level 1 in larger scales for selection of priorities on regional scale and detailed cost assessments
3. Level 3 – Local / Community Level, overlooking communities and their typical landscape zones which have to be treated with mine clearing. Scales of 1:5.000 to 1:50.000 for definition of local requirements. With data input function for information collection and regular GIS update, GIS evaluation for local requirements, safety issues.

4. Level 4 – Operational Level. Field maps in a scale of 1:2.000 to 1:5.000 and higher resolution, for MAC and Mine clearing companies, local authorities, collection of local information and processing and display of the ARC data. This level acts as final information collector on high resolution images for improving the General Mine Action Assessment (AGMM), the Technical survey and Area Reduction.

The design of the system and the implemented data-base with the specially developed software allows the upper levels to zoom into the higher resolution information of the lower levels. Main focus of the implementation of the demonstrator system was the Operational Level.

3 THE PROJECT TEAM

The ***ARC*** project team includes seven partners from six European countries, covering commercial companies, research institutes and an end-user organisation: CROMAC (Croatian Mine Action Center), FOI (Swedish Defence Research Agency), GEOSPACE (Austria), GTD (Ingenieria de Sistemas y Software Industrial, Spain), IMEC (Ineruniversity MicroElectronic Center, Belgium), Schiebel (Austria) and TNO (Netherland's Organisation for Applied Scientific Research).

The structure of the consortium guarantees direct access to the end-user situation in the field of demining as well as the technological and scientific background to produce the ***ARC*** demonstrator system. Schiebel acts as administrative and financial co-ordinator, GEOSPACE as technical co-ordinator for this project. Technically, all organisations act as equal partners in carrying out the work.

4 WORK DONE

4.1 SYSTEM CONCEPT AND DESIGN

Following from the Kick-off Meeting, which was held in Salzburg in January 2001, a series of meetings was held to guarantee the successful collaboration of the project partners within ***ARC***. In order to keep travel expenses as low as possible meetings with different focuses (technical, operational, and steering) were combined, project management issues were covered in each of the meetings.

The Trials and Minefield Tests and the meetings related with them had a special status, as they made a very direct access to problems arising during the Trials possible.

Main focus of the design was to set up an integrated system but nevertheless keep the modular structure of the system in order to allow for a distributed development work as required by the structure of the consortium.

During the first year, the focus of the consortium was laid on the sound definition of minefield indicators, combined with an optimisation both of the sensors to be used and their parameters in the ***ARC*** system to be developed, and, in a consequence, also on the system concept and operational requirements. These aspects were elaborated in close co-operation with CROMAC, the end-user involved in the project period. In this context the Trials (I and II during the first project year) together with the End-User Requirements played an essential role, as they provided deep insight into the real world problems the system has to cope with.

During the second project year the system design was elaborated in detail, based on the system concept, the system requirements and the operational requirements established during the first year. Refinement work concerning the system design mainly with respect to the AGM and its integration into the full system continued also in the third project year.

4.2 SYSTEM IMPLEMENTATION AND INTEGRATION

Based on the results of the system design phase, the components of the system were implemented and consecutively integrated in a series of intermediate steps to form at the end the ARC Demonstrator System 1.0.

System implementation started already during the first project year, as parts of the system were used during the Trials I and II already. This work was continued during the second project year, by using the consecutive draft versions of the System Design document as reference and the evaluation results of Trial III. A draft version of the System Implementation Report has been issued for the EC before the second Annual Review. The System Implementation Report served as the core document for the development work all through the project lifetime, the last (final) version is issued with the end of the project [D36].

An important test during the system integration phase was held in April 2003 with the Trial IV, where for a first time the interconnection of the system components was tested. The full integrated system was then used during the Minefield Test in Croatia (May 2003), and, after refinement work, during the Minefield Demonstration near Vienna (November 2003).

4.3 Trials

Extensive trials have been executed during the ARC project. Their aim was mainly to improve the understanding of minefield scenes as well as to enhance the System Operational Concept for airborne minefield survey.

The existing reference documents[1] for the research, test and evaluation for mine action can serve as general frames for the requirements and needs in the framework of technologies for mine action, but they do not offer precise requirements for a new technology such the one proposed by ***ARC***. Therefore a new approach, suited to the needs of research, development, testing and evaluation of the proposed airborne mined area survey system was designed. This has been done in a close interaction between the end-user and the technical partners. The main problem we encountered is the lack of well-defined and structured collection of representative and reliable (with satisfying level of confidence) data about airborne minefield indicators, as well as airborne scene interpretation. Trials in ***ARC*** have been planed to answer the above-mentioned tasks. The aims of the conducted Trials are (1) the *definition and approval of the minefield indicators* and their *continuous collection*; (2) the *sensor selection*; (3) the *reinforcement of the experience in airborne electro-optical mapping of mined areas at low altitudes* in a pyramidal, top – down manner, under variety of conditions, and (4) *training the end-users for the use of airborne survey and scene interpretation for mine action*.

Apart of the above-mentioned Trials goals and tasks, a continuous (during the duration of project) collection of airborne images and ground truth are foreseen, for the definition of *reliable and statistically significant representative of typical mined areas and minefield indicators in South Eastern Europe.*

4.3.1 Trial-I

Work on Trial-I has been started early after the project kick-off. Figure 4-1 shows the platforms used during Trial-I. Airborne data (from the Mi-8 helicopter), as well as data from a sky lift have been acquired over the Marin Brod minefield, given in Figure 4-5, and Glinska Poljana, Pristeg, Ceretinci. Prior to the Croatian trials, integration, testing and dummy minefield data acquisition have been conducted at the test facilities of TNO. During the TNO and Croatian trials, 7 different optronic sensors have been used, 6 of them have been mounted on the Mi-8 helicopter, and all on the sky lift (see Table 4-1).

[1] [1] IMAS 03.30. DRAFT First Edition 2001-10-01. Guide to the research of mine action. Chief United Nations Mine Action Service (UNMAS). United Nations. FF-360. New York. NY 10017. USA.

[2] IMAS 03.40. DRAFT First Edition 2001-10-01. Test and evaluation of mine action. Chief United Nations Mine Action Service (UNMAS). United Nations. FF-360. New York. NY 10017. USA.

Figure 4-1: The different platforms used during Trial I in Croatia. From left to right: Test team inside the Mi-8 helicopter; aircraft Cessna 172-R - used for the selection of the candidate test areas-, colour camera; sky lift (Denka) and mounted sensors for the diurnal thermal IR data acquisition; cameras mounting in the Mi-8; armoured vehicle used for hyper spectral data acquisition.

Sensor	***Spectral Range*** µm	***Lens/ FoV***	***Resolution***	***Frame rate*** Hz	***Temp. Resolution***	***Provider***
AGEMA, Thermovision 900, SW (FLIR)	2-5.5	5, 20 deg.	272x136/68	15/30	0.1 K	FOI
AGEMA, Thermovision 900, LW (FLIR)	7-14	5, 20, 40 deg.	272x136/68	15/30	0.08 K	FOI
ThermaCAM SC3000 (FLIR)	8-9	20x15 deg.	320x240	50	0.03 K	FOI
IMC-201 (6 bands multispectral)	200 – 800	Depends on the optics	400 tv lines	25		FOI
SONY FCB-IX470P (color camera)	400 - 850	Depends on the optics.	725x582	25		FOI
Sony, SSC-M370CE (near IR)	830-1100	Depends on the optics.	625x570	25		FOI
ImSpector (*Hyperspectral line scanner*)	430 – 900	Depends on the optics.	400 tv lines	25		TNO/CRO MAC
MS3100, DuncanTech (*CIR digital multispectral camera*)	visible red, green and NIR	Depends on the optics.	1390x1039	7.5 frames/s		TNO/CRM OAC

Table 4-1: Sensors used during the trials

Figure 4-2 and Figure 4-3 show some of the used sensors, and sensors mounting for both sky lift and helicopter,

Figure 4-4 shows the dummy minefield at TNO used for Trial-I.

Figure 4-2: Complete setup of the sky lift in front of the minefield indicator field (left image) and camera mounting on the lift (right image).

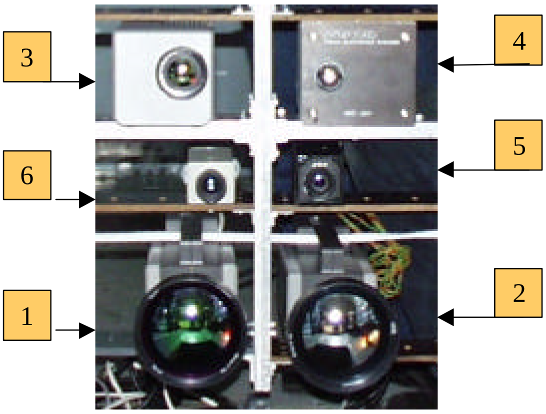


Figure 4-3: Camera mounting setup in the MI8 helicopter.

Figure 4-4: Some of the minefield indicators at the TNO part of trial 1.

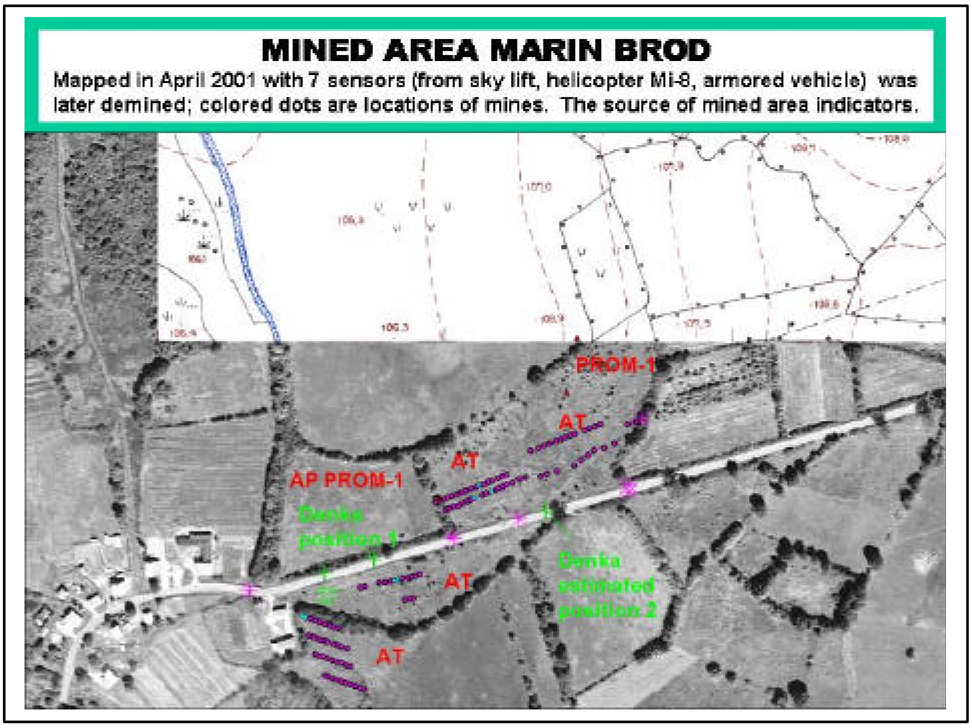


Figure 4-5: Marin Brod Mined area. Digital ortho-photo map and raster map at the large scale 1:5000

Figure 4-5 shows the Marin Broad area, used as one of the test sites during Trial-I. After the trials, the area has been cleaned by CROMAC, and a large number of AT and AP landmines have been found. Their position has been recorded. This ground truth information provided an excellent source for further analysis of the acquired data for further image analysis, and will serve for the derivation of indicators for mined areas.

4.3.2 TRIAL-II

4.3.2.1 OBJECTIVES OF TRIAL II

According to the Description of Work [DoW], Trial II was planned to be performed with the UAV Camcopter® equipped with both cameras, VNIR MS3100 (TNO), TIR SC3000 (FOI) integrated and synchronised, above a test area in real minefields in Croatia. Due to the non-availability of VNIR camera and its acquisition system and to the limited availability of UAV Camcopter® in 2001, the foreseen integration was not possible and the consortium decided to perform Trial II in two versions and thus mitigate the risk:

- Trial II – Bell above minefields in Croatia, TIR and VNIR cameras on helicopter Bell-206.
- Trial II – Camcopter® in Vienna, TIR camera on Camcopter®.

Trial II – Camcopter® was a short test of the behaviour of the TIR camera SC3000 on board of the UAV Camcopter®, performed above a field in Vienna. Trial II-Bell was performed in real and complex environment, performed using a small manned helicopter Bell-206, and was considered as material for modelling the minefield aerial survey imaging for the UAV Camcopter®. Beside the differences between the aerial platforms the most important difference was the flight height of 100m and more for Bell-206, while the UAV Camcopter® was tested at flight heights of 10m and above. The use of a helicopter was comfortable for testing the cameras, their modes and image acquisition over the test areas.

Main objectives of the Trial were:

- Acquire data by use of manned helicopter Bell-206 instead of UAV Camcopter® with both foreseen cameras (TIR SC3000 of FOI and VNIR MS3100 of CROMAC, without synchronisation and foreseen data acquisition unit.
- Collect the VNIR and TIR images, at lowest height and speed permitted for manned helicopter Bell-206 (130m and 35 km/h), whereas UAV Camcopter® shall fly at 10m and shall hover.
- Collect experience about the influence of the pilot in the loop in manual guidance and control of the Bell-206 helicopter flight. Apply for the derivation of a Standard Operational Procedure for the foreseen minefield aerial survey by UAV Camcopter®.
- Check assumed modes of aerial survey, and derive concept for their later application to UAV Camcopter®.
- Derive an initial concept of the exploitation of the ***ARC*** system for aerial survey and identify main phases, as input to System Operational Procedures – SOPs.

4.3.2.2 TRIAL-II – CROATIA

Figure 4-6 depicts the used helicopter and the camera mounting on a passive damping platform. Note that vibrations and flight instabilities did not produce blurred images. Figure 4-7 shows a map of the surveyed area near Vrankovici.

Figure 4-6: Bell-206, and cameras mounting used for Trial II and for continuous data collection. Sensors: thermal IR camera ThermaCam SC3000; VNIR camera MS 3100. For continuous data collection, a thermovision camera Agema THV-1000 was also used.

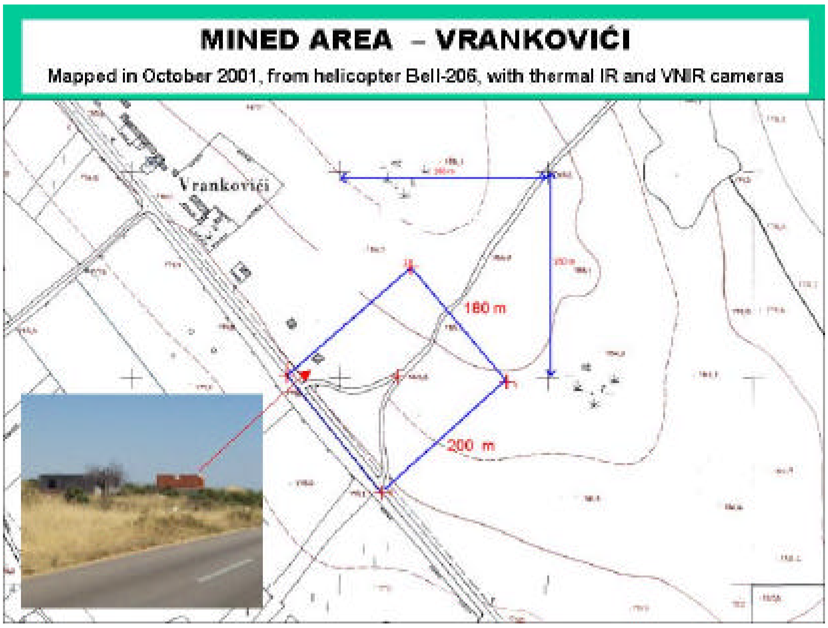


Figure 4-7: Mined area Vrankovici. Map 1:5000, and a photography of a demolished house.

Figure 4-8 and Table 4-2 illustrate the pyramidal top – down mapping approach used for Trial-II. Trial-II experience with the Bell helicopter served for the derivation of the Operational Requirements and Standard Operational Procedures.

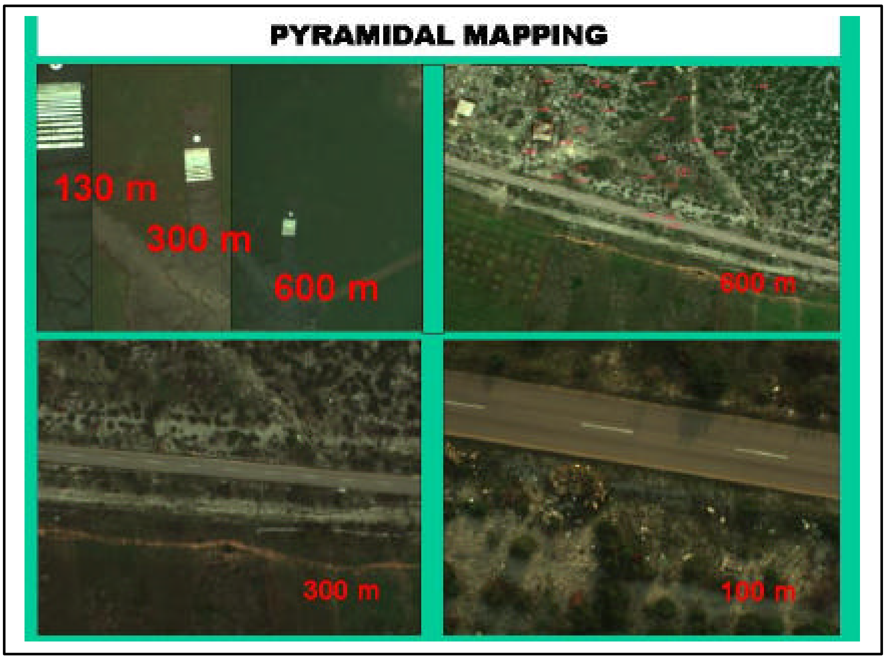


Figure 4-8: Pyramidal, top–down mapping, from 600 to 100 m. Upper left – calibration bars for the assessment of the spatial resolution and modulation transfer function (MTF) of the mapping system in the visible bands. The other three images show details from Vrankovici area.

Area [m*m]	Resolution [cm] VNIR	Resolution [cm] Therm IR	Height [m]	Over-lapping [%]	Images incl. overlap
200*200	20	80	600	0	1
100*100	10	40	300	0	1
50*50	5	20	150	60 (Stereo)	16+
25*25	2,5	10	75	30	25
12*12	1,2	5	37	30	125

Table 4-2: Specification of the flying parameters for Trial-II

From the Trial-II specifications (flight height and area coverage), given in Table 4-2, and the chosen areas, flight paths have been decided and programmed. During this test the pilot has been included in the loop in order to correct the flight path.

Based on the analysis of Trial-I data and on the observation that the thermal IR provides reliable detection of artificial objects and that it is complementary to the VNIR camera for the discrimination of vegetation, it has been decided to use the following sensors: (1) the thermal IR camera ThermaCam SC3000, with a colour camera for image mosaicking, and (2) the VNIR camera MS 3100. Calibration markers, given in Figure 4-9, and soil temperature sensors have been also used for the purpose of registration, geo-coding and thermal calibration.

Figure 4-9: Thermal IR image illustrating a demolished house which served as a bunker, the area on the right side is mine contaminate. Metallic markers appear with very strong contrast.

4.3.2.3 TRIAL-II – SENSOR INTEGRATION INTO THE CAMCOPTER

The part of Trial II dedicated to sensor integration tests was performed at Vienna in addition to Trial II in Croatia. Integration of sensors into the Camcopter system and data transfer as well as data storage have been tested. A test flight has been carried out for collecting data by a fix mounted Infrared camera and a visible light camera. A first data evaluation showed that vibration was damped very well, thus pictures could be captured without blur. Figure 4-10 shows the camera mounting on the Camcopter.

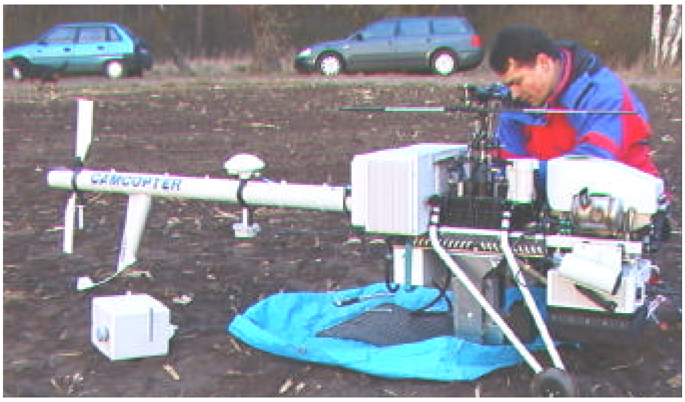


Figure 4-10: Sensors used during trial 2. The right image shows the cameras mounted on CAMCOPTER®

The Camcopter® UAV System consists of the following main components:

- Aerial Vehicle
- Control Station, including a Pilot Control Unit
- Sensor Control Unit (optional)
- Ground Transport Vehicle (optional)

For save and comfort in various applications one has to consider the following design criterions:

1) Payloads can easily be changed

2) No rebalancing when changing payloads.

3) No difficult recalibration of flight parameters in the autonomous flight stabilisation system.

As a consequence the centre of gravity from the payload must be in line with the centre of gravity from the CAMCOPTER and the main rotor axis. Therefore customized payload modules are mounted under the rotor shaft between the landing gear (or optional on top of the main rotor hub).

The Trial-II integration flight was performed to collect data, Video- and IR-Images of different objects on ground in order to evaluate the ARC concept. Flight parameters of the UAV were recorded during the complete test flight.

For redundant safety a downgraded GPS –sub carrier board was installed. This additional GPS system ensures autonomous return of the UAV to the starting point also in case the main GPS has technical problems.

To increase reliability and safety the Data Link was improved to higher quality link modules. Data and Video transmission from CAMCOPTER to ground station was originally done on two different frequencies in the S and C band. This method required also two different electronic module and antenna sets, one for data and one for video transmission. The new data and video link concept operates at one frequency. Since the number of electronic and antenna modules are reduced this system is more fail save with respect to the previous version. In addition it requires less space in the Camcopter®.

4.3.2.4 CONCLUSIONS OF TRIAL-II

From the objectives of Trial-II summarized above, the conduction of Trial-II allowed the accomplishment of:

- The Aerial survey: VNIR and TIR images were collected for three mined test areas, Vrankovici, Pupovac Pristeg and village Glinska Poljana.
- Ground truth and contextual data have been collected for the test areas. For two test areas demining (clearance) results were provided.
- A start set of set of images, ground truth and contextual information have been provided for the image processing and feature extraction algorithms.
- Minefield indicators have been identified and approved, at the test areas Vrankovici and Pupovac Pristeg. They have been assessed by the subjective interpretation by VNIR and TIR images, MAGIS [2] data, inspection on the test sites, use of contextual information's provided by deminers after clearance and extracted from images by means of image processing.
- The TIR camera SC3000 was tested and approved as suitable, onboard of Camcopter®, without stabilised gimbal.
- Experience about the influence of the pilot in the loop in manual guidance and control of the Bell-206 helicopter flights was collected. This will be used as input for the derivation of the Standard Operational Procedure.
- Different modes of the aerial survey were checked and a concept for their later application has been derived.
- The initial concept for the ARC system for the aerial survey was checked and main phases have been identified for exploitation as inputs for the System/Standard Operational Procedures – SOPs.
- Three different calibration markers have been used for calibration the optronic sensors. While being very useful the calibration should be strengthened in Trial III and foreseen the option for the ARC system exploitation.

Finally, after the efforts on installing, testing and using the Bell helicopter for Trial-II, and regarding the good results obtained the consortium decided to reinforce the ***Continuous Data Acquisition*** for minefield scene understanding, refinement of the minefield indicators list, and contextual/ground truth data gathering. These extra trials, approved by all partners shall be planned in advance and accomplished upon specific request or upon the feedback to previously acquired data. For this purpose the Bell-206 helicopter will be equipped with the (a) VNIR DuncanTech digital camera MS3100, (b) an upgraded thermovision camera THV-1000 (owned by CROMAC prior to the project), (c) the hyperspectral line scanner ImSpector in spot mode, (e) a video TV camera with zooming possibility (owned by CROMAC prior to the project), and (f) an onboard data acquisition. A GPS based navigation unit, with real-time position estimation and display on a digital map, has been implemented.

4.3.3 TRIAL-III

4.3.3.1 OBJECTIVES

Trial-III was planned as a continuation of the data gathering over minefields (Trial-I and Trial-II) for minefield scene understanding (including visual and computerized image analysis), data fusion, and a first mission of the integrated Camcopter® as platform for airborne survey. Its results were important for the project continuation in terms of platform aspects and operational procedure.

The aims of Trial-III were to

1) operate with an Integrated Camcopter® (payload, cameras, data acquisition and synchronization), with
2) repetitive and accurate scans (flight paths),
3) test the Camcopter® control station, and data gathering (position GPS/INS and images) in operational conditions,
4) test the multi-view and multi-temporal data acquisition,
5) reinforce the "Top-Down" approach with low altitude flights (10-30m),
6) verify the concepts of the Operational Procedure for UAV airborne survey, and finally
7) collect extra data (contextual, ground truth, maps, satellite and airborne images) for GIS refinement and Minefield Scene Understanding including, minefield and ground truth assessment, visual interpretation, image analysis and minefield indicators list refinement.

Trial-III has been performed in the Vrankovici – Pristeg region (for the detailed description please refer to D15, D26). The Camcopter® used for Trial-III is fully described in D22 D27 and D38. The following figures illustrate the platform (Figure 4-11) and its control station (Figure 4-12).

Figure 4-11 Camcopter® during the Trial, without hull to avoid excessive heating.

Figure 4-12 Camcopter® control station based in a trailer.

4.3.3.2 DATA EVALUATION

The results of Trial-III are fully described in D28. Here a summary of the results is given. Trial-III was successful for the following:

- Camcopter®, equipments and trial team were operational under extreme weather and working conditions,
- Very valuable data have been acquired at low attitude (70m).

Mitigated success was achieved for the following:

- Full capabilities of the ARC system concept (pyramidal data acquisition, diurnal flights, ground truth assessment),
- Trial preparation: Flights requirements and missions preparation.

Trial-III was very valuable and an exciting experience for all participants and even more for the better definition of next actions. This was the first flight of the Camcopter® over real minefields, and partners have analysed and estimated the gained results and lessons learnt.

The rational consequence of the collected experience (especially the negative ones) was transformed by all partners into positive actions aimed to overcome future difficulties. Technical aspects (lighter payload, fast and larger solid state disk, etc ...) were addressed in the design and implementation reports, as well as the current activities, while the Operational aspects, including the GIS (consistent GIS projection parameters, missing Legend of reference maps, etc ...) ground truth data assessment (Minefield records, historical data, etc...), and flight mission preparation, were addressed, enhanced and assessed during an Operational Committee meeting, and in an internal draft report used for the Specifications for Minefield Test and Continuous Data Acquisition.

4.3.4 TRIAL-IV

A fourth trial, which constituted an important step in the integration phase of the ARC project, was performed in Grossmittel near Vienna from April 17 to April 21. The main goal of this trial was to test the integrated system prior to its application in the Minefield Test. In detail the objectives of this trial are described in the Description of Work [DoW] and in the Trial-IV Specification Report [D37].

During Trial-IV the integrated system was used for the first time. The results of this successful trial were an important input for the final integration works on the way to the final demonstrator system.

The validation of system components comprised the functions of:

- Airborne Platform (UAV, Payload, Data Acquisition Unit on board)
- Control Station (On Site): UAV Control Station, Payload Control Station
- Ground Station (Head Quarter): Mission Planning (pyramidal approach, flight waypoints generation), AGM (pre-processing, geo-registration, mosaicking), Image Processing algorithms (at least 1 per partner), Data Fusion (integration in the GIS of all spatial generated data)

In addition to the components of system interfaces were validated:

- Mechanical Interfaces: Airborne platform
- Electrical Interfaces: Ground Station
- Data Interfaces: Feature Data Interface

During the Trial a total of six flight missions could be executed, with three of them covering a full pyramidal dataset in the morning, around noon and in the afternoon, thus applicable also for diurnal analysis.

This first operation of the integrated system yielded important results for the refinement of the components and their interaction, e.g. for the functionality of the Mission Planning (definition of missions, integration of data acquisition START/STOP, improvement of interfacing with Ground Station), but also for the operational aspects of the system (operational procedure).

Figure 4-13: The Camcopter® with payload mounted (left) and after take-off (right; background: weather station).

4.4 MINEFIELD TEST

4.4.1 OBJECTIVES

As defined in the DoW, the goal of the minefield test was to "demonstrate the feasibility of the ***ARC***-concept and its application to Level 2 survey, post clearance Quality Control, minefield area reduction and (if possible) delineation, and to evaluate the area reduction performance. This final phase of the project starts with a minefield test, followed by a demonstration test and system performance and reliability analysis. The minefield test will be crucial, while it has to answer how and to which extent ***ARC*** fulfils the aims. After the trial CROMAC's deminers will assess the borders of the minefield by using the proven and generally acceptable technology, according to the Standard Operational Procedures and according to the demining law in Croatia. Analysis of their results (e.g. dimensions and characteristics of the minefield) will determine the achievable reliability of the ***ARC*** system. An important factor for the ***ARC*** system evaluation is the price of labour of the deminers and the price of the intensive survey by geodetic surveyors. The ***ARC*** evaluation will strongly depend on these factors and their importance should be stressed here."

4.4.2 SURVEYED AREAS

4.4.2.1 MILEKOVICI

Figure 4-14 indicates (1) the proposed surveyed area as indicated in D43 - Minified Test Specification, and (2) the really surveyed one. To cover the area proposed in (1) two landing/takeoff positions for operating the Camcopter have been proposed. The fact that position on top of the hill was not secured by CROMAC, only a reduced are (due to the low topographic altitude of the second landing/takeoff position and limited visibility) has been flown.

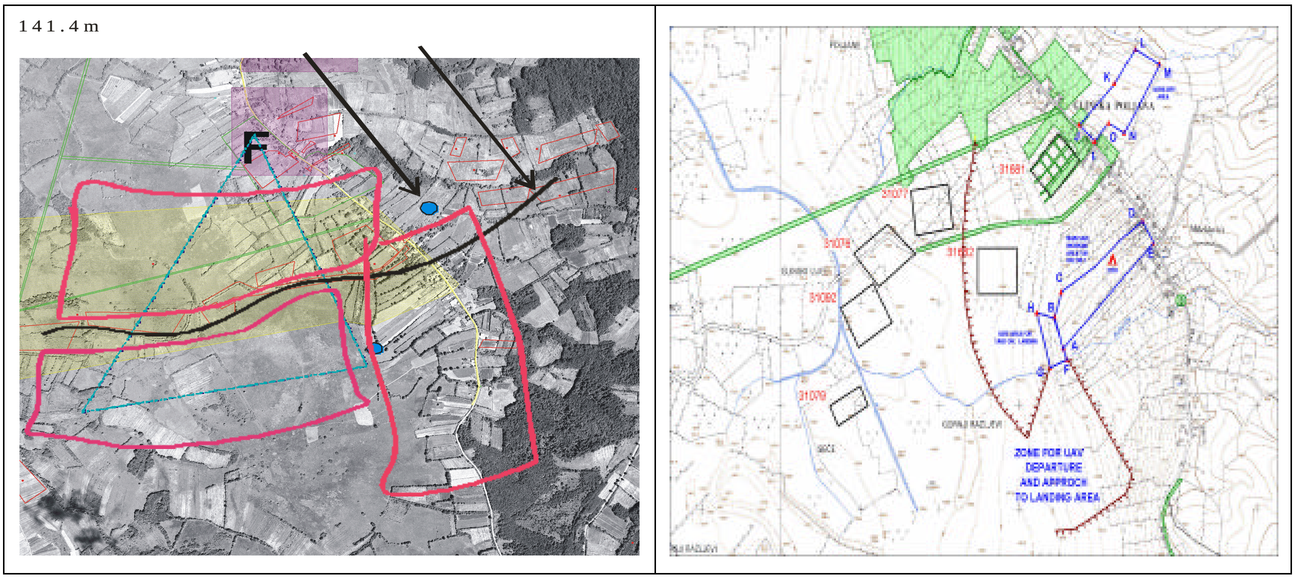


Figure 4-14 Left: proposed survey area (red); Right: surveyed area during MFT (red)

4.4.2.2 VRANKOVICI

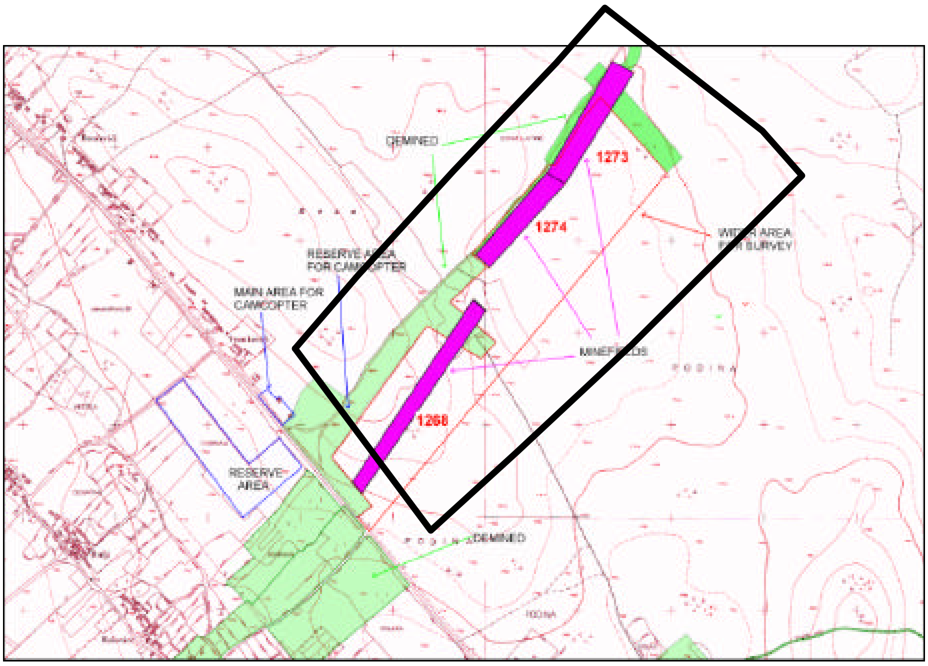


Figure 4-15 Black: proposed and surveyed area; Red: area proposed by CROMAC.

Figure 4-15 shows both proposed and surveyed areas. As it can be seen during MFT the covered area has been in order to cover important minefield indicators, not present in the originally proposed area by CROMAC.

4.4.3 EXECUTION

The Minefield Test played a central role in the concept of the project, as it was planned to vital for several aspects:

- Operational test of the integrated equipment
- Test of the operational procedure
- Acquisition of data for subsequent analysis and evaluation

This Minefield Test was performed in Croatia from May 12 to May 23 2003, as test areas two regions were selected, which have been surveyed during Trial-I, Trial-II and Trial-III as well as during the Continuous Data Acquisition:

- Pristeg/Vrankovici region (coastal part of Croatia)
- Glinska-Poljana/Milekovici region (central part of Croatia).

The results of the Minefield Test are presented in section 5.3, here an overview of the procedure is given.

Test area at Milekovici

Landing zone at Vrankovici

Camcopter with payload

ARC Crew

Figure 4-16: Impressions from the Minefield Test Campaign in Croatia, May 2003.

4.4.3.1 Performed Flights

Whereas the flight conditions were very good in the Milekovici region, the second test week in Vrankovici suffered from In the following the accomplished flight missions are listed for the two test areas.

Milekovici

Flight	Start-End	Temp	Height	Area	Results & Comments
F1	19:07-20:02	26°	30, 100, 300	MF31092	Data acq. only for 30m and 2 strips in 100m because of: 1: authorization flight time till 20:00 2. SC-3000 was not on during start up procedure -reset the payload (practical acquisition at 30m) 3. recording was at 0.5Hz -> correction 1Hz
F2	9:12-10:20	15°	30, 100, 300	MF31092	Morning flight of diurnal. FR=0.4Hz at 300m

Flight	Start-End	Temp	Height	Area	Results & Comments
			300		
F3	11:54-12:32	15º	900	MF31092	FR=0.15Hz
F4	13:10-14:05	14.5º	30, 100, 300	MF31092	Noon flight for diurnal mission. No DA at 300m an on some strips af 100m.
F5	17:52-19:00	16.4º	30, 100, 300	MF31092	Evening flight for diurnal mission. Skipping last two strips of 30m.
F6	11:50-12:50	18.0º	30, 100, 300	MF31077	Noon flight for diurnal mission. At 12:50 flight stopped because of ignition system problems.
F7	17:58-19:05		30, 100, 300	MF31077	Evening flight for diurnal mission. FR=0.9Hz. Strip 7/8 for 30m was with exposure 30 and gain 75. Strip 15 for 30m was with exposure 45 and gain 75.
F8	09:10-10:04		30, 100, 300	MF31077	Morning flight of diurnal. FR=0.9Hz Not full mission possible, less strips at all levels.
F9	11:40-12:35		300	MF31077	Additional flight at 100m over the road.
F10	18:20-19:00		300	MF31077	300m with 0,4 Hz Duncan.

Table 4-3 Performed flights in Milekovici

Vrankovici

Flight	Start-End	Temp	Height	Area	Result & Comments
F11	10:15-11:07	28	900	MFR 1273, 1274	flight 450m from landing point 1000*800 meter
F12	15:30-16:00	temp drop.	300	MFR 1268	Strong wind ca. 22 Kn., temp drop.

Table 4-4 Performed flights in Vrankovici

4.4.4 REFERENCE SCENARIO

This section gives a short overview of the GIS database content of thematic maps, satellite imagery and Mine Information System.

4.4.4.1 THEMATIC MAPS

Thematic maps covering the following information have been available (in different degrees of completeness):

- Maps
- Land cover
- Rivers
- Topographic maps
- Orthomaps
- Digital Elevation maps
- Infrastructure maps:
    - Roads
    - Streets
    - Power lines
    - Water supplies
    - Bridges
- Population settlement

4.4.4.2 SATELLITE IMAGERY

IKONOS images were purchased for both Minefield Test areas, an example for the Milekovici area is given in the figure below. The additionally purchased Landsat TM data were not used because of the strong limitations of scale.

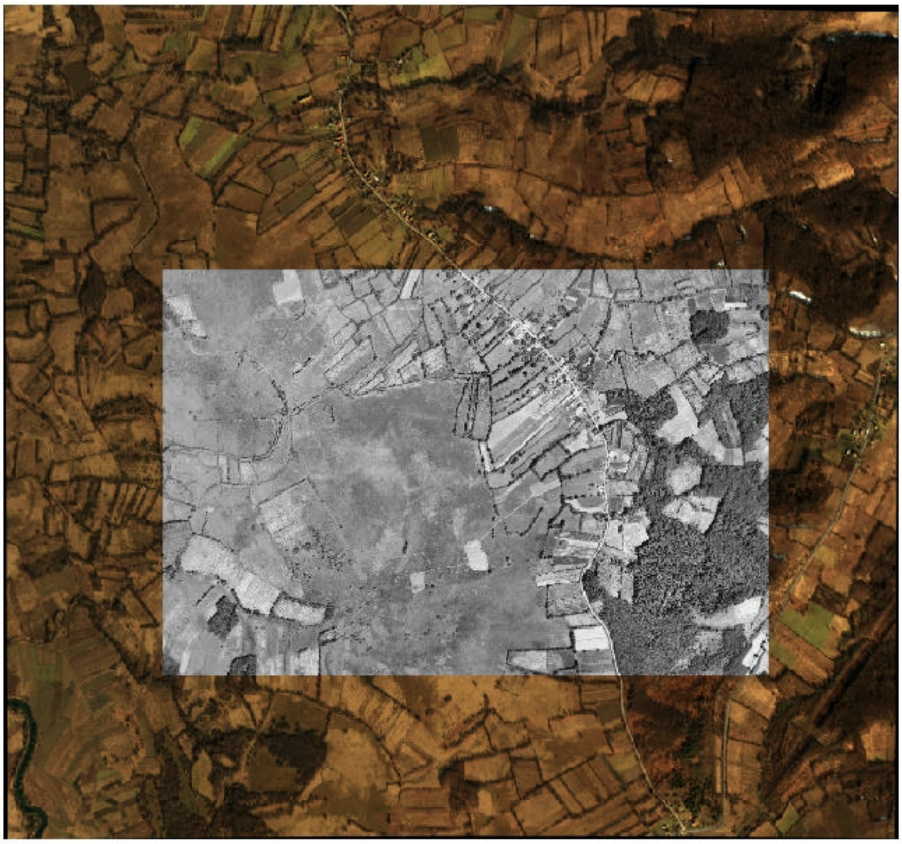
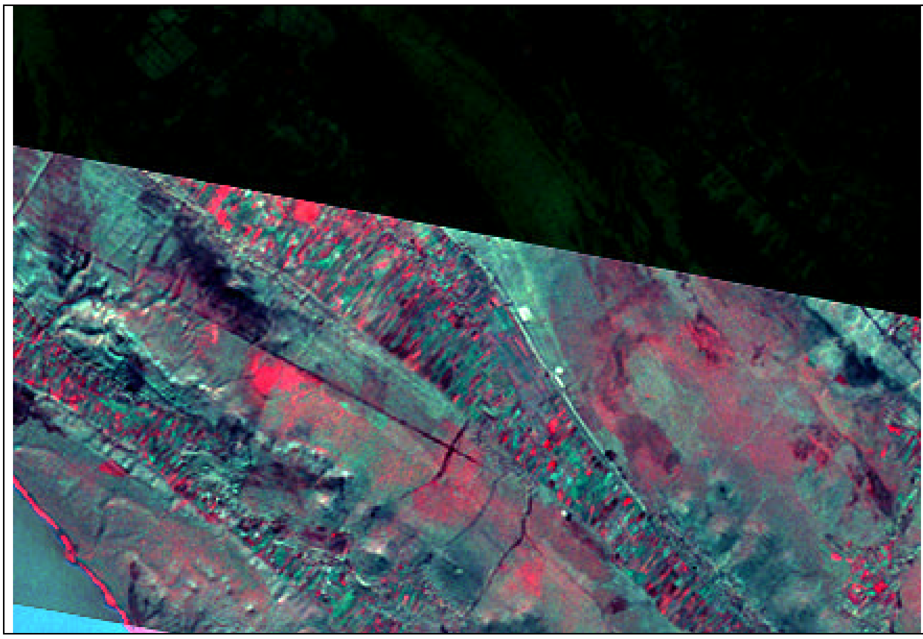


Figure 4-17 Outer image: IKONOS Satellite image; Inner image: reference orthophoto.

For satellite change detection two periods have been used, 1997 and 1984. For reasonable results on change detection and change classification at least two multi-seasonal datasets are required. This is a well-known pre-requisite already under central European conditions and even more important in the dryer climate in Croatia.

During the search for appropriate satellite data it became clear, that only a limited number of datasets was available for the test areas both for Landsat TM and SPOT sensors. For the project a set of Landsat TM data have been purchased, ortho-rectified and evaluated.

Because of the limited amount of data and the rather low resolution of the data (30m/pixel) the conclusions which can be drawn from the results are restricted.



Change detection (Difference image) of the Landsat TM data above. Vegetation decrease between the two acquisition dates appears in red, new roads in dark grey, removed buildings and unused roads in brighter grey.

Figure 4-18 Change Detection Results for the Vrankovici area.

4.4.4.3 MINE INFORMATION SYSTEM

The Mine Information System refers here to MAGIS: the Geographical Information System of CROMAC. The different geographical mine information received for MFT are listed in Table 4-5, and shown in Figure 4-19.

Data Category (acronym)	Type	Feature Type Reference	Feature Type Name	# of files	# objects in GEO-DB	Observations
Mine Information System						
Mine Field Records (MIS)	Scanned paper - GIFs			3		
MIS	Vector	FT_CRO_001	Incident	1	4	
MIS	Vector	FT_CRO_003	Suspected	1	29	
MIS	Vector	FT_CRO_005	MFRarea	1	6	
MIS	Point	FT_CRO_006	MFR	1	32	
MIS	Vector	FT_CRO_002	ClearedArea	1	27	

Table 4-5 Mine Information Layers

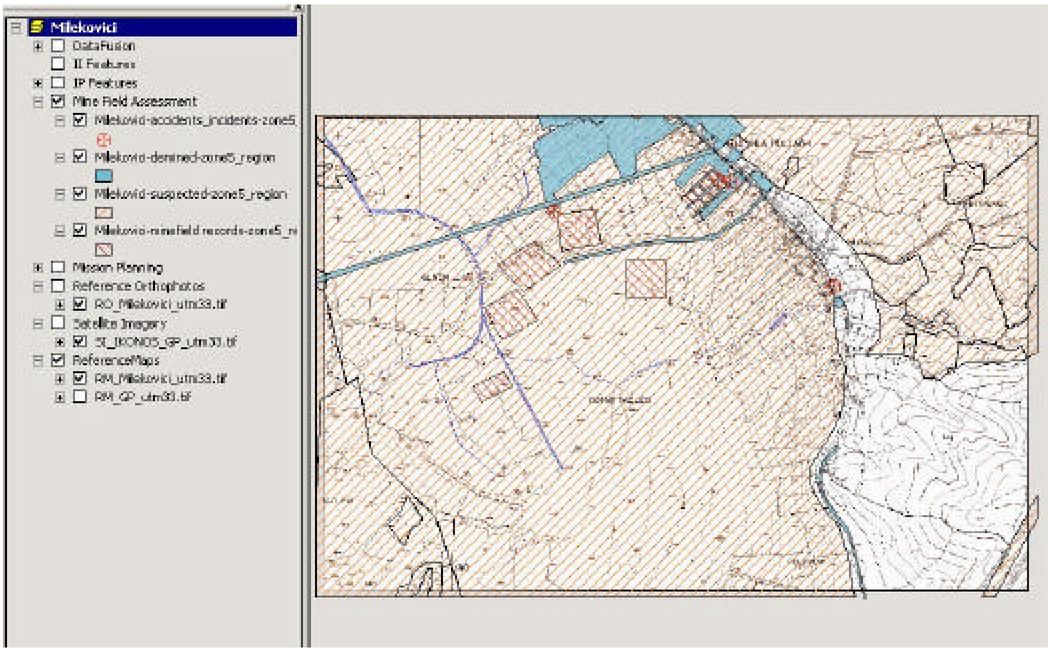


Figure 4-19 Mine Information layers (Blue: Cleared areas, rectangles: minefields, red circles: mine incidents, hashed red: suspected area

4.5 MINEFIELD DEMONSTRATION

As a final activity within the ARC project the developed system and the achieved results were presented to a wider public on November 27th, 2003. Although originally planned to take place in Croatia, the Demonstration was held in a military exercising area in Grossmittel near Vienna, Austria. The reason for this change was that the demonstration could be executed more efficiently in this way both in terms of logistics and travels of the visitors.

The demonstration activities extended over a full day and were preceded by a preparation day. The demonstration schedule comprised the following main activities (see also Annex 1):

- General Presentation of the ARC Project and Concept
- Presentation of the Survey Platform and the Flight Mission
- Flight Demonstration
- Detailed Presentation of the ARC Concept and Results

For the demonstration day the project coordinators sent out roughly 700 invitations by email all over the world (with an emphasis on Europe), the consortium partners used their direct contacts to support this invitations. The demonstration was attended by 35 persons of this circle, plus 20 persons of the ARC Team (half of them from Schiebel) and 25 persons from the Austrian Army.

The reception of the ARC Demonstration was generally very positive and a number of contacts for potential co-operation have been made.

The images below give an impression of the demonstration event.

Figure 4-20: The attendants of the Minefield Demonstration day (left), real-time projection of flights (Camcopter and data acquisition, right)

5 RESULTS

This section summarises the results achieved during the lifetime of the ***ARC*** project. It is mainly based on deliverables D22 (System Design Document), D36 (System Implementation Report), D49 (Minefield Test Evaluation) and D50/53 (ARC System Report).

5.1 SYSTEM DESIGN

This chapter provides an updated (identifying specific design choices for the implementation) summary of system concept design provided in D13 (System Concept) and D09 (System Requirements), and is a summary of D22, System Design Document.

5.1.1 SYSTEM ACTORS

The term *ARC Operator* (as defined in [D04]) refers to entity who will operate the **ARC SYSTEM**. Can be MAC or non governmental organisation or company hired by MAC (e.g. follower of **ARC** consortium). For the use of the **ARC SYSTEM**, the *ARC Operator* entity shall involve a *team of ARC operator* and a *supporting group from MAC*.

System actors refer the different roles of the human team that operates the ARC system. As they were identified in [D09], they are the following:

1. MAC Team Member
    - 1.1. Manager: i.e., the End User representative
    - 1.2. De-miner Expert
2. ARC Team Member (generic ARC team member)
    - 2.1. Team Leader
    - 2.2. UAV Pilot
    - 2.3. Sensor Operator
    - 2.4. Maintenance Operator
    - 2.5. GIS Operator
    - 2.6. Data Analyst
        - 2.6.1. Image Processing Operator
        - 2.6.2. Image Interpreter Operator
        - 2.6.3. Data Fusion Operator

The *Team Leader* role refers to the person in charge of the coordination of the different activities in the operation of the system, leading the operational decisions (mainly in mission planning).

UAV Pilot role is charge of receiving the mission planning specification and conducting, in cooperation of the *Sensor Operator* the data gathering flight mission. These two roles, together with the *Maintenance Operator* conform the ARC Control Station (on-site) human team.

Data Analyst refers to the generic role of dealing with the gathered data across the different stages of the system data flow. Depending on the type of data and type of process to be performed, this role is further split in Image Processing Operator, Image Interpreter, and Data Fusion Operator. Nevertheless, the main point in common of this three sub-roles is that all of them drive the generation of features on the basis of a) the available data, and b) their own knowledge about the process:

- Image Interpreter must posses knowledge about the sensors characteristics, the type of objects have to be found in the image,
- Image Processing Operator must posses the domain knowledge about the software algorithms that are to be used,
- Data Fusion Operator must posses knowledge about the concept of Minefield boundary, Minefield area reduction, and knowledge about the data fusion concept and data fusion algorithms, in order to be able to configure the system (i.e., to perform what in [D10] and [D13] is called *Human Reasoning*).

This categorisation of the system user roles is based on a functional point of view. That is, the different actors activate the different system functions.

On the other hand, the *GIS Operator* role refers to a generic actor that is involved in the several functions that are perform on the system GIS. Since many of the system functionalities (e.g., planning, data interpretation, product exploitation) are based on GIS applications, this role overlaps with the Data Analyst and Team Leader one.

5.1.2 USE CASES

ARC System use case view specification describes how it is posed to use the whole system. It in fact represents the system requirements. Accordingly, the detailed specification of the use case view is a matter of deliverable D09 (System Reqs). Nevertheless, the next paragraphs provide a summary for self completeness of the present document.

The main use case of the ARC System is to “Perform Airborne Minefield Technical (Level 2) Survey”. Derived from this one, the operation of the system involves the other sub-use cases. Diagram below represents the main diagram of ARC Use Case model, with the associated actors in each case.

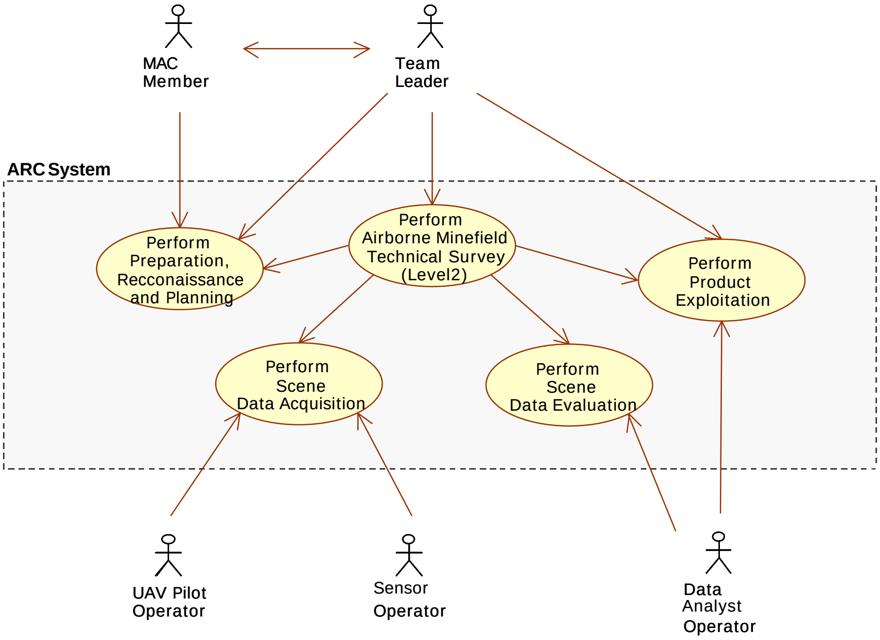


Fig. 5-1 ARC System Use Case View Diagram with Actors

Advancing an insight into the ARC system components, a further detailed view of use cases is as follows:

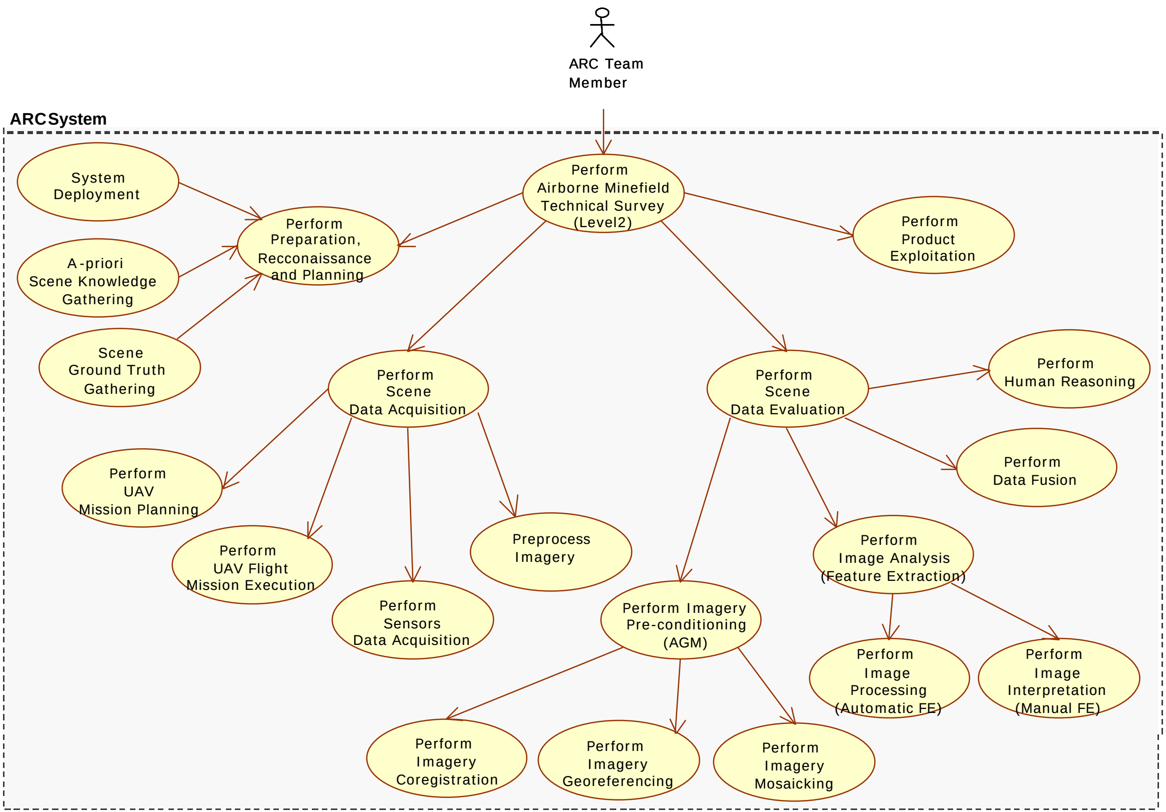


Fig. 5-2 ARC System Use Case View Diagram: System main operations

UC0. "Perform Airborne Minefield Survey (Level2)"

UC1. "Perform Preparation, Reconnaissance and Planning"

UC1.1. "Perform System Deployment"

UC1.2. "Perform A-priori Scene Knowledge Gathering"

UC1.3. "Perform Ground Truth Knowledge Gathering"

UC2. "Perform Scene Data Acquisition"

UC2.1. "Perform UAV Mission Planning"

UC2.2. "Perform UAV Flight Mission Execution"

UC2.3. "Perform Sensors Data Acquisition"

UC2.4. "Import Data & Preprocess Imagery"

UC3. "Perform Scene Data Evaluation"

UC3.1. "Perform Imagery Pre-conditioning (AGM)"

UC3.1.1. "Perform Imagery Co-registration"

UC3.1.2. "Perform Imagery Geo-referencing"

UC3.1.3. "Perform Imagery Mosaicking"

UC3.2. "Perform Image Analysis" (Feature Extraction)

UC3.2.1. "Perform Image Processing" (Automatic Feature Extraction)

UC3.2.2. "Perform Image Interpretation" (Manual Feature Extraction)

UC3.3. "Perform Data Fusion"

UC3.4. "Perform Human Reasoning"

UC4. "Perform Product Exploitation"

This decomposition reflects in a chronological sense how the system shall be operated. In fact, it summarises the operation of the system.

5.1.3 COMPONENTS

According to the System Concept as presented in D13 and the following design work, the system components identified and chosen for the implementation of the ARC system are summarised in the following diagrams. These diagrams represent the basis of the system component and system interfaces design specification which are detailed in [D22A].

The next diagram shows the overall system architecture logic view. The blue blocks (*Functional Blocks*) represent the pure data processing components. That is, automated processes supported by the user. Each one has specific HMI, although as the system implementation progresses (evolutionary prototyping approach), these components are though to perform more autonomously and with less user intervention. This does not count for the remarkable case of DataFusion Processing block. It is envisaged that the domain expert will have to feed the knowledge base of the DataFusion Processing block for an undefined time, as far as the domain expert itself acquires this knowledge, along the lifecycle of exploitation of the ARC system. On the other hand, on the right side of the picture, the green blocks represent functionalities that are mainly based on human processes, supported by the tool. All this functions are based on the GIS HMI. In the centre, grey blocks represent the main types of data that are managed in the system.

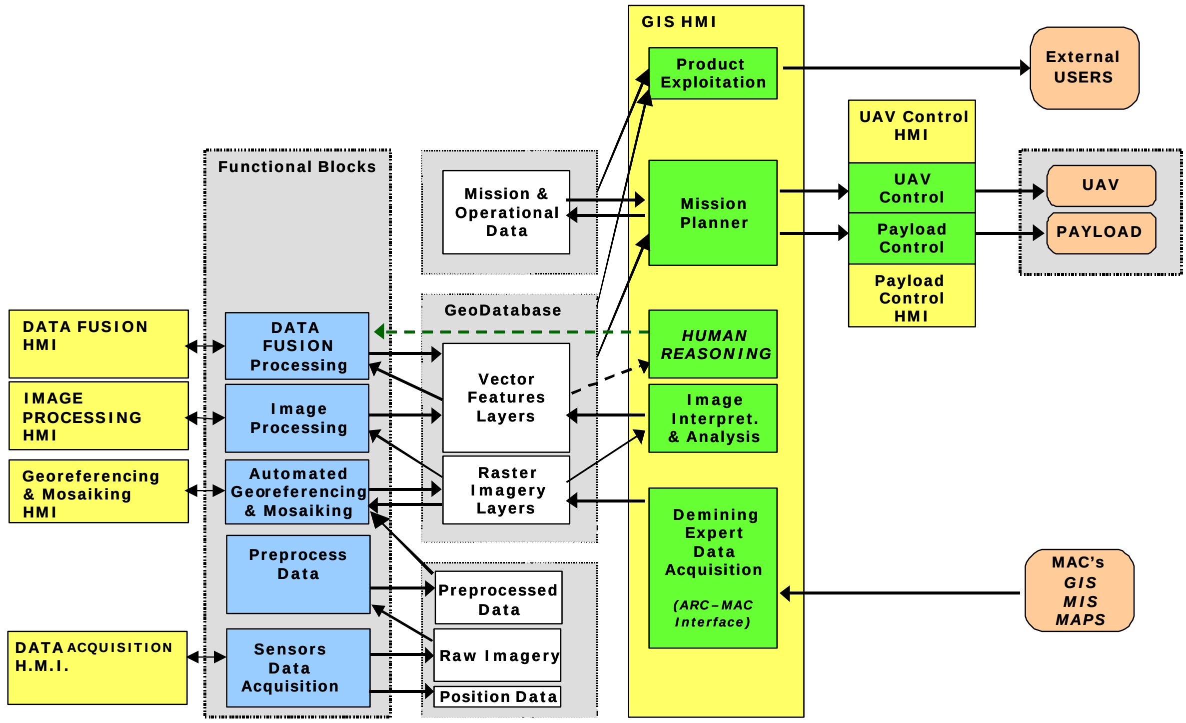


Fig. 5-3 ARC System Logical View

The following two diagrams show with more detail this architecture, enhancing the interfaces between blocks. The interfaces are defined in Chapter 2 in Annex document.

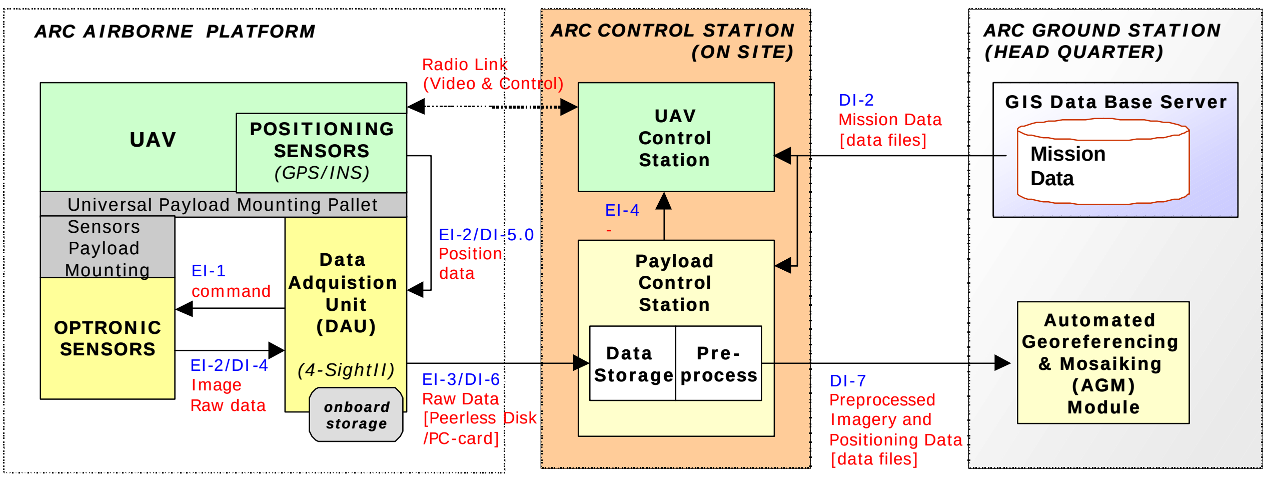


Fig. 5-4 ARC Airborne Platform and Control Station On Site System Components Overview

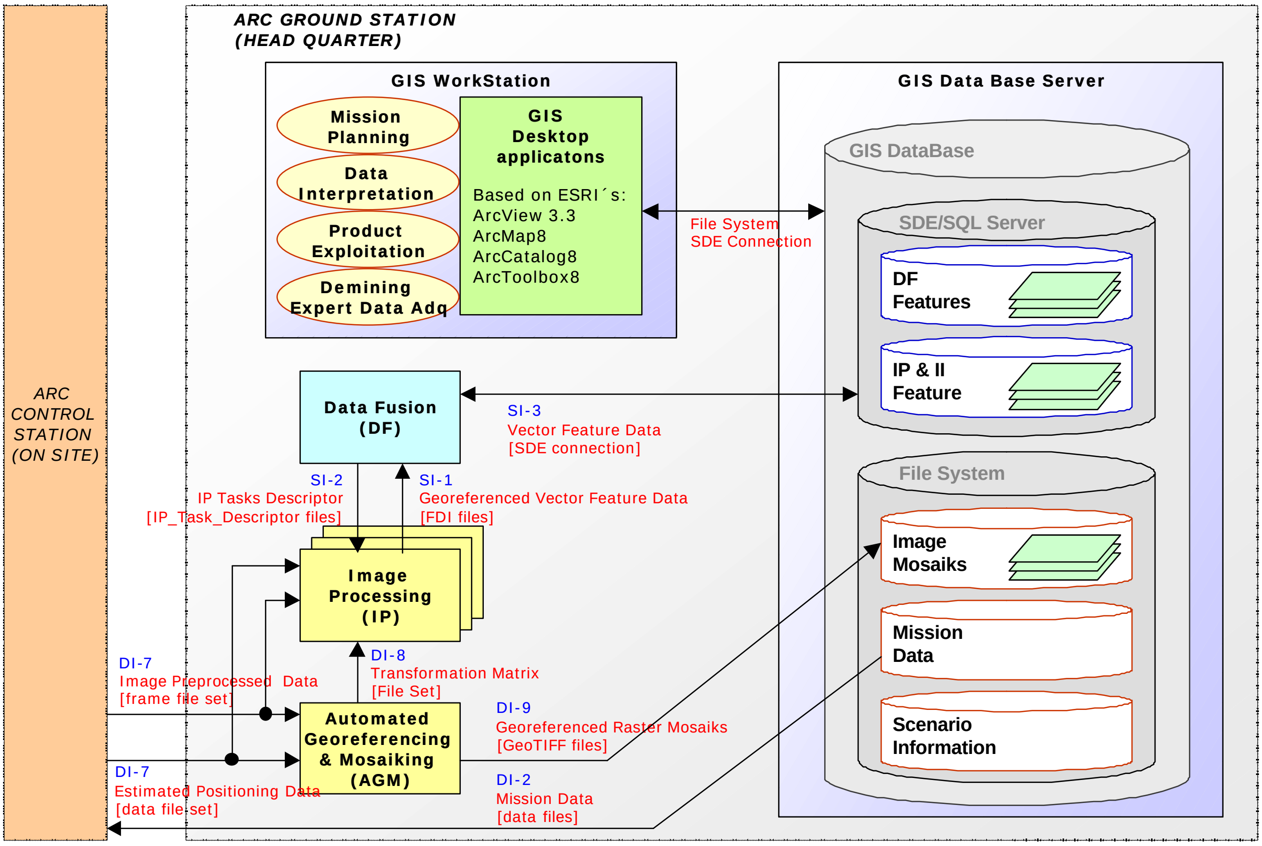


Fig. 5-5 ARC Head Quarter System Components Overview

5.1.4 DATA FLOW

Data Flow Operation Sequence

For a nominal execution scenario, the sequence of execution of the different components of the system, from a point of view of data flow (messages interchange between the system components), can be seen as follows:

Step	UC#	Actors involved	System Component Used	Main Process / Outputs produced
1)	UC1.1	MAC member GIS User	MAC-ARC Interface	• Outputs *Scenario Information CD*
2)	UC1.2	GIS user	ArcCatalog	• Imports Satellite images and Change Detection Results
3)	UC1.3	GIS user	ArcCatalog	• Imports MAC´s Scenario Information CD, and sets up the basic data structure in ARC GIS
4)	UC2.1	GIS user	Mission Planning	• Outputs *Mission Plan Data Package*
5)	UC2.1	UAV Op	UAV Control Station	• Outputs *Navigation Plan*
6)	UC2.1	Sens Op	Payload Control Station	• Outputs *Sensor Flight Plan*
7)	UC2.2	UAV Op	Airborne platform	• Executes mission (navigation) plan
8)	UC2.4	Sens Op	Payload Control Station	• Imports Raw Data from Data Acquisition

Step	UC#	Actors involved	System Component Used	Main Process / Outputs produced
				Unit • Preprocess Raw Imagery and Position Data
9)	UC2.3	Sens Op	Payload Control Station	• Performs Sensor Data Acquisition • Outputs *Position Raw Data Package* • Outputs *Imagery Raw Data Package*
10)		Sens Op	Arc Head Quarter	• Imports Preprocessed Imagery and Position Data
11)	UC3.1	Data Analyst	AGM	• On the basis of, a reference orthophoto image, the available set of images (frames), and the positioning information from GPS/INS, and Produces: o *Geo-referenced Acquired Images* o *Geo-referenced Image Mosaics* o *Transformation Matrix*, (rotation, translation, distortion, and World Coords Origin of each frame
12)		Data Analyst	ArcCatalog	• Imports *Geo-referenced Acquired Images* • Imports the *Geo-referenced Image Mosaics* into de Geodatabase
13)	UC3.2.1	Data Analyst	Image Processing	• Processes each frame, and produces the vector feature objects in pixel coordinates. • Transforms the obtained objects in pixel coords into world coordinates, by applying again the transformation matrix • Saves the feature objects (with coordinates geo-referenced in world coordinates) into a matlab file, by means of the provided matab API • Outputs a *Feature Data File Package*
14)	UC3.2.2	Data Analyst	ArcMap	• Performs visual image interpretation of mosaics and acquires images using ArcGIS desktop software, and produces *features objects* inside the Geodatabase.
15)		Data Analyst	Feature Data File Import tool	• Imports the Feature Data Package into the Geodatabase. • Thus, produces a set of Feature Layers in the Geodatabase.
16)	UC3.3	Data Analyst	Data Fusion	• Applies data fusion rules to the available feature objects in the Geodatabase. • Produces *Data Fusion Features* in the Geodatabase • Produces a *Data Fusion Process Report*.
17)	UC3.4	Data Analyst	Data Fusion	• Performs Human Reasoning on *Data Fusion Features*
18)	UC4	Data Analyst	Product Exploitation	• Produces *Scene Maps* with the available feature layers in the Geodatabase.

Table 5-1 System Components Batch Processes definition Table

5.1.5 DEPLOYMENT

ARC System is structured around three main components (or segments):

- ARC Airborne Platform
- ARC Control Station (On-Site)
- ARC Head-Quarter

The following diagram shows the equipment to be deployed when building the ARC system. On the diagram there can be identified the main physical interfaces present in the system.

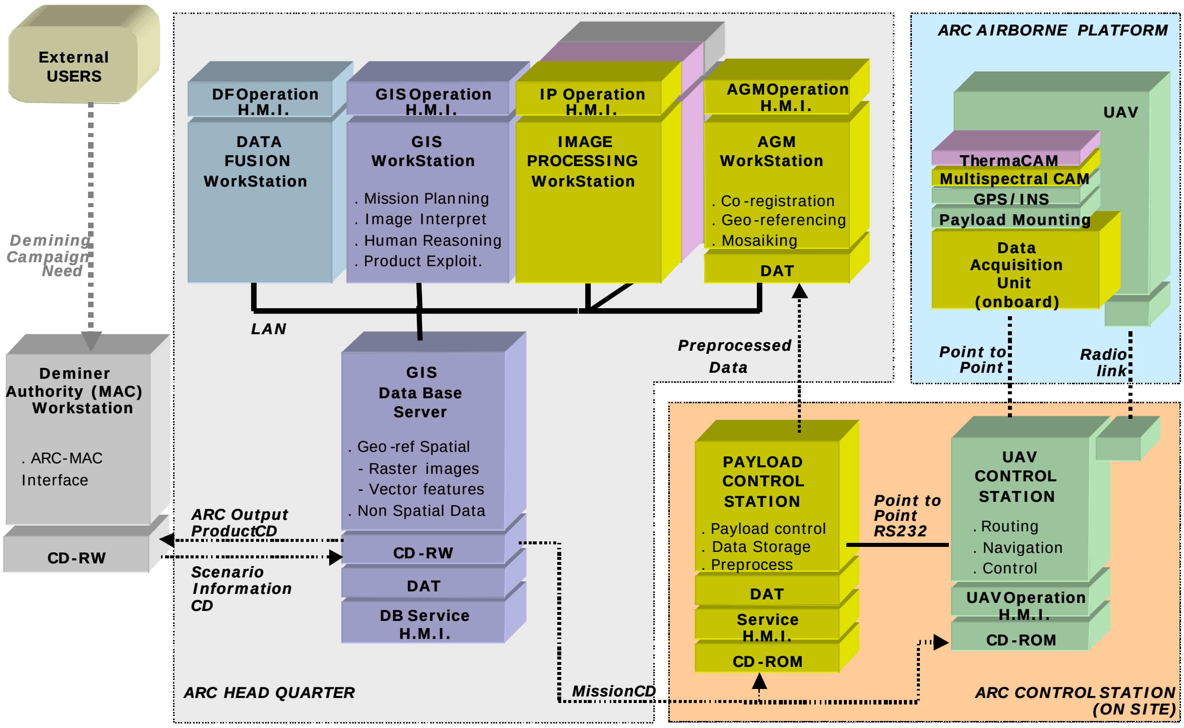


Fig. 5-6 ARC System Deployment Overview

System Components and Configuration Items

As shown Fig. 5-6, the deployment of the system is structured in the following components:

- **CI-1: ARC Airborne Platform**
  - CI-1.1: Unmanned Aerial Vehicle (UAV)
    - (Includes: GPS/INS positioning sensor)
  - CI-1.2: Payload Mounting
  - CI-1.3: Optronic Sensor Set Payload
    - CI-1.3.1: Thermal IR Camera (ThermaCam)
    - CI-1.3.2: Multispectral Camera (Duncantech)
  - CI-1.4: Data Acquisition Unit Onboard

- **CI-2: ARC Control Station On-Site**
  - CI-2.1: UAV Control Station
    - For the control of the UAV navigation, and flight mission data loading.
  - CI-2.2: Payload Control Station
    - For the control of the Payload, flight mission data loading and storage, and pre-processing of the data.
- **CI-3: ARC Ground Station Head-Quarter**
  - CI-3.1: GIS System
    - CI-3.1.1: GIS Server Station,
      - Which deploys the software for the storage, management and distributed access of the Geodatabase of raster and vector feature data.
      - COTS software has been chosen for these functionalities: Microsoft SQL Server 2000 Relational Database Server, and ESRI´s ArcSDE software (the bridge from the client applications to the spatial data inside the SQL server).
    - CI-3.1.2: GIS Client Workstation,
      - which deploys the software for the functionalities of:
        - Mission Planning,
        - Data Interpretation,
        - Human Reasoning, and
        - Product Exploitation.
      - That is, the manual inspection and interpretation of the layers of raster and vector feature data, and the creation of mission data and final product generation.
      - These functionalities shall be implemented over ESRI´s GIS software (ArcView3.3, ArcGIS8 desktop)
  - CI-3.2: Automated Georeferencing & Mosaicking (AGM) Module,
    - Which deploys software for the co-registration, geo-referencing and mosaicking of the gathered sensory data
  - CI-3.3: Image Processing Workstations
    - Which deploy the software application for processing the raster imagery and the consequent production of vector feature data.
  - CI-3.4: Data Fusion Workstation
    - Which deploys the software application for the processing of the feature in the geodatabase, and the production of richer feature types, according to knowledge models about the minefield scene? It shall allow the domain expert to maintain the models knowledge base.

5.1.6 INTERFACES

System Interfaces specification are the basis for the integration of the different subsystems that compose the whole ARC system.

A total of 18 interfaces present in the system have been identified in four categories, for which different numbers of individual interfaces were defined:

1. **Mechanical Interfaces (MI; 1 interface)**: refers to the mechanical attachments between components (here particularly the mounting of the cameras + other equipment on the Camcopter®).
2. **Electrical Interfaces (EI; 5 interfaces)**, refers to the electrical and connectivity interfaces of the components.
3. **Data Interfaces (DI; 10 interfaces)**, refers to the specification of data files produced or consumed (i.e., interchanged) by different components.
4. **Software Interfaces (SI; 2 interfaces)**, refers to the interfaces between software modules (e.g. Application Programming Interfaces (API) or other type of middleware systems).

5.2 SYSTEM IMPLEMENTATION AND INTEGRATION

5.2.1 AIRBORNE PLATFORM AND CONTROL STATION

UAV Overview

The CAMCOPTER® UAV System is made up of the Vertical Take Off and Landing (VTOL) Unmanned Aerial Vehicle (UAV), a Surface Station, and Support Equipment. The CAMCOPTER® UAV's design consists of the modules:

- Mechanics Module
- Engine Module and Fuel Tanks
- Landing Gear Module
- Electronics Module
- **Payload** (redesigned after trial III)

Camcopter® Payload

The development of the payload system has progressed in three major versions. After the first version a test flight with the Camcopter® was performed and experiences were taken into consideration for development of the second version. The second version was also tested with the Camcopter® in Vienna and minor changes gives the third version. The third version, was used in Trial III in Croatia and enhanced for Trial-IV.

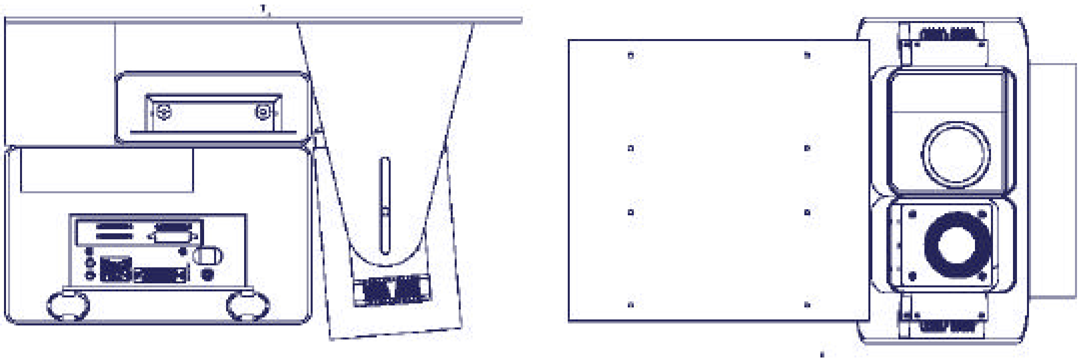


Figure 5-1: Final ARC Payload

5.2.2 ARC GROUND STATION

The ARC ground station is fully described in D22 and D36. The following figures give its main structure with its components and the relations and data flows between the components.

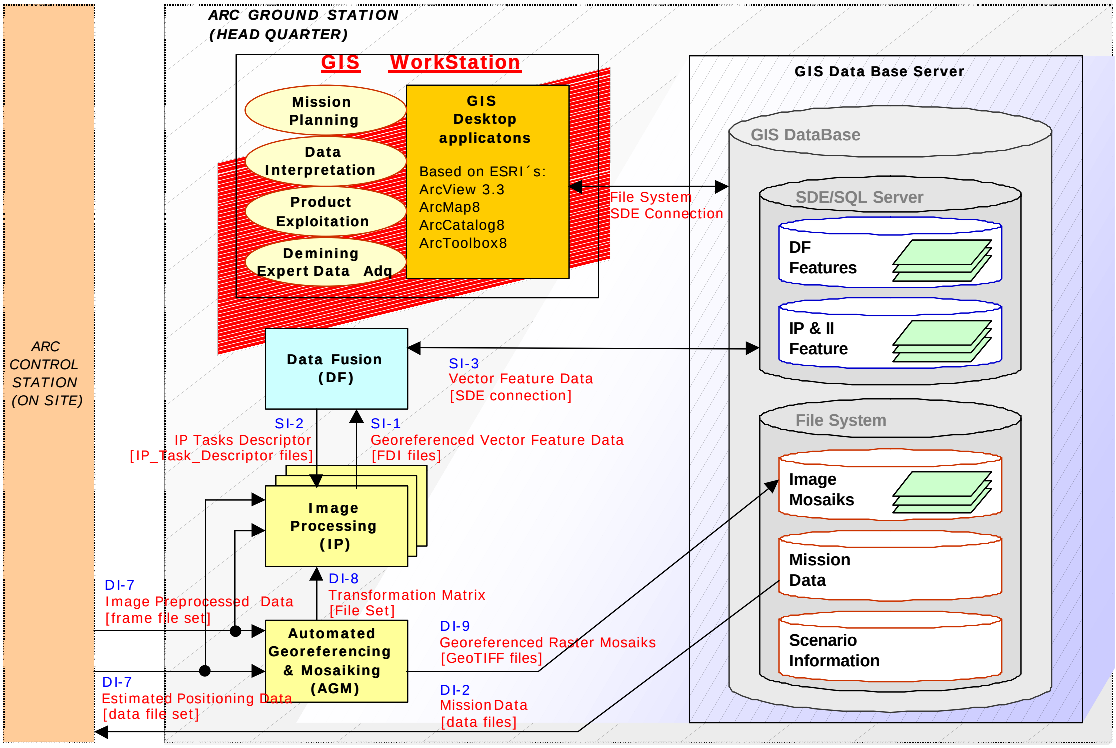


Figure 5-2 GIS Workstation inside the ARC Head Quarter System Components Overview

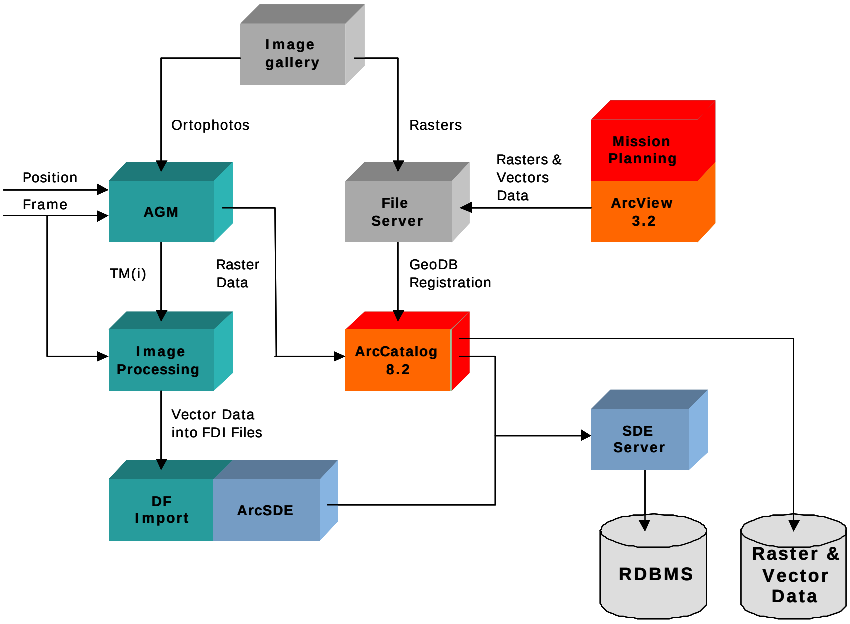


Figure 5-3 GIS applications in the Data Flow chart layout

5.2.3 SYSTEM CAPABILITIES

As a summary the capabilities of the integrated system are given in the tables below. As an important fact it is mentioned here, that for within the typical flight time of the system of 1 hour either an area of about 1.5 hectares can be covered by a full pyramidal flight for detailed analyses (resolution down to 1 cm), or – at an altitude of 900m – an area of 1.5 km² for a general overview with a resolution of 30 cm.

5.2.3.1 SYSTEM OPERATIONAL PROCEDURE

This section summarizes the operational parameters of the ARC survey platform, the operational costs and compares these numbers to conventional methods.

Data collection

The following tables summarize

(1) General data collection parameters, in terms of ground resolution vs. flight height

(2) Flight characteristics vs. covered distance from takeoff/landing point

(3) Typical coverage during a day with one pyramidal mission and two separate missions with larger coverage

(4) Survey (airborne data collection) cost per day.

Flight Height	Footprint (m)	FLIR resolution (cm / pixel)	VNIR Resolution (cm / pixel)	Data acquisition rate (Hz)	Flight Speed (m/s)
30	10*10	4	1	1	5
100	30*30	12	3	1	15
300	100*100	36	10	adapted <1	20
900	300*300	120	30	adapted <1	20

Table 5-2 Flight/Sensors coverage characteristics

Flight Altitude AGL	Climbing time[s]	Descent time [s]	Start and Landing time [s]	Max flight speed [m/s]	Flight time at Flight Altitude AGL [s]	Covered Distance [km]
900	600	870	360	20	1770	35.4
300	200	270	360	20	2770	55.4
100	67	70	360	15	3103	46.5
30	20	0	360	5	3220	16.1

Table 5-3 Flights/area coverage characteristics at ISA atmosphere (15°C,1013mBar, 0m ASL)

Flight Height	Covered area [m^2]	Number of strips	Flight Duration (minutes)	VNIR number of images	FLIR number of images
Pyramidal flights – One Mission			**60**	**780**	**780**
30 m	15.000	24		590	590
100 m	32.000	7		150	150
300 m	70.000	3		40	40
Large Coverage – Separate Missions					
300 m	700.000	12	45	400	400
900 m	1.400.000	4	40	40	40

Table 5-4 Typical Survey Missions Characteristics per day

Maximum Mission Duration	Number of Missions/day	Covered area [km^2]	Number of Persons	Cost per person/day
60 minutes	4-5	7	4 persons operating the UAV and Payload control	1,390€

Table 5-5 Survey cost per day

The total cost per day of survey: 5,560€.

Data Analysis, Integration, Interpretation and Reporting

Considering as example two missions a pyramidal and a large coverage, respectively, the following table gives an estimate of the processing chain in terms of duration and man power in case of operational system. These numbers are given following the exploitation perspectives of the partners to make their products (AGM, Image analysis and Data Fusion) operational.

Covered Area Example two missions: (1) covered area at 900m, and (2) pyramidal flights 300, 100, 30 m	**Acquired data** (Number of Images/Kbytes)		**Automatic Georeferencing** (Number of days/number of persons cost: Euro)		**Image Analysis/ Interpretation** (Number of days/ number of persons)		**Knowledge Rules** (Number of days/ number of persons)	**Data Fusion** (Number of days/ number of persons)
	VNIR	**FLIR**	**VNIR**	**FLIR**	**VNIR**	**FLIR**		
Pyramidal flight **70 000 m² (300m)** **32 000 m² (100m)** **15 000 m² (30m)**	780/ 4Gb	780/ 2GB	**0.25/2MM**	**0.25/2MM**	**5/3MM**	**5/2MM**	**1/1MM**	**5/2MM**
Large area flight **1.4 km² (900 m)**	40/ 0.2Gb	40/ 0.1Gb						

Table 5-6 Man power v.s. processing task

If we consider that an engineer costs 930 Euro/day, the total cost of the analysis of the data acquired over 1.4 km² is 34,410€ and will take 5 days.

5.2.3.2 MINEFIELD INDICATORS

The majority of minefields are laid for specific purposes, for example to deny territory to an opponent (tanks), or to provide defensive capabilities to a target vulnerable to enemy attack. Exploiting any causal relationships that exist between positional targets and minefields presents the opportunity to infer the existence of minefield indicators to be closely related to the occurrence of the minefields themselves. Table 5-7 lists minefield indicators from the 'DG-8 Pilot Project: Airborne minefield reduction in Mozambique – Final Report' and used here as reference list, as it includes as well the minefield indicators detected in Croatia. Table 5-7 gives for each minefield indicator if it has been or not detected during the Trials in Croatia, from which type of sensor and image analysis type (Visual Interpretation or Automatic Image

Type of Indicators	VNIR Y(es)/N(O)/NA[2],		TIR Y(es)/N(O)/NA,		Satellite Y(es)/N(O)/NA,	
	Visual	Automatic	Visual	Automatic	Visual	Automatic
Trenches	Y	Y	Y	N		Y
Protection walls (dry walls)	Y	Y	Y	N		N
Foxholes	N	N	NA	N		NA
Embankment	Y	N	Y	N		N
Leftover military equipment	Y	N	Y	N		NA
Poles, laying and standing	Y	Y	Y	N		NA
Foundation of base camps	N	N	N	N		N
Watchtower	Y	N	Y	N		NA
Minefield markings						
Poles	Y	Y	Y	N		NA
Markers	N	N	N	N		NA
Roads and footpaths/tracks						
Roads out of use	Y	Y	Y	N		Y
New access and services paths	Y	Y	N	N		N
Restricted access	N	N	N	N		NA
Vegetation changes						
Regeneration of natural vegetation on arable land	Y	Y	N	N		Y
Changes in wild vegetation	Y	Y	N	N		Y
Destruction of houses/building	Y	Y	Y	N		NA
Scattered man made object	Y	Y	Y	Y		NA
Circular man made object	Y	Y	Y	Y		NA
Circular soil disturbance	N	N	Y	Y		NA
Circular vegetation disturbance	N	N	Y	Y		NA
Alignment of disturbances	N	N	N	N		NA
Direct identified of AT mine	Y	N	N	N		NA
Direct identified of AP mine	N	N	N	N		NA

Table 5-7 Impact Indicators and airborne sensors

2 NA: Non Applicable

5.3 MINEFIELD TEST RESULTS

5.3.1 OVERVIEW

The Minefield Test was the most important source of data for the evaluation of the system results. Therefore this section lists the results of the Minefield Test obtained by the individual system components as well as by the overall system, and compares the overall result with the ground truth information provided by the end user.

5.3.2 MISSION PLANNING

The surveyed area was limited in the east for safety reasons (start/landing zone lat lower altitude) and in the north due to the presence of a power line, which marks approximately the northern edge of the surveyed area.

The south-western part of the surveyed area has been extended during the MFT. The yellow dotted area in the figure below shows the area covered by the two planned 300m flights (Flight 9 and Flight 10). Flight 3, at 900 m altitude, covered the complete extent of the predefined area.

Several pyramidal/diurnal missions have been planned: Flights 1, 2, 4 and 5 over minefield No.31092 and Flights 6-8 over minefield No.31077.

The following figure illustrates a part of the planned flight paths and their coverage.

For the high altitude flights the flight path covered the planned flight missions. This is not completely the case for the pyramidal flights, as the limitation of the data acquisition unit (on board of the payload) was limited to 800 frames. The flown flight path for the pyramidal flights do not always correspond to the complete mission plan or was slightly modified.

To compare the flight mission to the real flown paths an *additional functionality* of the *Mission Planner* has been implemented after the MFT. This function creates a vector layer corresponding to the **projected** (on the ground) **image frames** and another layer projecting the GPS image centers. Note that, the GPS, frame number are extracted from the *data acquisition* log file.

This functionality helped

- the image analysis partners assessing the area coverage per flight and image, as well as accessing the data,
- assessing the *data acquisition* log file.

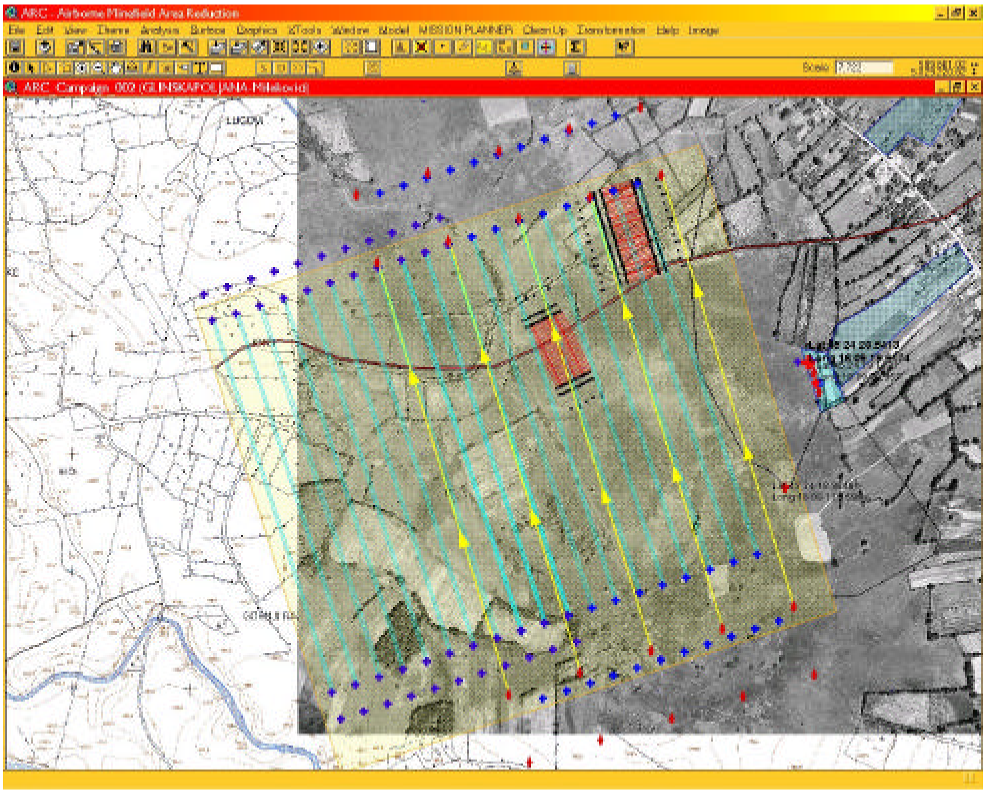


Figure 5-4: Area covered by the flights in Milekovici (dotted yellow area), with some of the planned flight patterns (dots and arrows).

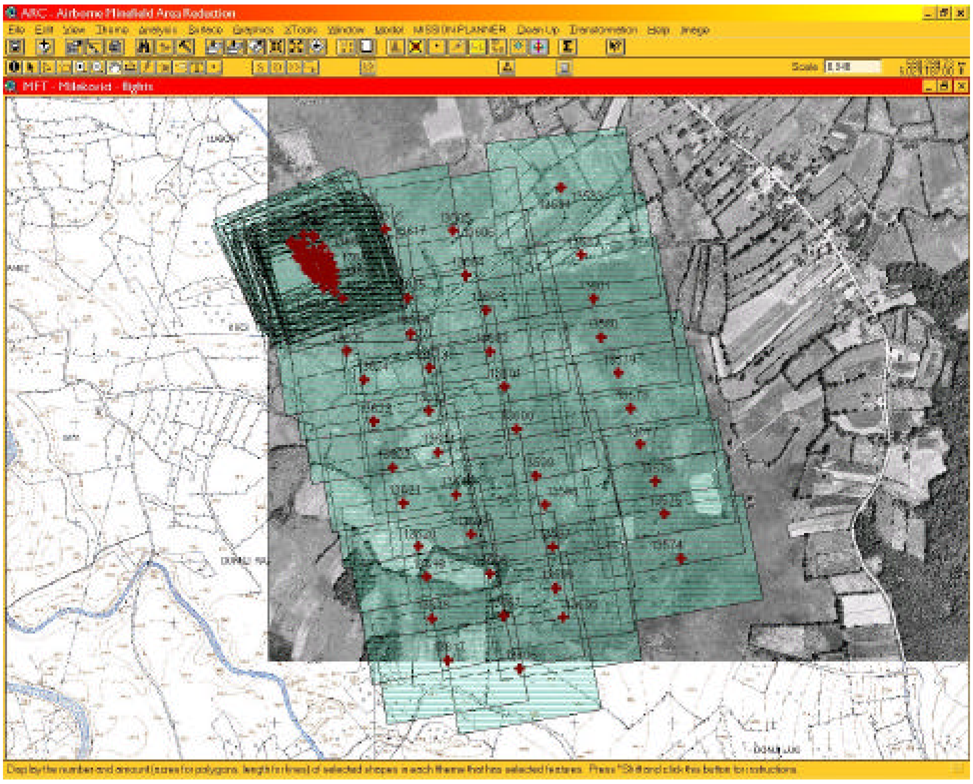


Figure 5-5 Image Frames of the scenes acquired during Flight 03.

5.3.3 AUTOMATIC GEO-REFERENCING MODULE (AGM)

The AGM was used to co-register the image data acquired using different sensors at different times and altitudes. It uses as input;

- VNIR images from 4sightII computer
- FLIR images from FLIR QWIP camera memory card
- GPS and INS data from Camcopter stored on 4sightII computer
- Gain and exposure log file for VNIR camera from 4sightII computer
- Transformation Matrix for 900 meter VNIR image geo-rectification to reference map

After pre-processing (calibration, conversion etc.), AGM performs the image co-registration steps:

- AGM image co-registration
- Transformation of 900 meter highest altitude image to reference map coordinate system
- AGM GEOTIFF image file creation with improved position accuracy
- AGM mosaic creation based on AGM improved position accuracy

The AGM image co-registration techniques are described in detail in D36.A3 'ARC System Implementation – Annex 3: Optronic Sensors'.

The following section illustrates some of the AGM results provided on November 18, 2003.

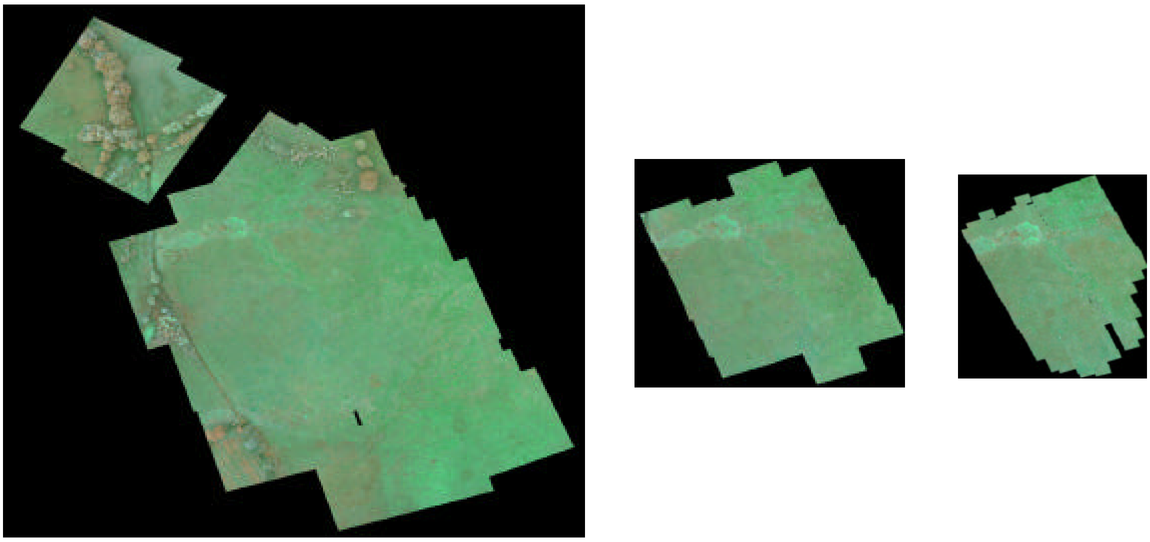


Figure 5-6 GPS based mosaics of Trial MFT flight2 at 300, 100m and 30m altitude, shown with a resolution of 1.5 meter per pixel, after vignetting corrections and colour intensity adjustment.

Manual Geo-referencing of the high-altitude mosaic

The high-altitude mosaic, which is used by AGM as the general reference image, must be geo-referenced to an orthophoto. AGM cannot handle images that were taken at different dates and by different sensors, and therefore this process is not yet automated.

The 900m AGM mosaic was manually geo-referenced to the satellite image RO.Milekovici.utm33.tif using the software package ARC-MAP. Figure 5-7 shows the AGM mosaic and the manually georeferenced mosaic. The mosaic is slightly shifted to the right and is rescaled by a factor 1.03.

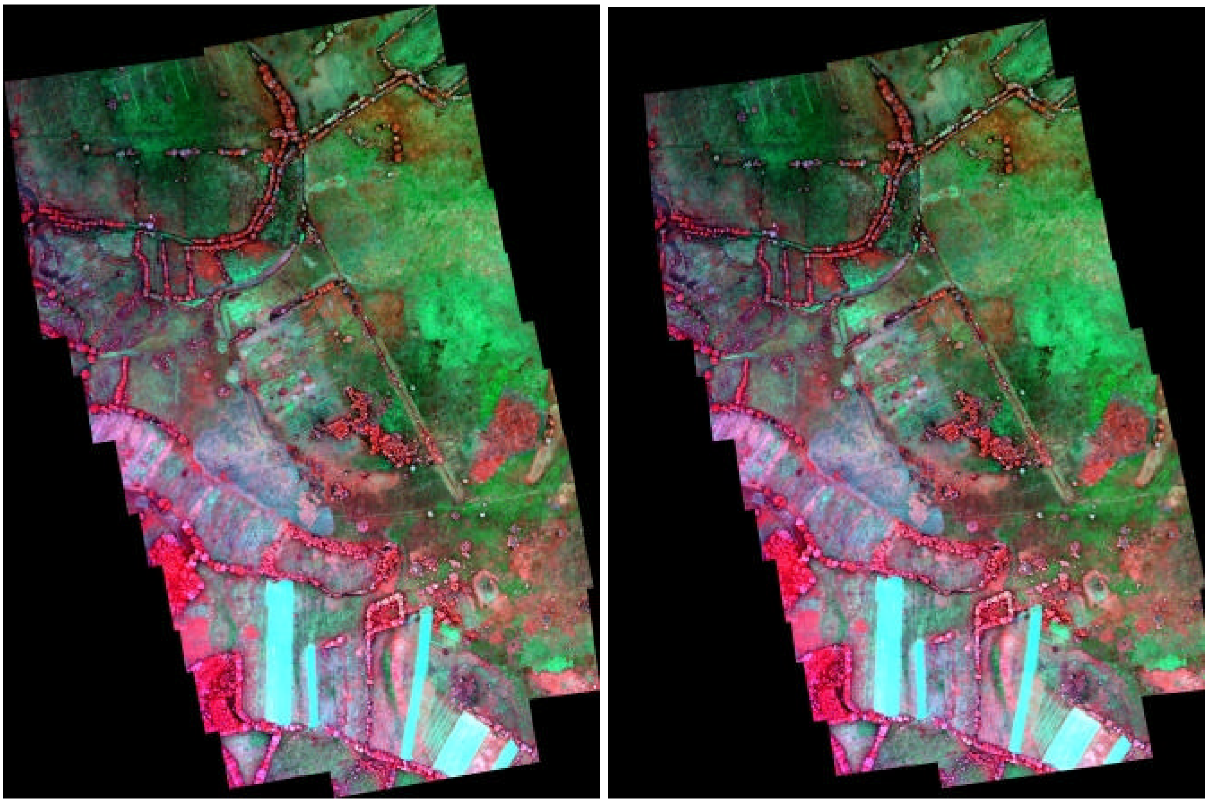


Figure 5-7: AGM mosaic and manually geo-referenced mosaic.

AGM evaluation

In this section, as an example, the AGM results of flight5 are evaluated. First a 900 m image from flight3 is referenced by hand to an aerial orthophoto with a resolution of 30cm. The accuracy is worse than 30 cm because a compression technique has been applied to the image which degrades the image significantly. The accuracy of the orthophoto was estimated to be about 1 m.

For the evaluation of the GPS/INS position accuracy objects in the GPS/INS mosaics and the orthophoto have been determined. The results are shown in Table 5-8. The average position accuracy with respect to the orthophoto is about 17m for an altitude of 900 meters and 1.6m for an altitude of 30 meters.

Table 5-8: Average position accuracy of the GPS/INS mosaics, with respect to the orthophoto.

altitude	average position accuracy (m)	standard deviation (m)
900 m	17.3	10.2
300 m	2.9	1.6
100 m	2.4	1.8
30 m	1.6	0.7

The 900m image was manually geo-referenced to the orthophoto. All images of flight5, taken at 300m, 100m and 30m, were geo-referenced by AGM to the 900m image.

The geo-referenced mosaics for flight5 which had an overlap with the orthophoto are shown in Figure 5-8 and Figure 5-9.

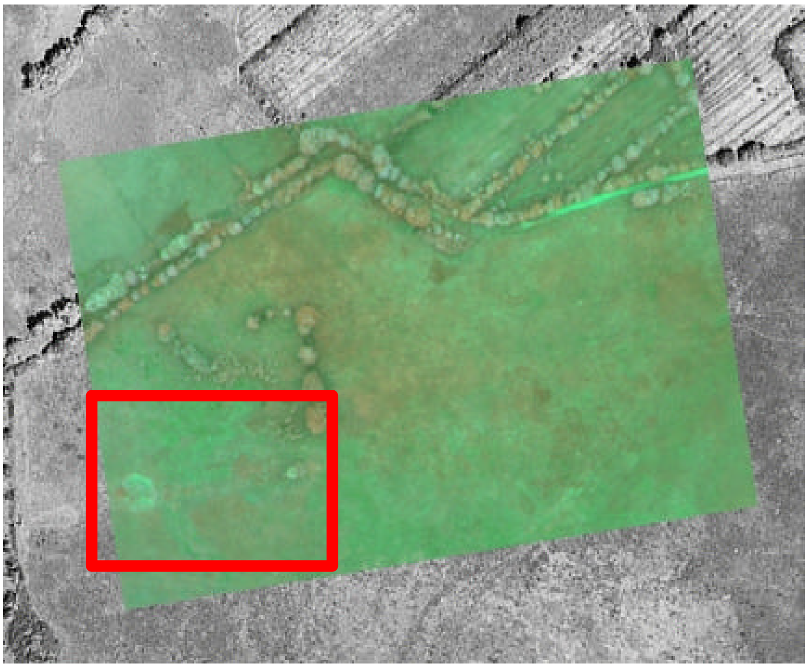


Figure 5-8 Geo-referenced Duncantech image of Trial MFT flight3 at 900m altitude, shown with a resolution of 1.0 meter per pixel. The red box indicates the overlap between flight5 and the low altitude mosaic of that area.

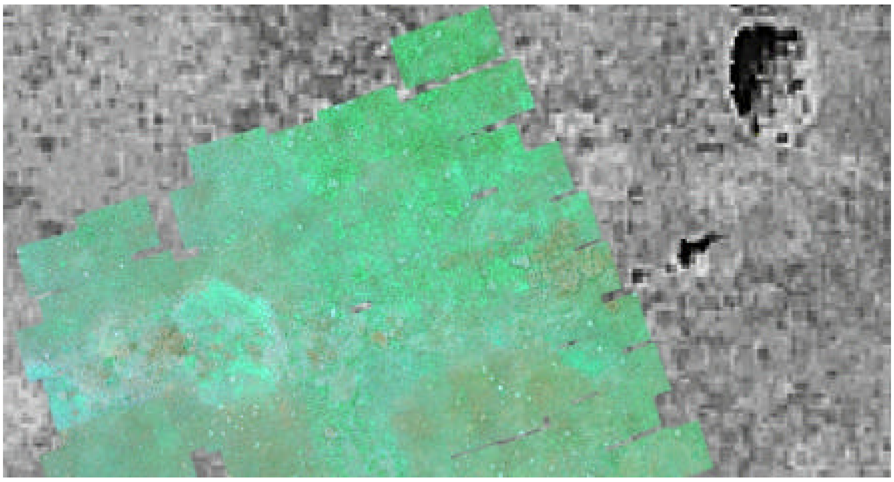


Figure 5-9 Geo-referenced mosaic of Trial MFT flight5 at 30m altitude, shown with a resolution of 0.2 meter per pixel.

For the evaluation of AGM objects the displacements between objects in the mosaics and the orthophoto have been determined. The results are shown in Table 5-9. The average position accuracy with respect to the orthophoto is about 2 m. It has to be noticed that the manual geo-reference at 900 m results in a position accuracy of 1.7 meters. This is due to the fact of the reduced accuracy of the orthophoto and the fact that the number of good reference points is limited, since there are only trees and bushes in the images of flight5.

Table 5-9: Average position accuracy of the geo-referenced mosaics, shown in Figure 5-8 - Figure 5-9, with respect to the orthophoto.

altitude	average position accuracy (m)	standard deviation (m)
900 m	1.7	0.7
300 m	2.0	1.5
100 m	2.0	2.1
30 m	1.8	0.9

In order to get a position accuracy of AGM without contributions of the manual geo-referencing process, the 300m, 100m, and 30m are compared to the 900m mosaic. Table 5-10 shows the position accuracy of the 300m, 100m, and 30m mosaics with respect to the 900m mosaic. The average position accuracy of AGM is about 1 meter, which is about 3 pixels of the reference 900m image. This is consistent with the position accuracy of the combination of AGM and manual geo-referencing of 2 meters, $\mathrm{sqrt}(1.7^2 + 1^2) = 2.0$m.

Table 5-10: Average position accuracy in meters of the geo-referenced mosaics, with respect to the 900m mosaic, shown in Figure 5-8.

altitude	average position accuracy (m)	standard deviation (m)
900 m	-	-
300 m	1.1	0.5
100 m	1.3	0.8
30 m	0.8	0.3

Conclusions

The presented co-registration concept worked technically, the results of mosaicing did not fully meet the expectations. This has several reasons:

1. The AGM starting assumption was to make only co-registration of the individual images to the higher situated lower resolution images with the same sharpness.
2. The interface between manual geo-rectification of highest altitude (900 meter) images and the reference map was not finalised. A temporary (lower quality) solution is currently implemented and tested.
3. Not all images do have the same sharpness. Therefore we use blurring to overcome this problem. Although for some flights it improves the results a bit, in general we cannot compensate.
4. Shadow effects deteriorate the results.
5. The data acquisition synchronization between FLIR camera and Duncantech camera was not technically feasible and caused timing difference and thus Transformation Matrix differences between the two images.
6. The initially planned co-registration algorithm used for image sequences required a much higher accuracy for the initial position estimation then provided by the GPS/INS

information. The currently implemented and integrated co-registration concept is estimated to have sufficient position accuracy to provide the required input for the sequence co-registration methodology with the at the start of the project anticipated performance characteristics.

7. The present implementation of AGM improves the position accuracy from 1.6 m to 0.8 m at an altitude of 30 meters and from 2.9 m to 1.1 m at an altitude of 300m. These figures do not take into account the accuracy of the manual geo-referencing procedure. These numbers can be improved, if all images are focussed, if there is a minimal change in camera settings between altitudes and if the manual geo-referencing is improved.

5.3.4 IMAGE INTERPRETATION/IMAGE ANALYSIS

5.3.4.1 IMAGE INTERPRETATION

Image interpretation results were obtained from the Continuous Data Acquisition (CDA) trials conducted in April 2003 and delivered to the ARC partners by the end of October 2003.

VNIR and TIR image mosaics of the hill in the Western part of Milekovici, acquired at 260 m and 500 m respectively, have been used for the analysis. Military activity minefield indicators have been identified, namely trenches, anti aircraft artillery shelters and paths. Figure 5-10 shows the detected minefield indicators, overlaid onto the reference orthophoto map

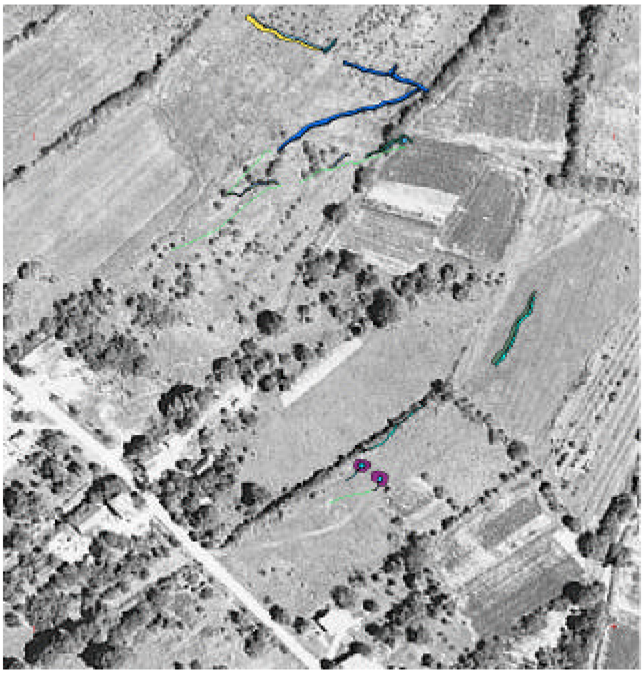


Figure 5-10 Trenches (blue, yellow, black, green), anti aircraft artillery shelters (violet), paths (light green), detected from the mosaics of Figure 5-11.

5.3.4.2 THERMAL IR IMAGE ANALYSIS

The used detection method is a combination of anomaly detection and classification in the spatial and temporal domain as described in D36.A3 'Optronic Sensors Implementation'. The method is also a combination of image processing of IR images and physical based numerical modelling of the dynamic temporal behaviour of different objects with real weather data as boundary conditions.

During the MFT a weather station has been used for recording air temperature and irradiation during. Figure 5-12 shows such measurements.

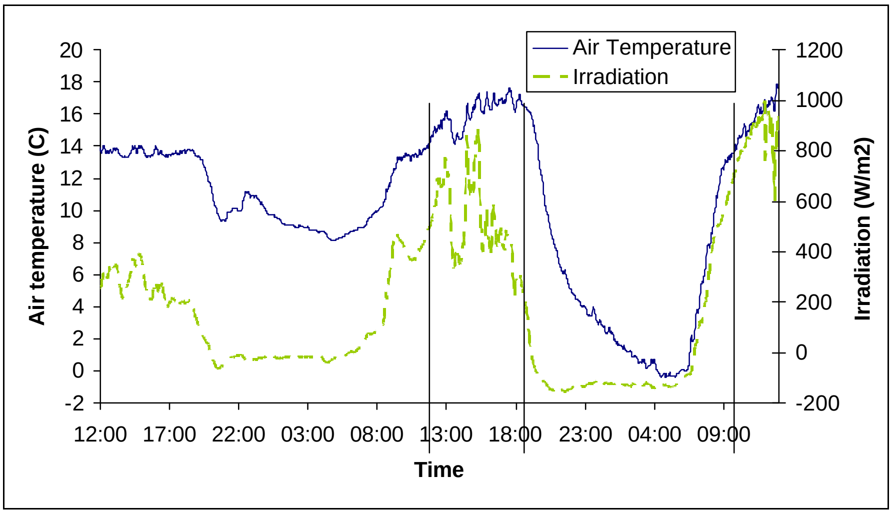


Figure 5-12 Air temperature (solid) and the irradiation(dotted) during the period 13/5 – 16/5.

Reference markers were used for calibration purposes of the IR camera and the images on different operational heights. The markers are painted with black colour and four with white colour with known reflectivity. pt-100 temperature sensors are attached inside the aluminum in the centre of two of the black and two of the white markers, the data were stored for analysis together with those collected for the environment.

Figure 5-13 Left: Reference markers. Right; The 24-channel 16-bit logger system used to gather data from the pt-100 temperature probes.

Co-registration

A multi-stage approach has been used to co-register the thermal data. First, images from a limited local area are chosen, typically 10-50 images from one flight. The pair-wise co-registration of the overlap between all images from the area is computed using the algorithm described in D36.A3 'Optronic Sensors implementation'. The algorithm is initialised with the navigation GPS/INS data. Moreover, corresponding landmarks are indicated by the operator. The resulting three mosaics of a local area from Flights 6, 7, and 8 are shown in Figure 5-14.

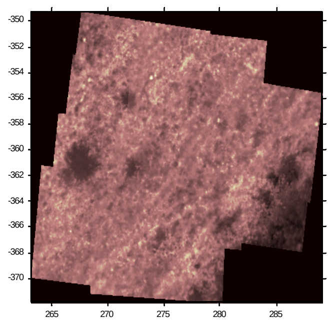
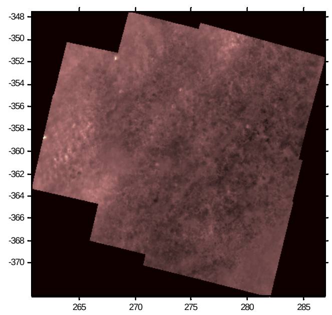
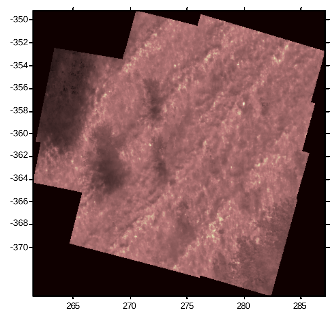
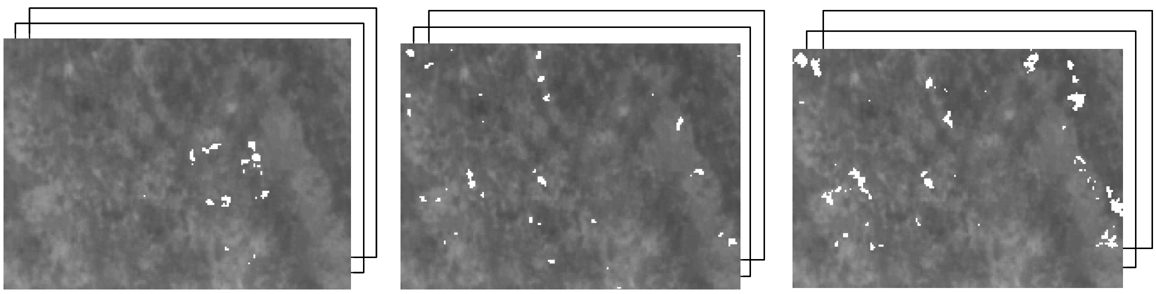
		
Local mosaic from flight 6 (noon).	Corresponding local mosaic from Flight 7 (evening)	Corresponding local mosaic from flight pass F8 (morning)

Figure 5-14 Diurnal co-registration.

Temporal analysis

Diurnal data are used for reducing false detections since a model has to fit the data at several times. The data is analysed using a contrast measure applied on each of the images in the sequence. The measured contrasts are compared to the estimated contrast from the numerical modelling of different objects.

The temporal detection by classification relies on the analysis of the data from the same area but at different times. The temporal signature of every position in the diurnal scene is classified according to the temporal signature of the modelled objects. The classification results, based on the co-registered images of Figure 5-16 are given in Figure 5-15.



Al cased AT mine | Steel cased AT mine | Stone

Figure 5-15 Results from the temporal analysis of three diurnal images from the same area. Positions for detected areas are marked as white pixels in the images.

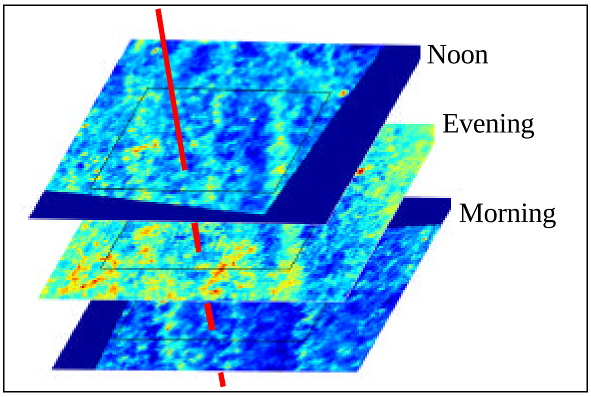
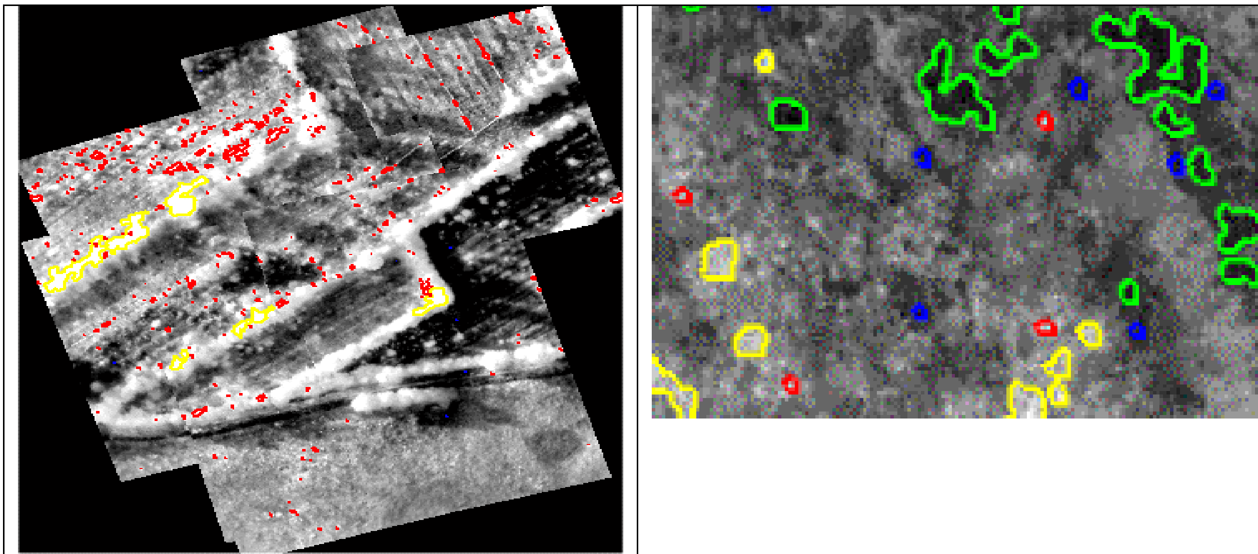


Figure 5-16 Example of co-registered diurnal set of IR images over minefield number 31077.

Anomaly detection

Spatial anomaly detection aims at finding objects or areas in an image having spatial properties that, in some statistical respect differs from the background. Anomaly detection can be used for the detection of objects with all kinds of average temperature contrast with respect to the background as long as the spatial variation of temperatures is different. The algorithm is described in D36.A3 ‘Optronic Sensors Implementation’.

Some examples of hot/cold spot detection are shown in Figure 5-17. Red indicates small hotspots, while yellow indicates larger hot spots, called regions. Blue represents small cold spots, while green represents cold regions.



MFT_flight7_FLIR_Mosaic_0300m_res_0.10.tif. Detected anomalies. Higher threshold than in the right image

Spatial anomaly detection. The arrow points to the only spot that corresponds to a position detected also by the temporal analysis.

Figure 5-17 Detected anomalies.

Conclusions

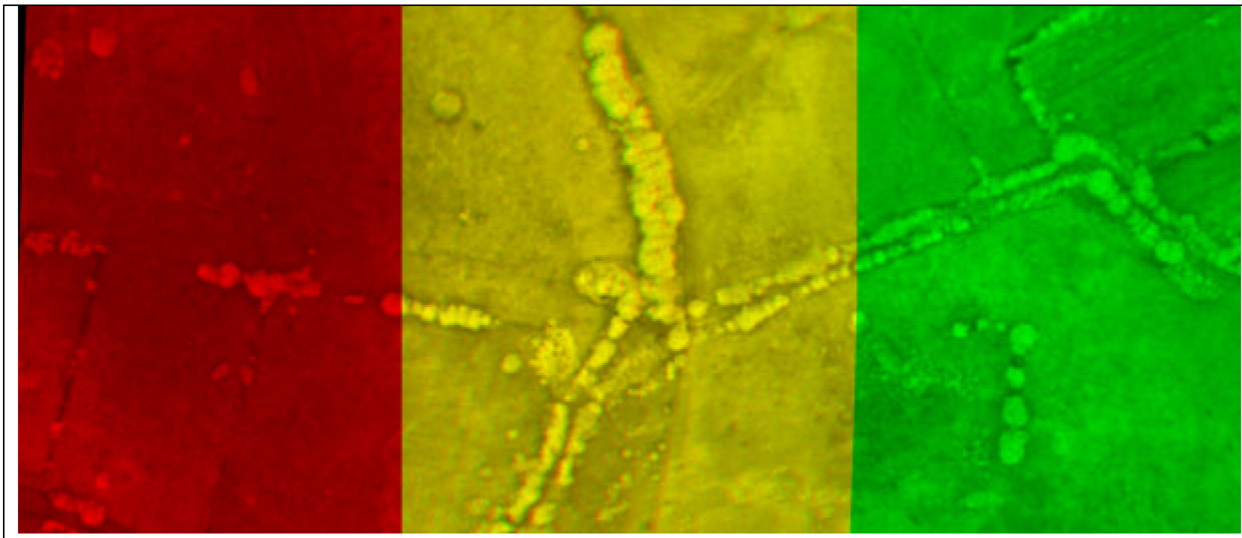
The use of a physical based model, where the boundary conditions are measured weather parameters, give a qualified guidance and could enhance the probability for anomaly detection and find objects or image areas with properties, in some respect, different from the background. The more diurnal images are collected the better the detection and/or classification is.

The quality of the provided features is to a high degree dependent on the geo-rectification, co-registration and calibration of the images. Then it is possible to search for areas that give correspondence between simulated and “real” contrast temperature levels.

5.3.4.3 SPECTRAL/STRUCTURAL IMAGE ANALYSIS

Assessment of AGM data

The originally provided (calibrated and geo-referenced) VNIR data showed inconsistencies in the calibration process as well geo-referencing errors.



After colour calibration and co-registration

Figure 5-18: Mosaic of two successive images from Flight 3. The NIR channel is codified as Red for the left image and Green for the right image. The overlapping part is therefore in yellow, with co-registration errors showing up in red or green.

Table 5-11 gives the root mean square error (RMS) between the overlapping areas of Figure 5-18 for both the uncorrected (first row) and the corrected images (second row). The RMS has been reduced by a factor of around 2 due to the colour balancing and another factor of 2 due to the estimated and corrected shift between the two images. This indicates that the two overlapping areas are much more similar after applying this procedure.

Band	Uncorrected	Colour balanced	Corrected
NIR	2334	1319	569
Red	870	275	143
Green	815	315	164

Table 5-11 Root mean square error (RMS) of intensity difference of the overlapping part for the uncorrected and corrected images.

VNIR/VNIR co-registration of different resolution images

Images from different flight heights can be co-registered as well. For this one of the images needs to be up/down-sampled. It is logical to down sample the high-resolution image (i.e. the 30m image), since otherwise the up-sampled 100m image becomes blurred (no information can be added by up-sampling). In Figure 5-19 an example of this type of co-registration is shown. The RMS of the difference is reduced by 30%, which is lower than the RMS reduction for either the 100m images or the 30m images. Some residual rotation remains visible, which is not corrected for by the gradient-based motion estimator. Another observation was that the 30m image (if down-sampled) is much sharper than the 100m image. Obviously the focussing was not adapted while going from 30m to 100m.

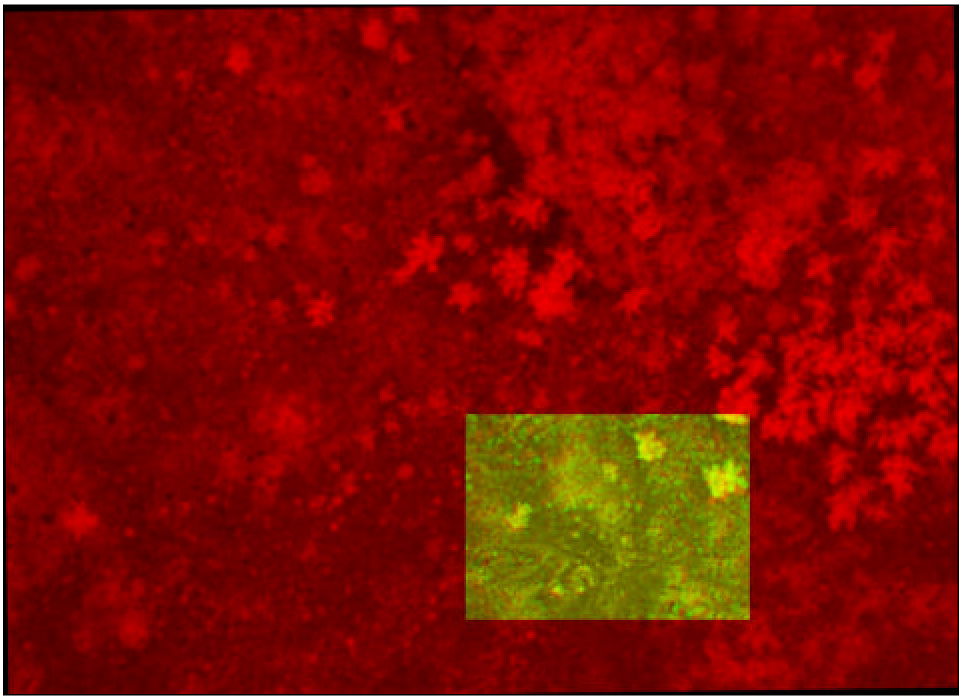
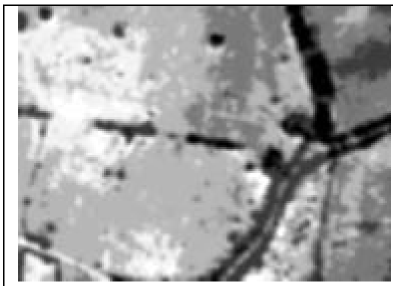


Figure 5-19: Overlapping of two images from flight 4 at two different heights, only NIR channels are shown.

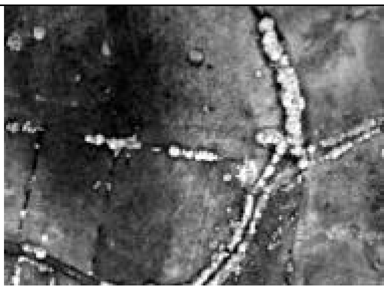
VNIR/FLIR co-registration

Looking the acquired VNIR and FLIR images, the two images overlap very well, since the cameras were observing in the same direction. However, the FLIR and VNIR images do not have the same resolution, that of the VNIR is 3.9 times higher. Furthermore the dynamic range of these particular FLIR images is extremely limited (only 7 different values). Nonetheless it is possible to co-register the FLIR and VNIR images. To be able to do this the NIR image is inverted and its dynamic range is adapted to the FLIR image. The results are shown in Figure 5-20. This procedure allows to obtain a multi-spectral image and to compare features detected from the two modalities.

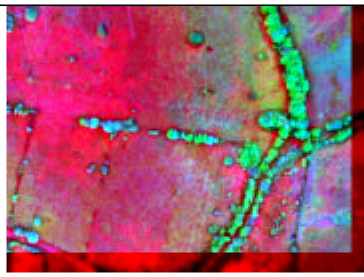
This method has been applied to all 36 images of Flight 3. However, accurate co-registration has been made for only 27 images. The average shift between the two modalities was 11 pixels in the x-direction and 15 pixels in the y-direction, with a standard deviation of 2 to 3 pixels implying that the estimation should be made for each image combination and therefore cannot be considered constant.



FLIR



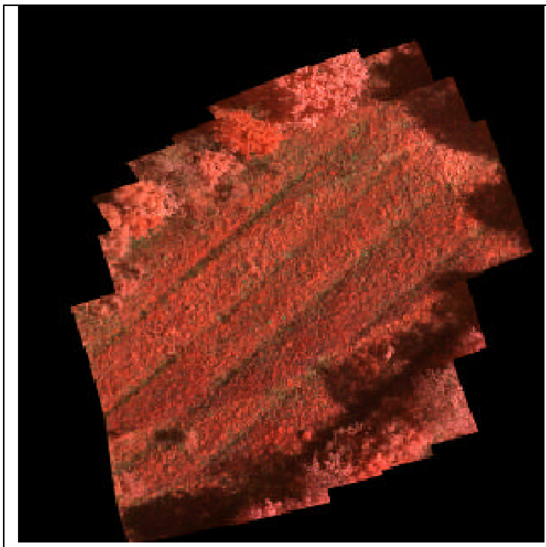
NIR



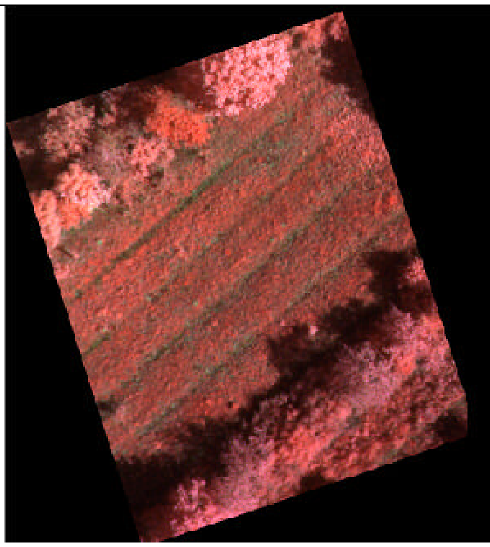
combined

Figure 5-20: co-registration results of the two modalities.

Image Mosaics

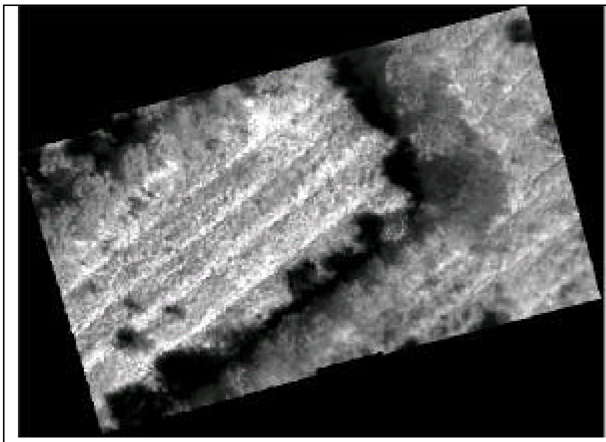


Flight 8 - 30m mosaics (36 images at 1cm resolution)

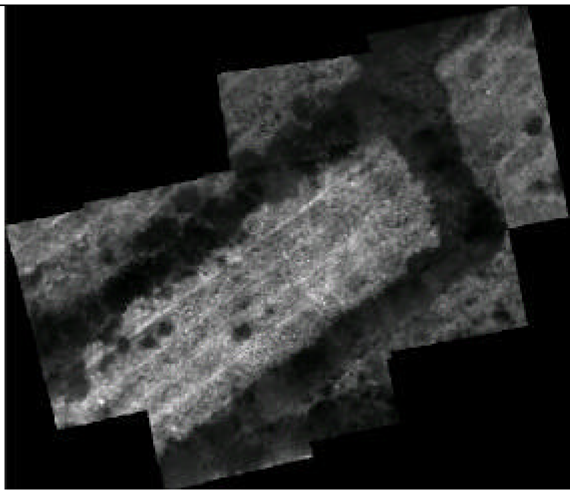


Flight 8 - 100m (1 image at 2 cm resolution)

Figure 5-21 Pyramidal flights mosaics



Flight 8 - 100m FLIR mosaic (Morning)



Flight 6 - 100m FLIR mosaic (Noon)

Figure 5-22 Diurnal flights mosaics

Land cover Classification

Figure 5-23 illustrates the land cover classification results: Green: forest/hedges, light green: cultivated land.

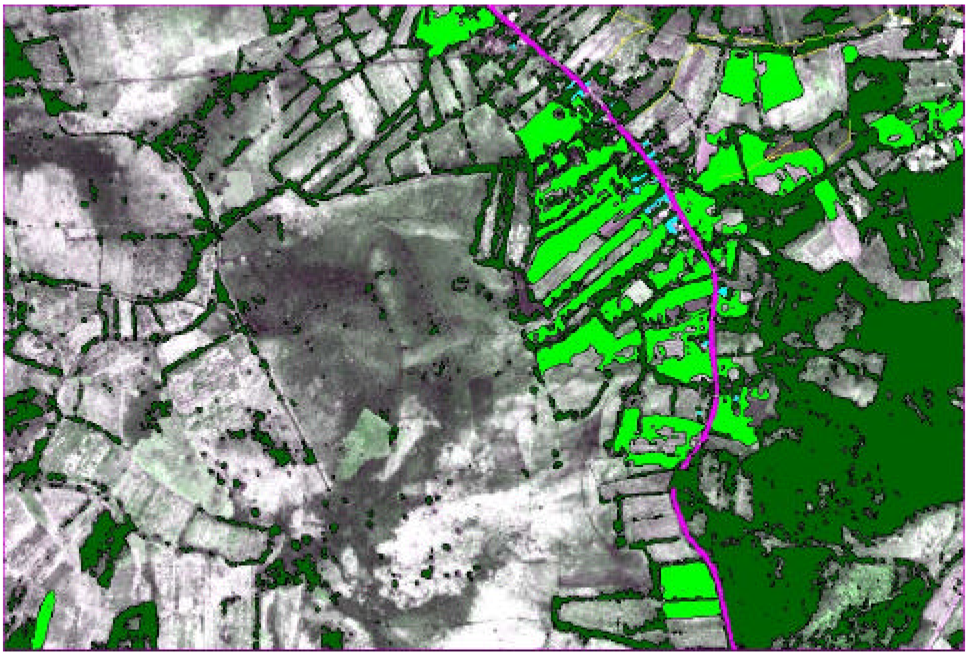


Figure 5-23 Land cover features from the IKONOS data

Linear Features extraction

Figure 5-24 and Figure 5-25 illustrate the results of linear features detection.

contrast stretch of NIR band	morphological response	linear extraction result

Figure 5-24 Demining Activity (Linear Structures extraction)

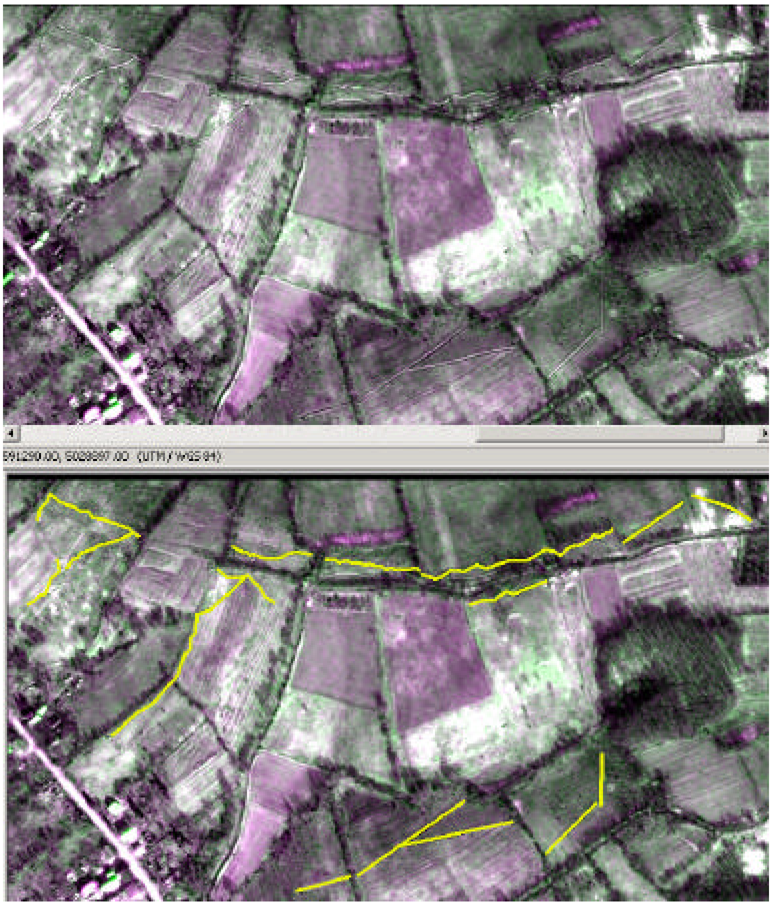


Figure 5-25 Trenches (Linear Structures extraction)

Poles detection

The following figure illustrates the developed method for the extraction of fencing systems using poles.

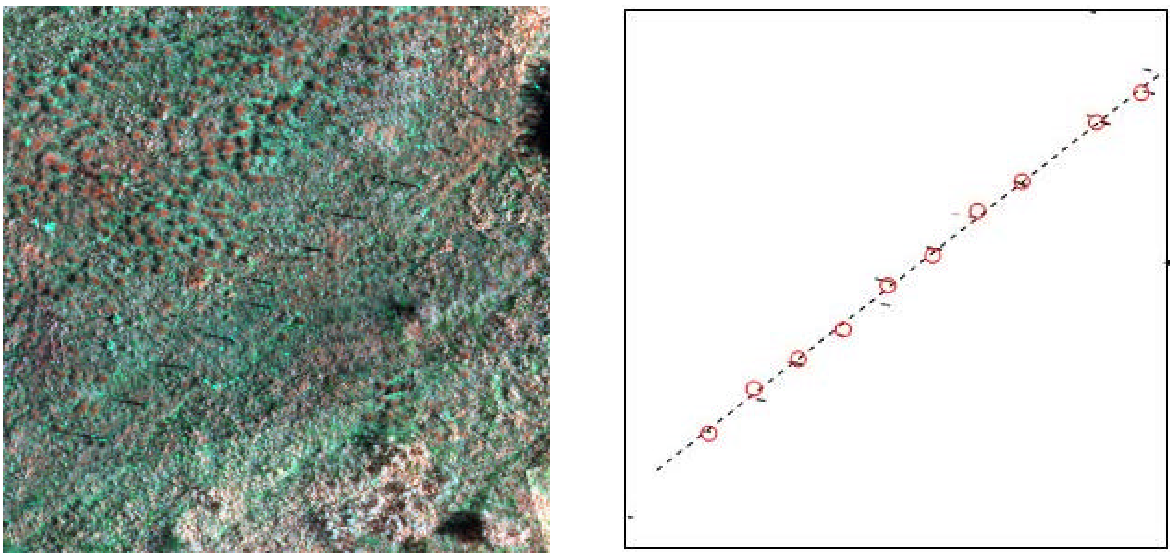


Figure 5-26 Fencing system (Poles) detection: original image (left), final results (right)

5.3.4.4 OBJECT BASED IMAGE CLASSIFICATION

Supervised land cover classification combined with spatial analysis was used to provide the following three feature types.

- Rectangular areas, in order to identify agricultural fields
- Circular areas, in order to identify for example craters, trees, tyres
- Individual trees, distinguish from larger forest areas for vehicle passage

Features have been generated and delivered using eCognition software, applied to the mosaics from Flight 3 and Flight 8.

First, pre-processed mosaics are segmented by eCognition. Multi resolution Segmentation allows the segmentation of multi spectral images into highly homogeneous image objects in any chosen resolution and the generation of a network of image objects.

This means that neighbouring pixels with similar spectral characteristics are recognized and segmented into homogeneous objects. Next, in a user-defined number of subsequent steps, neighbouring objects can be merged into yet larger objects according to user-specified parameters. Analysing an image in eCognition means to classify the image objects based on sample objects (training areas) or according to class descriptions organised in an appropriate knowledge base. The knowledge base itself is created by means of inheritance mechanisms, concepts and methods of fuzzy logic, and semantic modelling.

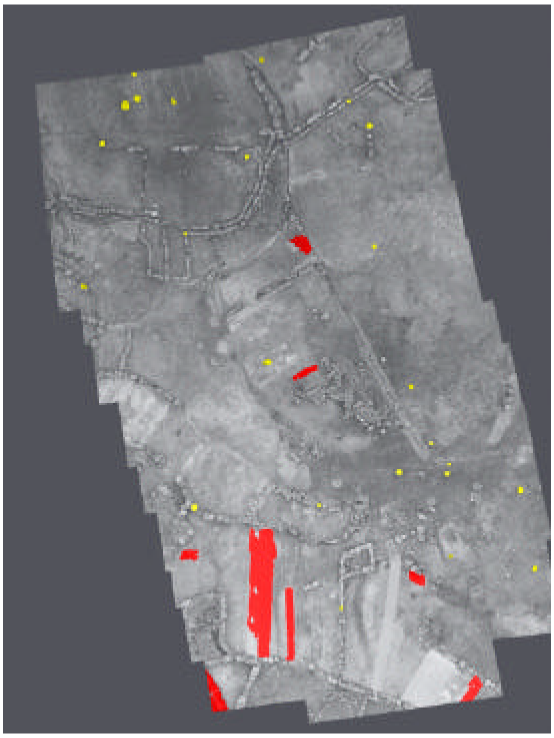


Figure 5-27 TNO Image Processing – flight 3 features: rectangular areas (red), circular objects (yellow)

Spectral classification has been performed using NDVI and training on perceived ground truth in the mosaics, and applied to the whole mosaic. The classification method is object-based. The objects are classified using a rule-base for reasons of robustness. After classification adjacent objects with the same class are merged to reduce the number of polygons.

Land cover	Colour
vegetation type 1 (trees)	dark green
vegetation type 2 (low vegetation)	green
vegetation type 3 (low vegetation with bare soil	light green
soil type 1 (bare soil with low vegetation	pink
soil type 2 (bare soil)	purple
none (unclassified/shadow)	black

Spatial analysis was then applied to the segmentation. User-specified criteria for rectangular areas and circular areas were defined. A sub-set of land cover classes were exported as features and provided to the Data Fusion.

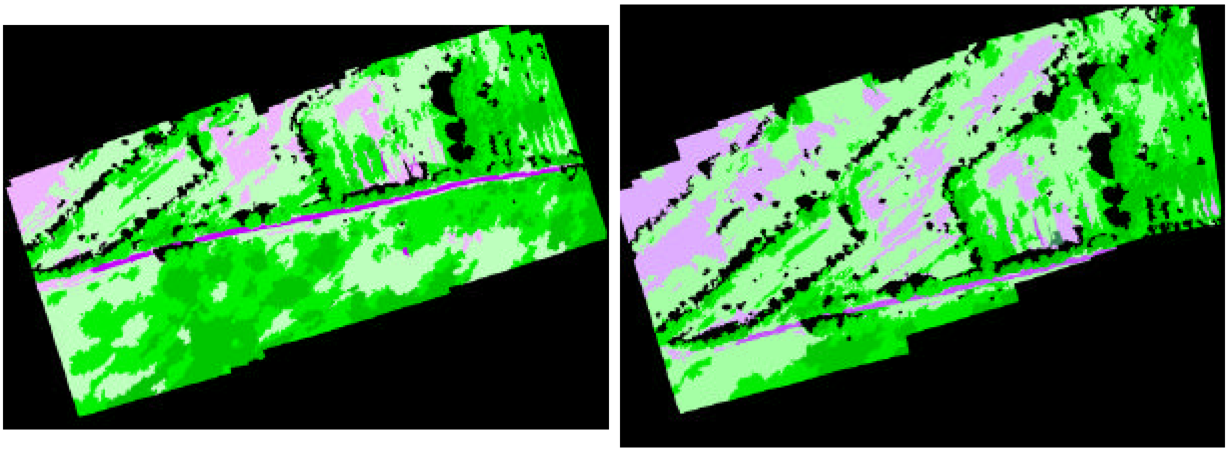


Figure 5-28 TNO Image Processing – flight 8 classification results

5.3.5 DATA FUSION

5.3.5.1 OVERVIEW

Features Categorization

Features extracted for the Minefield Test area Milekovici could be classified as:

- Scene Domain Knowledge
  - Landscape
  - Anomalies in landscape

- Expert Domain Knowledge
  - Direct military activity
  - A priori knowledge: MIS

The following table classifies the Image Analysis features, Image Interpretation features, the Thematic layers and MIS layers according to the defined sub-categories.

GIS-DB Data Space				Use for DF						
Data Category		Data Layers		Classification				Classification		
Main-Category	Sub-Category	Ref	Name	Landcover / landuse	Direct military activities	A-priori information	Anomaly detection	After QA of real contents	Positive / Negative	Mined, Suspected, Safe
MIS	MFA	FT_CRO_001	Incident			yes		yes	N	MINED
	GT	FT_CRO_002	Cleared area			yes		yes	P	SAFE
		FT_CRO_003	Suspected area			yes		yes	N	SUSPECTED
		FT_CRO_004	*MFRref*			yes		no	N	
		FT_CRO_005	MFRarea			yes		yes	N	MINED
		FT_CRO_006	MFR			yes		yes	N	SUSPECTED
		FT_GEO_005	MFPattern			yes				
		FT_GEO_007	TroopSepLine			yes				
		FT_GEO_009	TroopForces			no				
	MFR_FORMS									
IP	FOI	FT_FOI_001	Hot Spot				yes	no	N	n.a.
		FT_FOI_002	Cold Spot				yes	no		n.a.
		FT_FOI_005	High Contrast				yes	no		n.a.
		FT_FOI_007	Steel Mine				yes	?		SUSPECTED
		FT_FOI_008	Stone				yes	?		?
	IMEC	FT_IMEC_001	Grassland	yes					context	SUSPECTED
		FT_IMEC_002	Bare Land	yes					context	SUSPECTED
		FT_IMEC_003	Foot Path	yes					context	SUSPECTED
		FT_IMEC_004	Plough Land	yes					P	SAFE
		FT_IMEC_005	Trees Brushes	yes						SUSPECTED
		FT_IMEC_006	Car Track						P	SAFE
		FT_IMEC_007	Abandoned Demining Act		yes					SAFE
		FT_IMEC_008	Main Road	yes					P	SAFE
		FT_IMEC_009	Hedge Forest	yes						SUSPECTED
		FT_IMEC_010	Cultivated Land	yes					P	SAFE
		FT_IMEC_011	Trenches		yes					SUSPECTED
		FT_IMEC_012	House	yes					P	SAFE
	TNO	FT_TNO_001	Rectangular	yes						SUSPECTED
		FT_TNO_002	Circular				yes		P	
		FT_TNO_003	Trees	yes						
II	Thematic	FT_CRO_008	LandCover	yes						depends
		FT_CRO_010	Trenches		yes					SUSPECTED
		FT_CRO_011	Trenches		yes					SUSPECTED
		FT_CRO_012	Embankment		yes					SUSPECTED
		FT_CRO_013	Embankment		yes					SUSPECTED
		FT_CRO_014	Path	yes						SUSPECTED
		FT_CRO_015	Path	yes						SUSPECTED
	GT	FT_CRO_022	GT Pictures			yes				
	Thematic	FT_GEO_006	River							
		FT_GEO_008	Mountain							

Knowledge Rules Derivation

The derivation of the knowledge was made taking into account:

- Expert knowledge domain
  - Type of conflict & Objective of landmine deployment
    - Conflict involving regular army: north/south
    - Role of landmine in warfare: construction of barriers that impede the mobility of tanks
  - Minefield Construction
    - Socio-Economic landscape:
      - Infrastructure, villages, agriculture area, …
    - Physical landscape: terrain configuration
      - Terrain, topography, type and density of natural vegetation, rivers…
- Scene Domain Knowledge
  - 'Time series Analysis'
    - Changes in landscape: infrastructure, agricultural land, …
  - Direct minefield indication
    - Indicators justifying military activity
    - Evidence of mines
  - A priori information
    - Maps
    - Mine field records
    - Incidents
    - Suspected area
    - Thematic Land cover

In the following sections features categorization and Domain Knowledge will be used to derive Semantic Representation of the danger area classification defined in D50, i.e.

- Safe Area, Definitively Mined Area, Probably Mined Area and Possible Mined Area.

5.3.5.2 SAFE AREA MODEL

The following figure illustrates the Semantic Representation of a safe area. The model is based on in iterative approach subsequently combining information on ploughed land, cultivated land, land cover, roads, and houses to a final safe area layer. The resulting layer is shown in Figure 5-30.

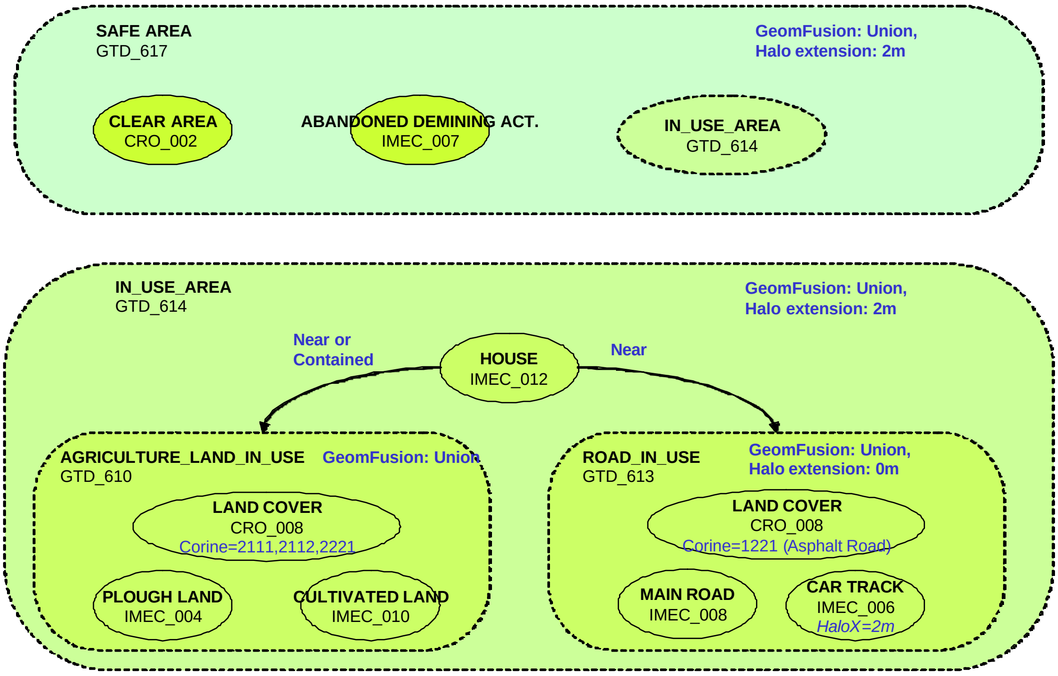


Figure 5-29 Safe Area Model

Figure 5-30 Left: Input features; Right: Safe Area output (using the union operator and halo)

5.3.5.3 POSSIBLE MINED AREA MODEL

The following figure illustrates the Semantic Representation of a Possible Mined Area. In this model information on grasslands and bare land (abandoned areas) together with forested and unused agricultural land is used as a basis for the definition of possible mined areas. The resulting layer is shown in Figure 5-32.

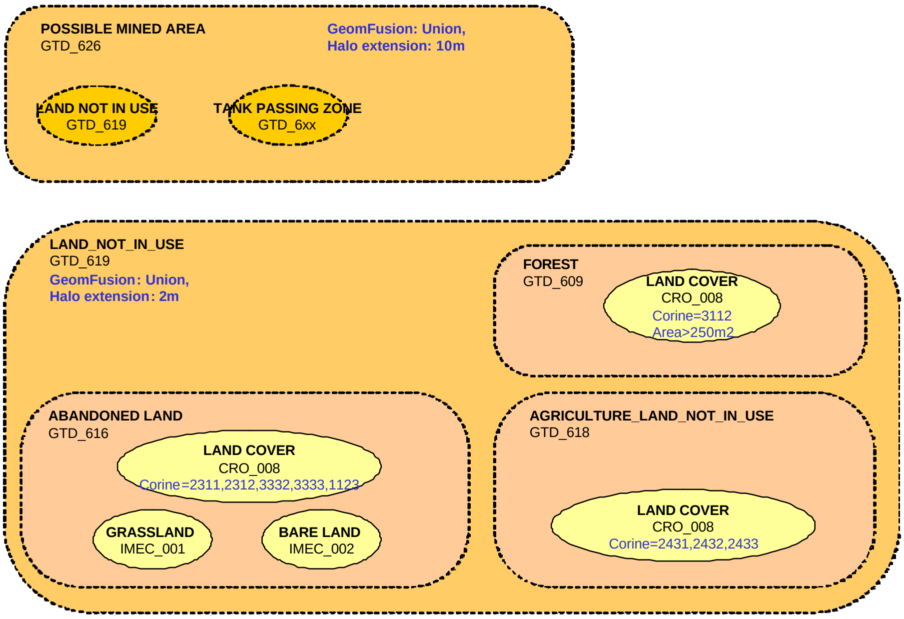


Figure 5-31 Possible Mined Area Model

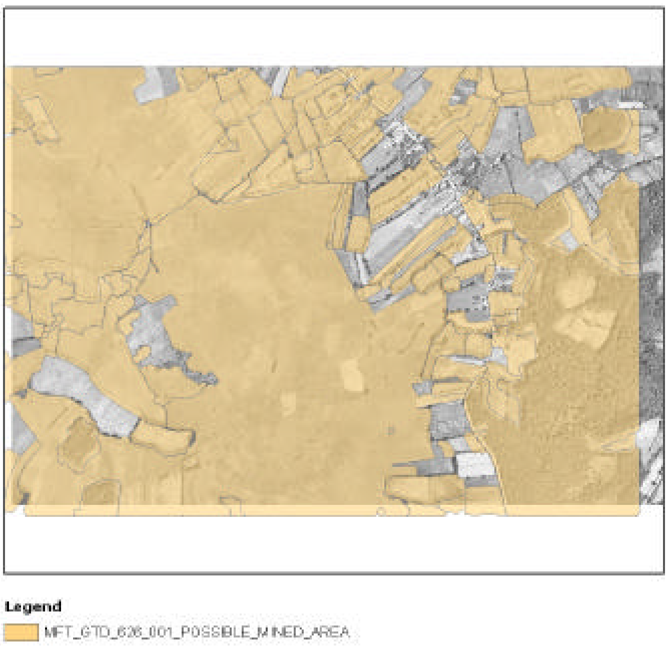


Figure 5-32 Possible Mined Area

5.3.5.4 PROBABLE MINED AREA MODEL

The following figure illustrates the Semantic Representation of a Probable Mined Area. The model is based on the use of information on military use of an area (trenches, embankments) as well as on information on paths which are of possible use for military actions. The resulting layer is displayed in Figure 5-34.

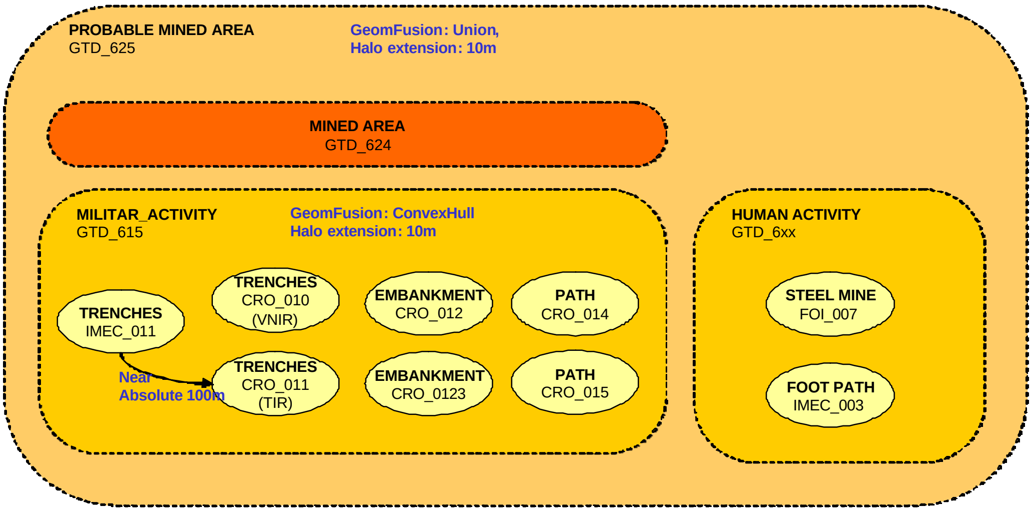


Figure 5-33 Probable Mined Area Model

Figure 5-34 Left: Probable Inputs; Right: Probable Outputs Zoom In

5.3.5.5 DEFINITIVELY MINED AREA MODEL

The following figure illustrates the Semantic Representation of a Mined Area. It uses the information of the Mine Information System (Minefield Records, mine incidents), the resulting layer is shown inFigure 5-36.

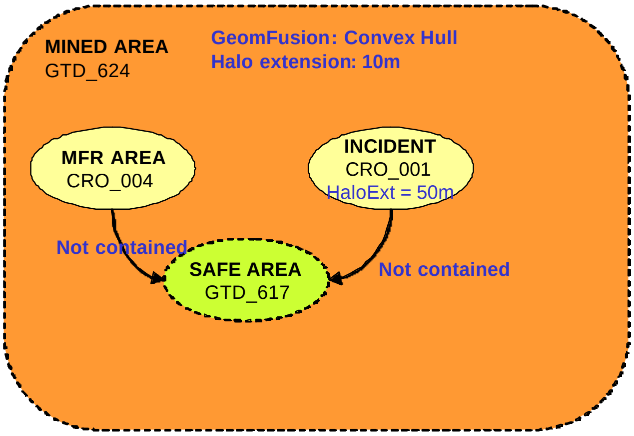


Figure 5-35 Mined Area Model

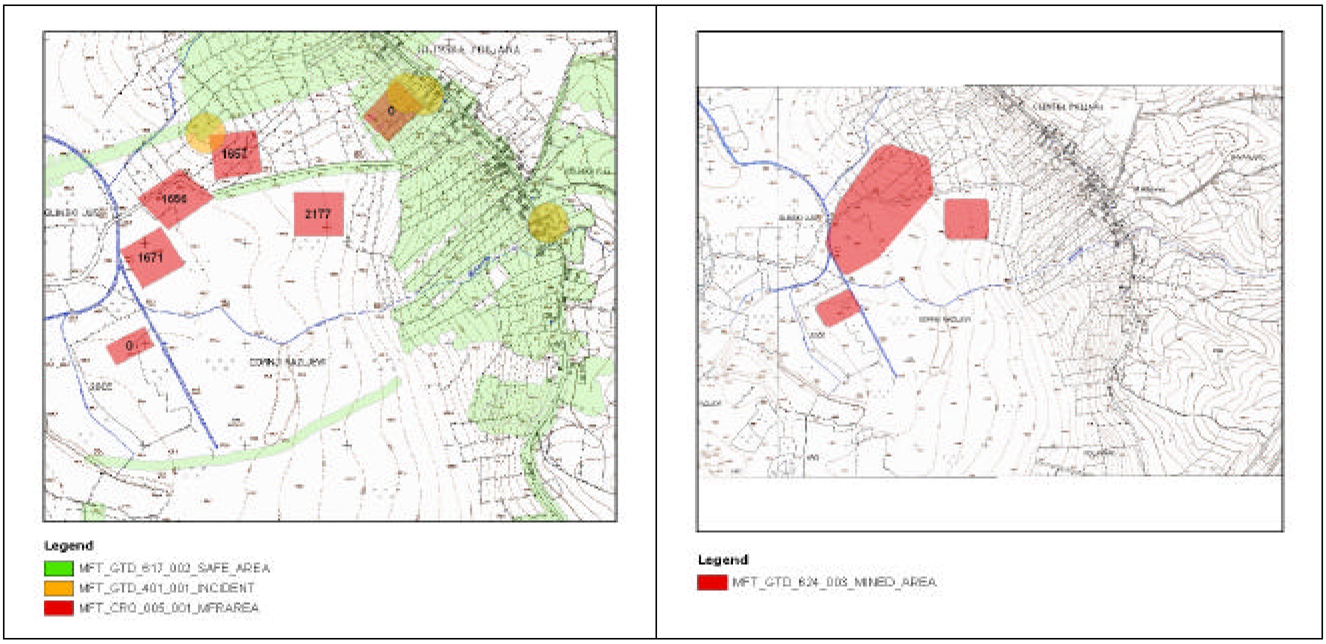


Figure 5-36 Left: Definitively Mined Area Inputs; Right: Definitively Mined Area Output

5.3.6 FINAL RESULTS

The following figure illustrates the Semantic Representation of a the Final Area Reduction Results, i.e. the way in which the layers derived above are interrelated.

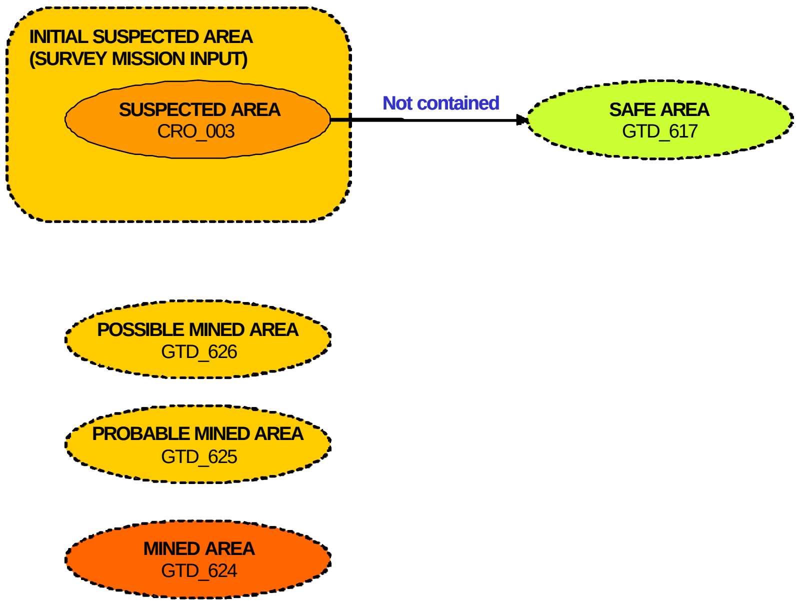
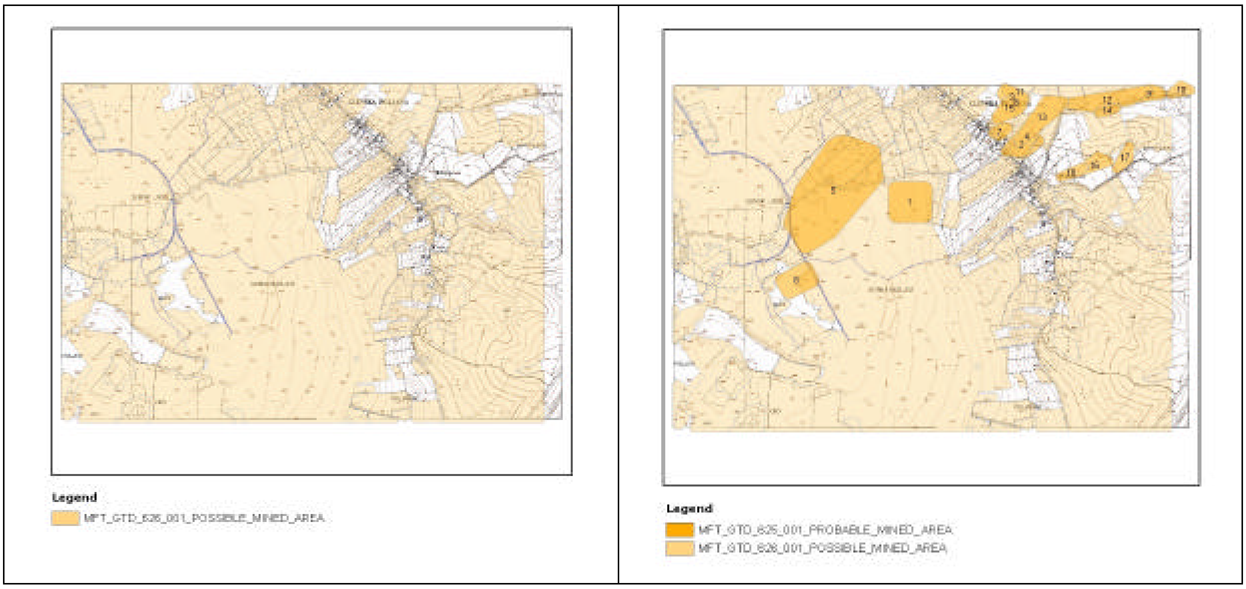


Figure 5-37 Area Reduction Results Model



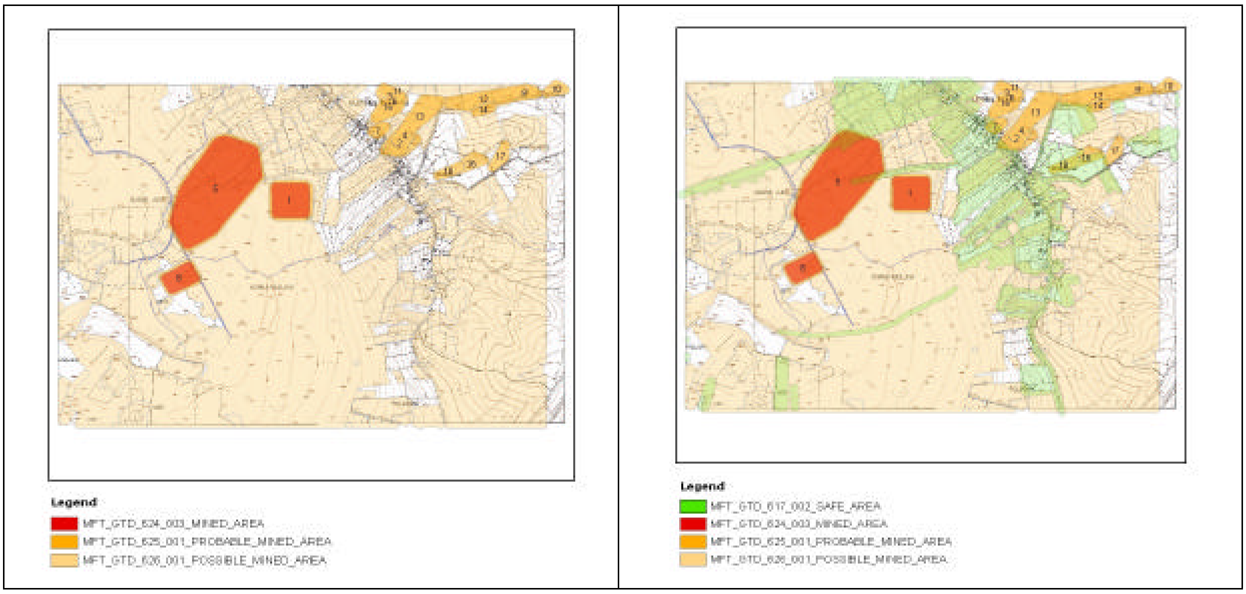


Figure 5-38 Incremental Overview of the Models

Finally Figure 5-39, shows the declared Safe Area superimposed upon the original suspected area

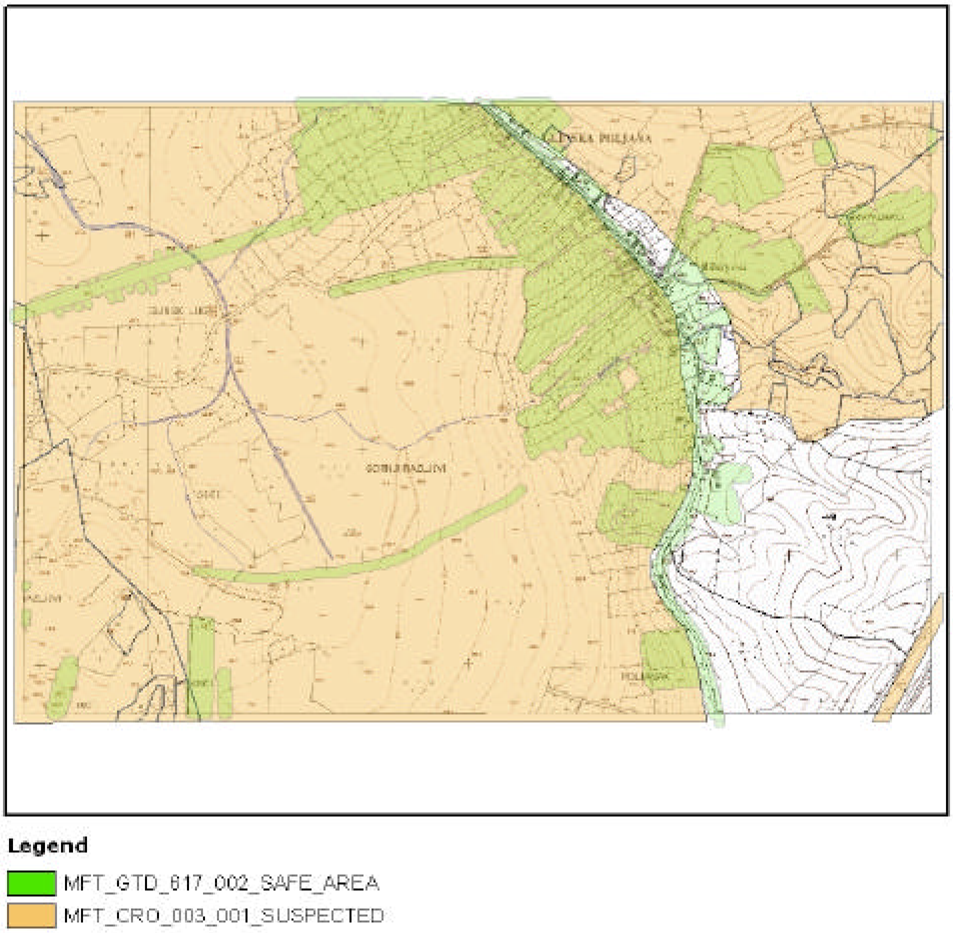


Figure 5-39 Safe Area compared with Initial Suspected = Map

5.3.7 CONCLUSION

This section presented the data processing flow and results applied to the MFT Milekovici data: GIS scenario information, Automatic Geo-referencing, Image Interpretation, Image Analysis, Knowledge formulation and finally Data Fusion. Taken separately, each step has been assessed according to its expected results. The full assessment of the information flow has been made indirectly via the Data Fusion:

1) Reference Scenario:
    a. limited infrastructure layers for the scene knowledge modelling
    b. no Mine Field Records, for assessing the high resolution VINR and Thermal Image Analysis results in terms of the detection of patterned perturbations
2) Image Interpretation/Analysis:
    a. ARC pyramidal approach has not been used efficiently mainly due to the poor results of the AGM
    b. Handicapped by the AGM results the Temporal & Spatial Thermal IR results have not been assessed
    c. Usefulness of the Temporal & Spatial Thermal IR processing for the automatic detection of minefield indicators not assessed
3) Knowledge formulation:
    a. Domain knowledge formulation suffered from the non involvement of the GMAA and Technical Survey specialists from CROMAC
    b. Image Analysis partners did not propose a sufficient number of scene knowledge rules: the semantic of the detected features

Finally the Data Fusion results have been assessed in D53 'ARC System Report' by comparing the ARC area reduction results v.s. 'conventional' area reduction results.

5.4 ARC SYSTEM EVALUATION

5.4.1 ARC SYSTEM EVALUATION CRITERIA

As defined in the project objectives, the final system performance should be measured in terms of

1. Potential improvement of existing mine action surveys, that can be obtained with the proposed system and system concept:
    a. The ARC-GIS
    b. The area reduction results
    c. The detection and identification of signature (spectral, thermal and spatial – shape-) associated to minefield indicators.
2. System operational procedure, including
    a. Survey procedure,
    b. Survey speed,
    c. Survey costs

5.4.1.1 POTENTIAL IMPROVEMENT OF EXISTING MINE ACTION SURVEYS

➢ ***Information System***

Comparing the ARC GIS data structure and information content to the reference MAGIS provided by CROMAC is immediate as the MAGIS is part of the ARC GIS. The emphasis was mainly put on the extra information provided in the GIS, e.g. mission planning, Data Fusion Reports, etc … .

➢ ***Area reduction / Minefield Delineation***

Suspected Area Reduction:

1. The produced ARC Dangerous Area Report and ARC Mined Area Report will be provided to CROMAC, as defined by IMAS (see Section D50 Section 2). This report will contain, among other the splitting of the reference suspected are, received from CROMAC, into 4 areas:
    - Definitively Mined area
    - Probably Mined area
    - Possible Mined area
    - Safe are
2. Area reduction and ground truth data collection using conventional clearance techniques will be made by CROMAC.
3. CROMAC will compare, using the concept of confusion matrix, the ARC Result (‘predicted results’) to the one produced by conventional survey techniques, which will be considered as the ‘actual results’ area reduction results. The results will be:
    a. The predicted **percentage of area reduction** vs. the reference one

b. The actual **percentage of area reduction** vs. the reference one

c. **Confusion matrix & Related Parameters**

A confusion matrix is a matrix showing the predicted (ARC results) and actual (CROMAC results) classifications.

actual\predicted	Negative	Positive
Negative	a	b
Positive	c	d

The confusion matrix can be used also to derive:

- The **Commission error:** the percentage of areas assigned by ARC to a category of class to which they does not belong to
- The **Omission error:** the percentage of areas which are not assigned by ARC to their appropriate category of class

➢ ***Minefield indicators***

The original goal of ARC was to "provide minefield indicators types that are statistically significant …". This objective has not been reached for the following raisons:

1. the planned trials concentrated in two specific areas in Croatia,
2. reduced survey area has been made
3. the planned Continuous Data Acquisition did not happen in time
4. the planned Continuous Data Acquisition did not cover other areas than the ones planned for the trials

A list of useful minefield indicators detected visually or automatically is given in Section 5.2.3.2.

5.4.1.2 SYSTEM OPERATIONAL PROCEDURE

The assessment of the System Operational Procedure has been made in terms of:

1. IMAS Standard
2. Data collection & Evaluation
3. Data Analysis, Integration, Interpretation and Reporting
4. Costs benefit compared to Conventional Survey.

5.4.2 ARC PERFORMANCE EVALUATION RESULTS

5.4.2.1 POTENTIAL IMPROVEMENT OF EXISTING MINE ACTION SURVEYS

Geographical Information System

The ARC GIS contains the reference MAGIS (CROMAC MIS-GIS – reference maps) information, augmented with

1) Reference Thematic maps, including land cover
2) Reference orthophoto maps
3) Satellite images
4) All the acquired ARC geo-referenced image data and mosaics, produced Data Fusion layers, as well as missions information layers.

Examples of some of these layers are illustrated in the following Figures.

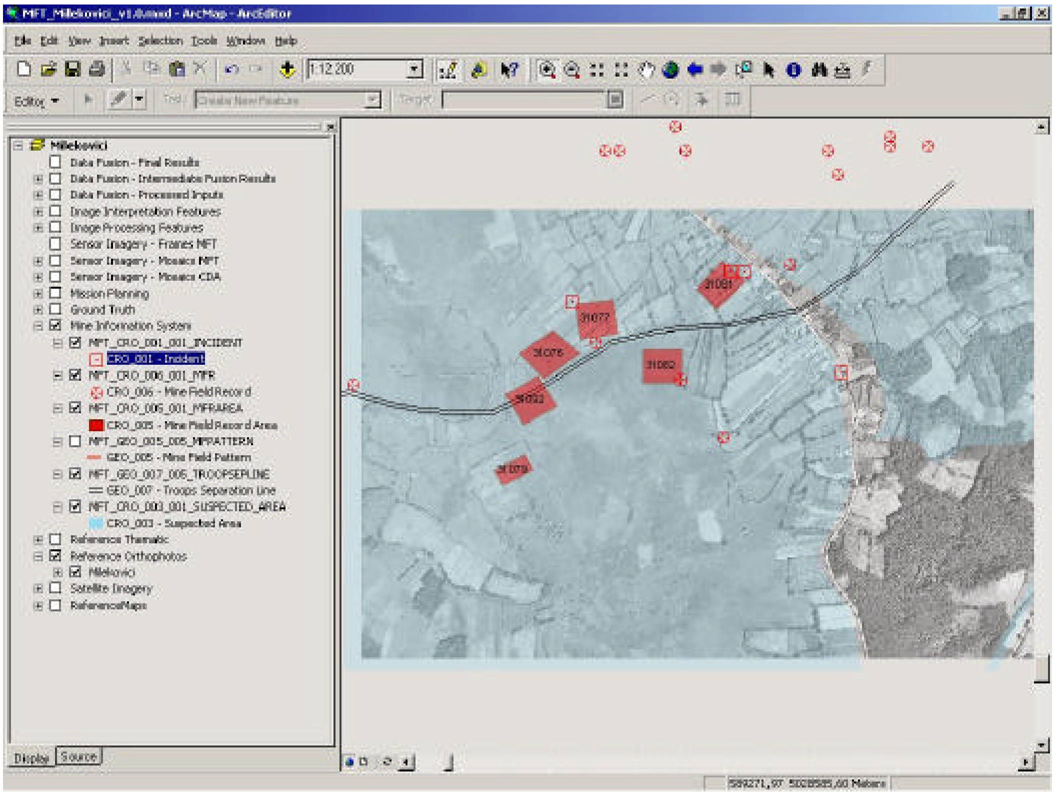


Figure 5-40 Reference Minefields (red rectangles), incidents (red points) and suspected area (blue) overlaid onto the orthophoto map

Moreover,

- Human Machine Interfaces (HMI's) for visualization, zooming, visual interpretation, data extraction/exploration, Data Fusion explanations, etc. have been implemented as Decision Support Tools for use in General Mine Action Assessment activities.
- Compatibility is given with IMSMA and its GIS in terms of information content and information access.

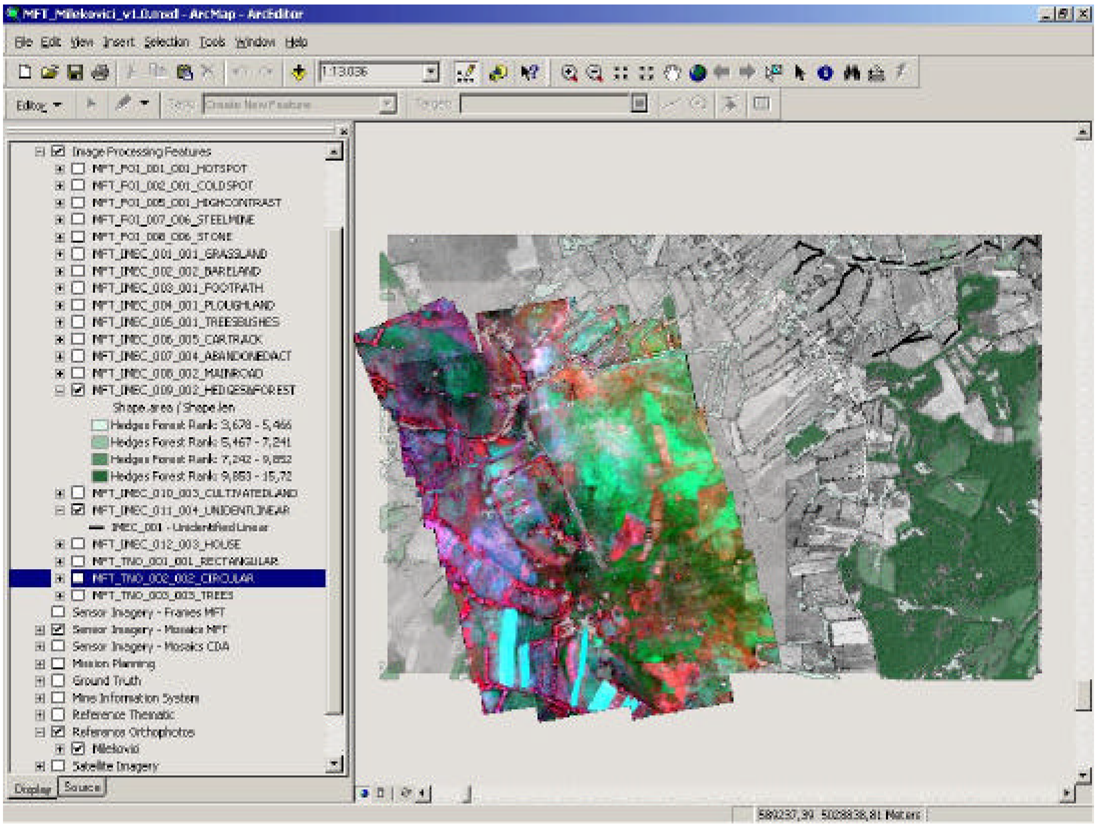


Figure 5-41 Minefield Test results: Mosaic of the surveyed area, land cover classification (green - forest/hedges) and detected trenches.

Area reduction Results

The area reduction results have been described above in section 5.3.5 – the surveyed area (originally suspected are) has been categorised to four classes of danger regions, namely

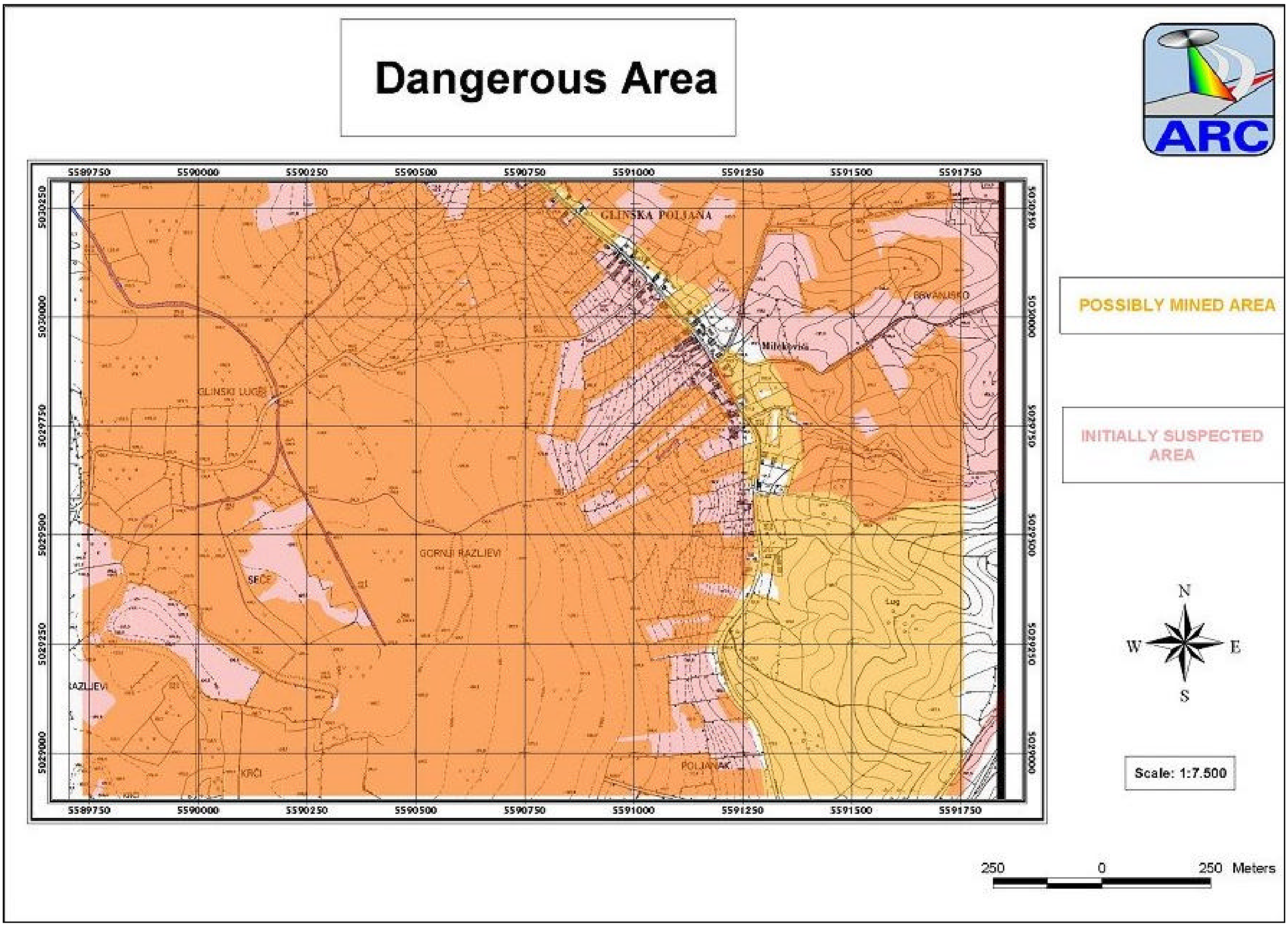
- **Possibly mined area,** having a probability within [0%, 50%) mined area
- **Probably mined area**, having a probability within [50%, 100%) mined area
- **Mined area,** defined as 100 Definitely mined area
- **Safe area,** defined as 100% safe area

The Safe Area is the most relevant as it addresses the overall goal of the project, Minefield Area Reduction.

The defined layers have been generated in the form of maps (GIS-layers) for *Milekovici/Glinska Poljana* (central *Croatia* province *Sisacko-Moslava*/district *Glina*) area during the Minefield Test Evaluation phase.

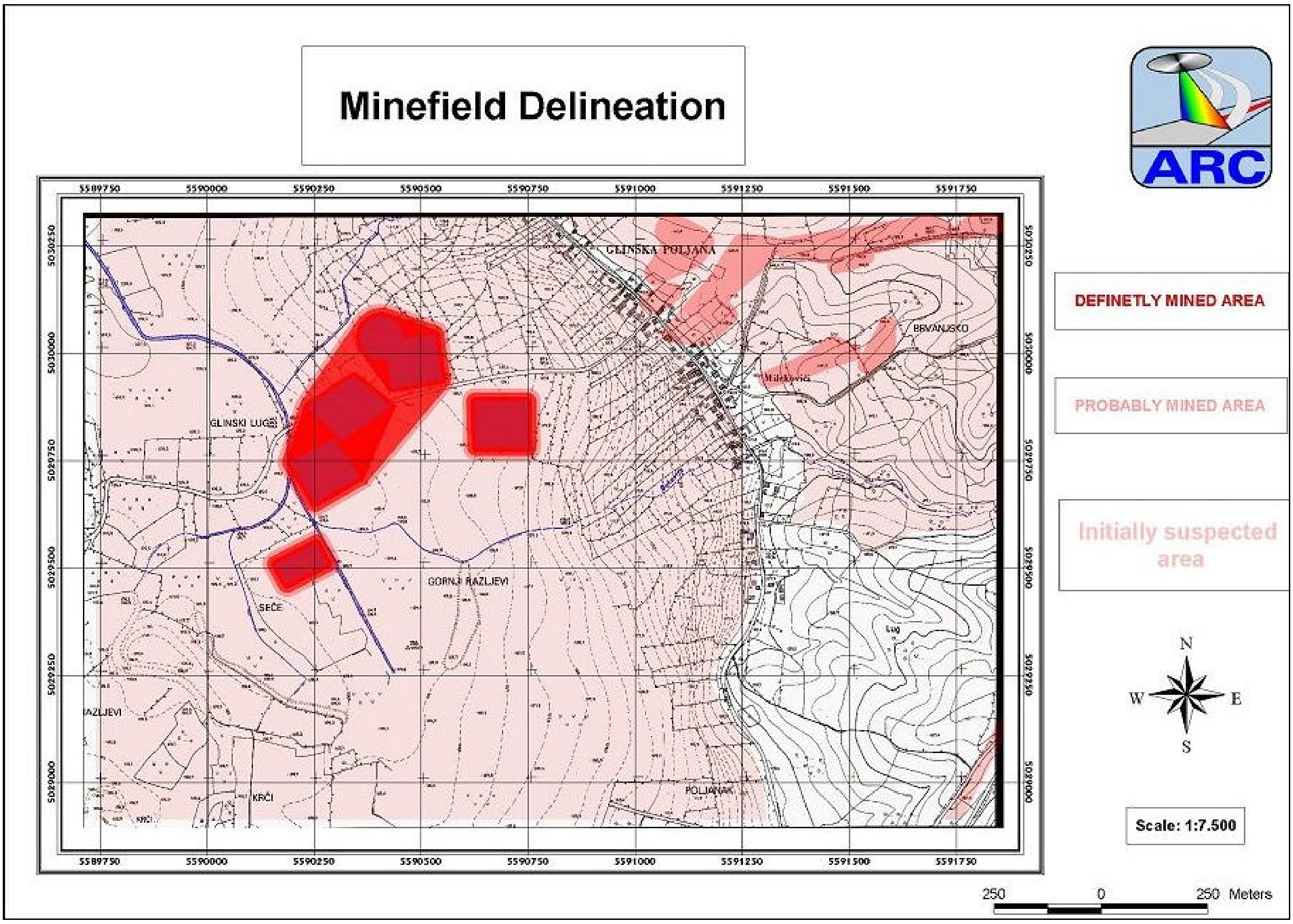
Based on the GIS-DB and the ARC Data Fusion layers, maps were generated (GeoTIFF format/channel distribution:1,2,3) using the reference map of the area (scale:1:5000). As the projection system used in ARC is UTM and the one used by the Croatian mine action centre (CROMAC) is Gauß-Krüger, a transformation has been made.

For the generation of the maps, submitted to CROMAC, The ARC vector layers were converted to raster layer (resolution 1m). The maps have been shown above in section 5.3.6.



- ***Map 1: Possibly mined Areas and initially Suspected areas (figure not to scale!)***

  Possibly mined area (colour: *orange*) overlaid on the reference MAGIS **suspected area** layer (colour: *light red*), provided by CROMAC, as a part of the basic scenario information of MFT Milekovici area.

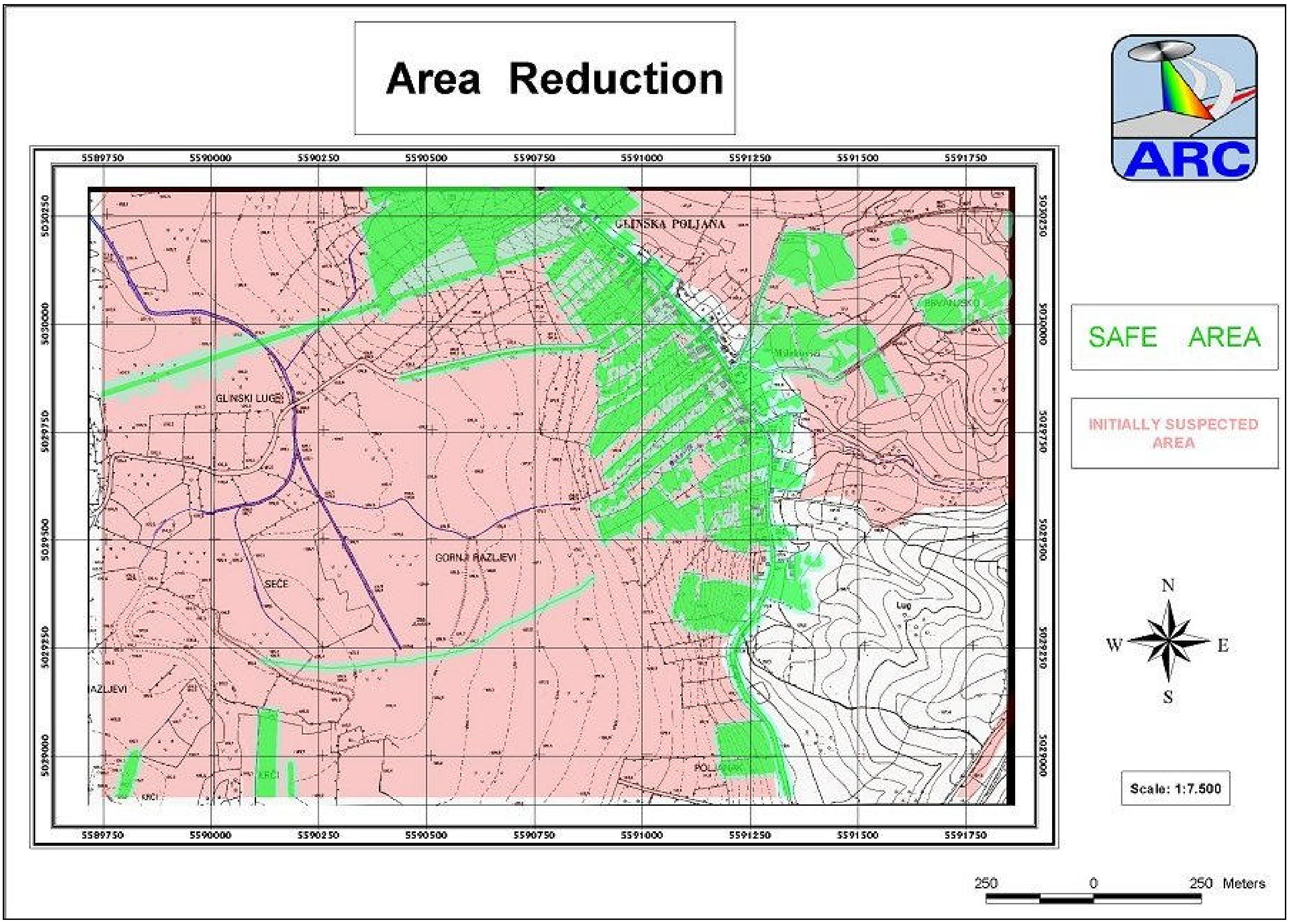


- ***Map 2: probably and definitely mined aeras (figure not to scale!)***

  This map displays the **minefield delineation** done by ARC.

  Probable mined area (colour: *red*). The mined areas are distributed along the former armies separation line t, on the north-eastern corner of the reference map along the hills, that rise east of the main road and in the valley west of the main road, marking a larger area around the polygons of **minefield layer** provided by CROMAC.

  The **mined area** (colour: scaled *red to purple*) is inside the polygons west of the main road and mark a bit larger area than the initial minefield layers of MAGIS. These areas are concerned to be **definitely mined.**



- ***Map 3: Safe Areas and initially Suspected area (figure not to scale!)***

  The **safe area** (colour: *green*) represents areas that are considered to be mine free. They are distributed mainly along the western edge of the main road.

  In comparison to the initially **suspected area** (colour: *light red*) a large area reduction has been made.

5.4.2.2 CROMAC AREA REDUCTION RESULTS AND COMPARISON

Figure 5-42 shows the suspected hazardous area and the cleared area in the vicinity of Milekovici. This information has been provided by CROMAC to the ARC project on 14.01.2003 before the Minefield Test.

Figure 5-43 and Figure 5-44 show the results of the surveys and demining activities of the area Milekovici as reported in CROMAC's MIS and GIS system on 15.11.2003:

- Figure 5-43 depicts the polygons of minefields assessed by technical survey and demining,
- Figure 5-44 depicts the polygons of the area reduced by general survey.

Table 5-12 gives the type and quantity of mines found during the conventional clearance.

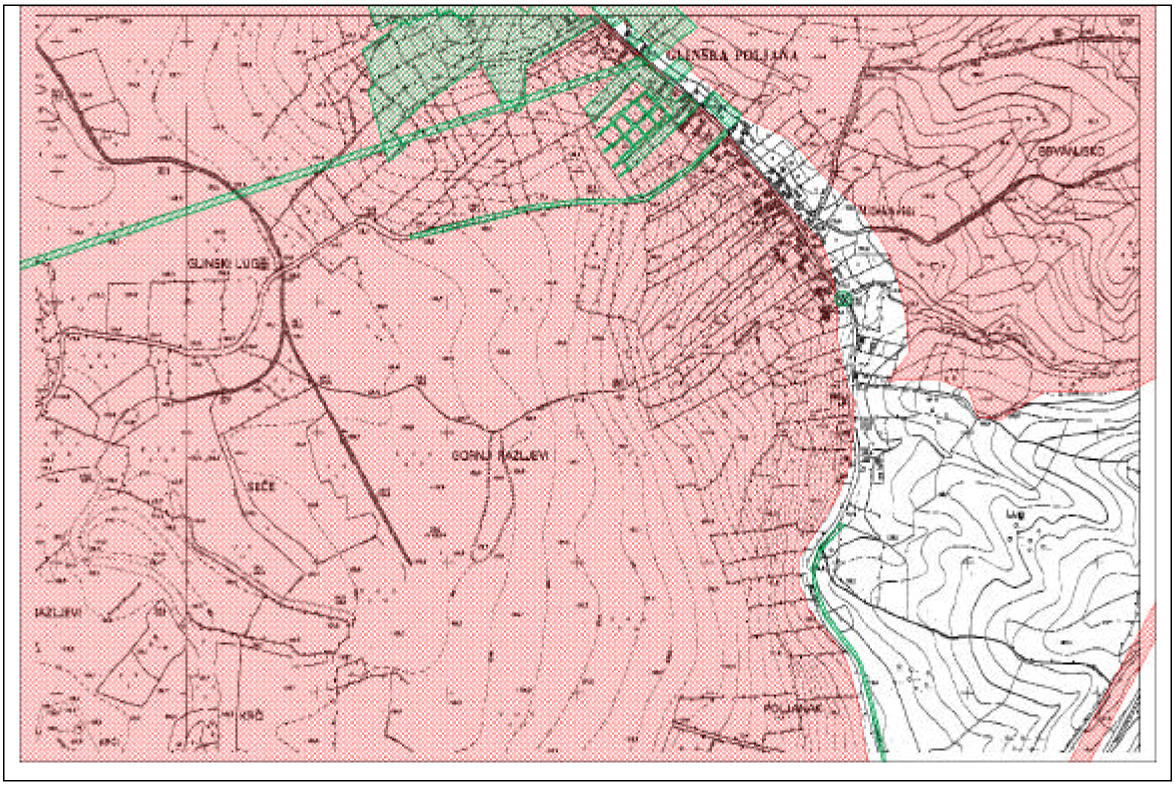


Figure 5-42 Suspected (red) and cleared area before the MFT (green)[3].

Nr.	Id of minefield in MIS	Number and type of mines
1	31092	88 mine TMM-1 188 mines PMA-2
2	31076	18 mines TMM-1 54 mines TMA-4 147 mines PMA-2
3	31077	12 mines TMM-1 88 mines TMA-1 185 mines PMA-2
4	New minefield, not in MIS	92 mines TMA-5 180 mines PMA-2
5	31681	0 mines, 0 UXO
6	31682	0 mines, 0 UXO

Table 5-12 Types and quantity of mines detected by conventional technology

3 The green line from title of the village Glinska poljana to the West, that crosses the channel, is not correctly drawn, while the power network is located northern (see e.g. digital ortho photo map, IKONOS image, etc.).

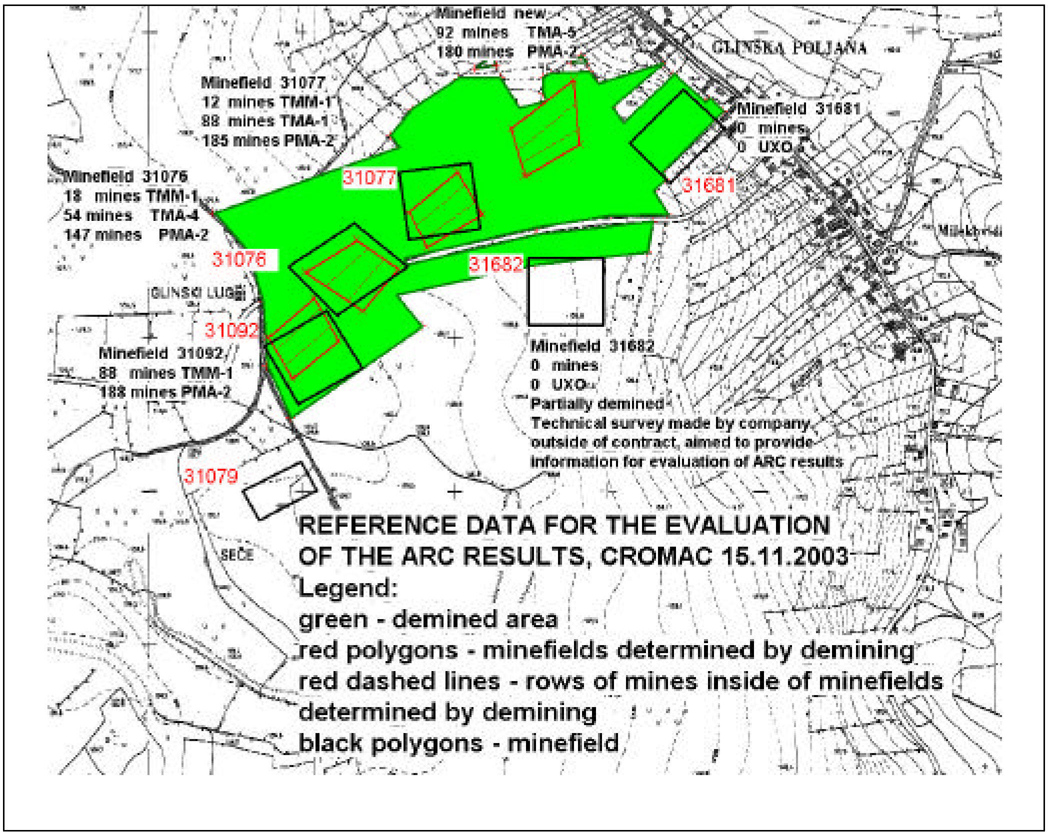


Figure 5-43 Reference Map-Part 1 - Green: cleared area, Black polygons: reference (before clearance) minefields, Red polygons: real minefields boundaries, Dashed lines: mine rows.

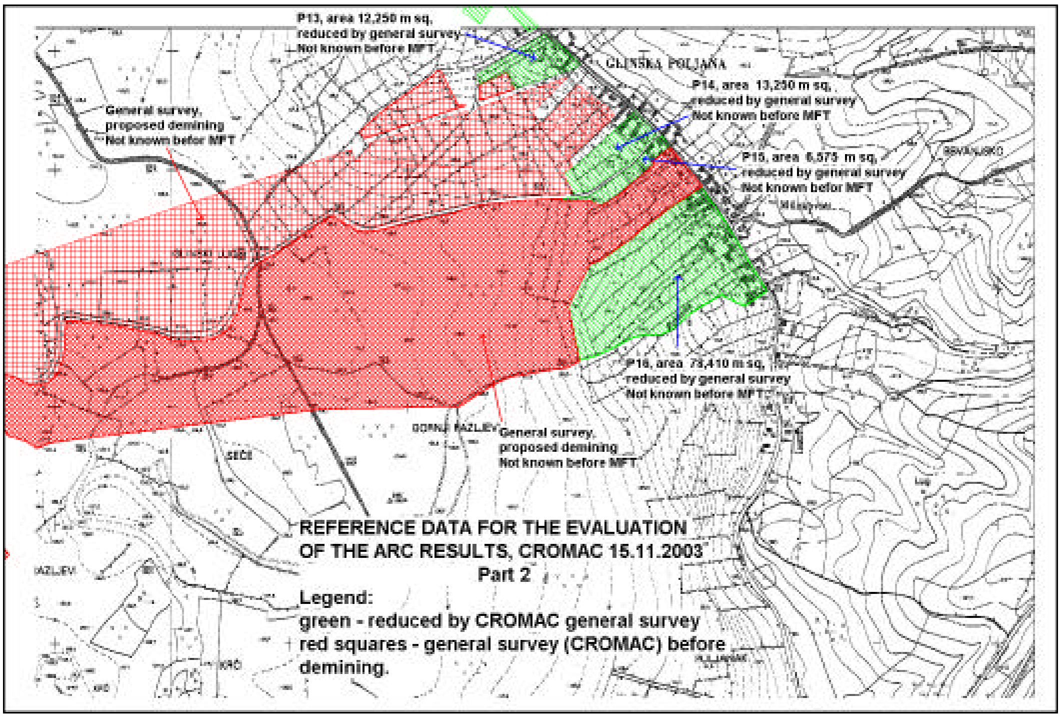


Figure 5-44 Reference Map-Part 2- Green: CROMAC General Survey results - Safe areas, Red: proposed area for clearance.

A. Safe area – suspected area reduction

The reduction of the suspected area and the determination of the safe area are the best results shown in the analysed data. Part of the declared safe areas coincide with the results of the survey made by CROMAC. Commission errors were found where the MIS information was wrong. A minefield not covered by the MIS was not reported in the maps provided to CROMAC (this area was not covered in the detail analysis by ARC).

B. Mined Area

This category of data provided by ARC shows the expected strong spatial correlation with the data provided by MIS before the MFT, as the MIS is part of the ARC GIS-DB and hence used as inputs in Data Fusion process. Minefield 31682 (Figure 5-44) was referenced in the CROMAC MIS, however, during the demining and technical survey this area was declared as not contaminated (Figure 5-44).

C. Probably Mined Area, Possibly mined Area

This information provided by ARC is spatially closely correlated with the minefield polygons from MIS as MIS information is an important part of the ARC database.

5.4.3 COSTS BENEFIT COMPARED TO CONVENTIONAL SURVEY

The following analysis of both, cost and benefits of the ARC system as well as the conventional method in area reduction is subject to two major restrictions:

1. In the course of the project the ARC system has undergone four trials and one minefield test. The number of sites which were investigated and the quantity of material tested has been small. Further testing and evaluation would have been necessary for a more detailed and reliable analysis.
2. The ARC system is a demonstrator, thus way from being a serial product. Market entry still requires two major steps: the development of a pre-prototype version and a real prototype of the system.

5.4.3.1 SYSTEM-INHERENT ANALYSES

Cost of the ARC system

At this stage (end of RTD phase and ARC available as a demonstrator only), further development cost for reaching market maturity cannot be calculated. Therefore, such additional cost are not included in the following numbers and tables.

Cost of Equipment: (Assumption**:** System consisting of 1 Camcopter with control station, cameras, data storage, 1 Ground Station Workstation, 1 Mission Planning Laptop with Software Licences):
Estimates for Subtotal I for ARC equipment sum up to roughly **EURO 1.000.000,-**

Cost of Personnel: (Assumptions: Area to be covered 1km² at 900m and 300m, 0.3km² at 100m, 0.1km² at 30m, Transfer of system to be indicated separately, Background information is available, Rules for Data Fusion are known, Quality Assessment activities are integrated in respective activities, Staffing indicated for HQ (Mission Planning, Analysis) and Field Work
Estimates for Subtotal II for personnel sum up to about **EURO 40.000,-**

Total estimate cost for ARC area reduction under the assumptions given above sum up to approximately **EURO 1.040.000,-**

CBA Conclusion for ARC:

The introduction of technology-derived information in minefield area reduction work is costly. Obviously, the degression of the fixed cost (equipment cost) in the area reduction process by an airborne system is relatively high. The relation between fixed cost and variable cost makes the ARC system useful for bigger areas only.

5.4.3.2 CONVENTIONAL METHODS (CM)

Cost of the conventional method

The cost of the conventional method of the exclusion from mine suspected area (suspected area reduction) contains the total cost of equipment plus personnel (they are not separable).

In the current cost-benefit analysis we use data of the area Milekovici that was used in the Minefield test (MFT), the results were operationally validated by the clearing and surveys, technical and general. The cost of these activities can not be expressed separately. Therefore the cost of the conventional methods reported here is indeed very conservative. If recalculated for an area of 1 km^2, the total cost is **Euro 340.000,-** (includes clearing, technical survey and general survey).

CBA Conclusion for the Conventional Method

Conventional exclusion from mine suspected area (suspected area reduction) is an open system that applies a multicriteria set of procedures and is not limited to any exclusive technology. The reliability and guaranteed confidence is highest achievable and acceptable by international mine action standards, national demining laws and sublaws. Its application in Mine Action Centers is continuous, the knowledge and the understanding of the mine situation, reliability and efficiency have continuously grown up.

5.4.4 ANALYSIS: ARC SYSTEM VERSUS CONVENTIONAL METHOD

5.4.4.1 COMPARISON OF SYSTEMS' BENEFITS

Benefits of the ARC system

- Information gain compared to conventional method;
- Rapid surveying tool for the area of interest;
- Rapid identification of safe areas of special types.

Benefits of the conventional method

- Operational for years, adapted to needs of humanitarian demining,
- Developed on the basis of IMAS, demining laws and sub laws,
- Technical feasibility known.

5.4.4.2 COMPARISON OF SYSTEM COST

A cost comparison of both systems is difficult as they are used for different things, i.e. area reduction only (ARC) and general survey, technical survey, clearing (conventional methods).

Conventional methodists argue they cannot separate cost according to the three steps of their system. They have overall cost for the complete demining procedure, only. The numbers for ARC cost (i.e. equipment plus personnel cost) for area reduction of 1 km² have been shown above (EURO 1,040.000). The same area to be investigated and cleared by deminers costs EURO 340.000.

ARC is characterised by relatively high fix cost of almost one million EURO, but of low variable cost of approximately 40 kEURO per km². The conventional method has lower fix cost (supposed: 100.000 Euro), but relatively high fixed cost of EURO 342.000,- per km². The point of intersection of both systems is at 3 km² area to be reduced (ARC) / cleared (CM). Conclusively, the ARC system operates more cost efficient if the area to be investigated exceeds 3km².

In order to compare two systems on a similar level, one has to either (a) calculate (assumed) additional cost to ARC for technical survey and mine clearing, or (b) reduce the CM cost to a certain (assumed) amount (to exclude the mine clearance process)

In the following ARC and CM are compared by adding different percentages of 1 km² CM cost to ARC area reduction to be used for complementary technical survey and clearing (i.e. the assumption is, that one half of the conventional tasks can be replaced using ARC).

The Assumption "ARC Extended"

The cost functions of systems using ARC for the general survey plus CM for the technical and clearing have been calculated for several additional cases (50%, 60%, 70% and 80% of the total cost of the CM). These cost functions shall be called "ARC Extended 60%", "ARC Extended 70%", etc., and they shall be compared to the CM function. The 'break even' points of these cost functions will be the higher, the higher the percentage of the "ARC Extended"-functions.

The table below shows the break even points of different humanitarian demining systems based upon ARC technology and the Conventional Method approach. All "ARC Extended" systems use the ARC system for the general survey. For technical survey and mine clearing, the four systems use the conventional way and it is assumed that the cost are 50%, 60%, 70%, and 80% of the total cost of CM.

	Cost (kEURO) of HD systems based on ARC and CM methods				
'Break Even' Area (km²)	ARCExtended 50%	ARCExtended 60%	ARCExtended 70%	ARCExtended 80%	Conventional Method (CM)
8	2.770				2.900
10		3.560			3.600
15			5.345		5.350
33				11.640	11.650

Table 5-13: HD systems (combinations ARC and CM) compared

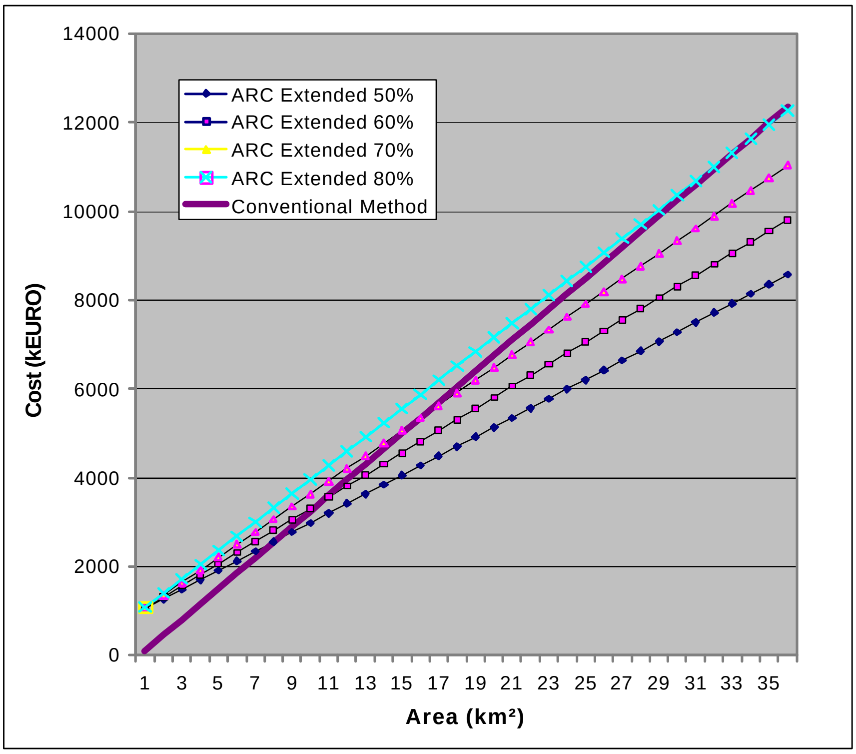


Figure 5-45: Break even analysis of HD systems (combinations ARC and CM)

5.4.5 CONCLUSIONS AND LESSONS LEARNED

This section summarized the ARC products (GIS-DB and reports) and results for hazardous area reduction. A subjective assessment showed its usefulness for Area Reduction. The ARC achievements can be qualified as good as they fulfil the initial objectives.

However, an effective benefit assessment of the ARC system for Mine Action, including costs, needs an objective assessment by the end-user, of the operational deployment of the ARC system in the mine action process in terms of:

1) the possible use of the ARC products (GIS-DB and reports) for enhancing the GMAA process, and as inputs for the planning/preparation of technical survey and clearance phases

2) the possible use of the ARC area reduction results as inputs for planning/preparation of technical survey and clearance phases

Demonstrating a Mine Action Technology System, as that proposed by ARC and pursuing it for further prototyping, production, and exploitation by the Mine Action Actors, apart of the financial aspect, important issues are a inevitable pre-conditions:

1) Understanding Mine Action by the technology provider partners, and

2) Understanding the system concept by all the partners, both technology providers and end-users.

6 DISSEMINATION AND EXPLOITATION

All through the project lifetime the dissemination activities by the ARC consortium have been set mainly in the following fields:

- **ARC** project web site
- Preparation of a Dissemination and Use Plan
- Preparation of an Intermediate Exploitation Report
- Project presentation at conferences and in media
- Mine related papers (e.g. Landmine Monitor Report)
- Presentation of the system during Demonstration events.

The **ARC** project web site is available under the URL http://www.arc.vub.ac.be and contains information on the project, the selected methodology and on the project consortium, as well as links to the EC (IST programme) and to the partner's home pages.

The DUP (Dissemination and Use Plan) was issued with contributions from all commercial partners within the consortium, describing the background of the project in terms of the global market of demining, the currently selected approaches and the valid standards e.g. deployed by the UN. Main project results defined in the DUP are the **ARC** system as a product on its own as well as sub-components of the system, e.g. the establishment of remote sensing maps for demining support or the Data Fusion concept which could lead to a separate product. Another potential product identified in the DUP is the image geo-referencing system based either on an active gimbal or on a software solution allowing a highly accurate positioning of the acquired image data. The Intermediate Exploitation Report details some of the aspects described in the Dissemination and Use Plan, in more detail the exploitation issues have been treated in the Exploitation Perspective Document.

A number of presentations on the project and the **ARC** system have been held at various opportunities, some of the presentations were accompanied also by publications and posters. An important event in this respect was the EUDEM2-Scot Conference on Humanitarian Demining in Brussels, Sept. 2003, where both the ARC Concept and some of the results have been presented.

The ARC system and the results obtained with it have been shown to a wider, thematically concerned public also in a special demonstration at Schiebel in June 2003, and, as an important final step of the project, during the Minefield Demonstration Day in November in Grossmittel near Vienna (see Section 4.5).

During the work in the Exploitation and Dissemination part of the project, a series of widespread potential applications of the full system as well as of its components have been identified. The listing below illustrates this multi-functionality of the selected approach:

1. Crisis Management - Disaster assessment and recovery (assessment of the situation before the recovery mission and after, detailed planning of missions), e.g. for
    a. mountain slides

   b. river flooding
   c. forest fires
   d. avalanches
   e. industrial (chemical or nuclear) disasters
2. Planning support for peacekeeping operations
3. Environmental monitoring
   a. vegetation assessment and nature planning (e.g. forests or protected areas)
   b. planning and assessment of the clearance of abandoned polluted areas
4. General remote sensing
   a. planning and assessment of archaeological field work (with the help of airborne survey/ground penetrating sensors)
   b. planning of infrastructure projects
5. Search for missing persons in forests or mountainous areas (e.g. using thermal information)
6. Detect new marks of trespassing across e.g. a border
7. Detect human activity, e.g. use or not use of houses
8. Detect leakage in pipelines e.g. for water, gas and oil, by means of change in thermal properties.

7 CLUSTER ACTIVITIES

Cluster activities in the field of Humanitarian Deming were strongly supported by the Directorate General for Information Society of the European Commission. **ARC** representatives attended the information exchange events organised by DG INFSO, and during October – December 2001 the **ARC** consortium continued and enhanced its involvement in the following cluster activities:

(a) with other projects financed under the IST-Programme (SMART) and
(b) with private projects (MINESEEKER)

Ad (a): A close cooperation with the SMART team aimed at exchanging essential background information on the actual situation of mined areas in Croatia. The Croatian Mine Action Centre has been a partner in both projects and should provide ancillary data for inter-changeable use. Further, it should be investigated in how far different sort of data (geographic data, sensor data) which have been used in **ARC** and SMART could have been of mutual benefit for the two projects. The SMART team has communicated its general readiness to cooperate in the above mentioned fields.

Ad b): A joint **ARC**, SMART and MINESEEKER cluster proposal “CASIM - Consolidate Airborne Survey in Mine Action” was submitted to the European Commission under the Call Identifier IST-02-8-2B, thematic priorities VIII.1.1 and VIII.1.8. Unfortunately, the proposal was not successful. In the proposal, the three project teams have identified the following major tasks and positive impacts of a co-operation:

- **Methodology of validation of tests and trials:** SMART and **ARC** wanted to exchange GIS and MIS data that are related to the scene. With the integration of the MINESEEKER-project the cluster wanted to focus on a task "investigation of possibilities of data exchange" in order to find out if there was data exchange possible between the two or between the three partners.

- **Harmonisation of end user requirements for airborne systems:** As the system is large the cluster wanted to think on the serious impact on large scale companies for demining.

8 DEVIATIONS FROM PLAN AND RISKS ANTICIPATED

During the project lifetime some deviations from the original work plan occurred, which had different reasons and different impact on the project progress, and which have been handled in different ways.

An important factor for the success of the project is the availability of minefield indicators which can be assessed using the sensors available to the project, and from the proposed lightweight airborne platform. The complexity of the situation made a more intensive information collection phase necessary, therefore the effort put into the Trials and the subsequent evaluation of the data was intensified compared to the original Description of Work.

A major technical problem was related to the development of the gimbal, this problem was identified already in the first project year. The selected sensors, as a consequence of the Trials, together with the accuracy requirements impose technical requirements on the gimbal, which are hard to be met with respect to the limitations of the weight and power consumption on a lightweight air vehicle like the Camcopter®. In order to minimise the risks which could arise if the construction of an active gimbal proves to be impossible, the consortium has decided to develop an alternative solution based on an unstabilized gimbal and GPS/INS with a software module for the retrieval of the required geo-referencing and geo-rectification information. This modification of the work plan was reflected in the Second Amendment of the project contract.

Tests of this modified system showed that the selected solution is viable, and that with the modifications the project was brought roughly back into schedule again. Nevertheless, with the Second Amendment of the project contract the overall project lifetime was extended by six months to end in December 2003. This allowed to put more efforts into the evaluation and the assessment of the Minefield Tests, which were done in May 2003.

9 CONCLUSIONS

During the first project year the trials I and II played a significant role - although they were foreseen as short in time, their contributions became the main catalyst for **ARC**. Besides this role, they allowed the scene analysis, image processing and data fusion partners to progress in their work, in detail in the (1) platform integration, (2) contextual data collection, (3) airborne minefield scene analysis, (4) data processing, (5) refinement of GIS and data fusion principles, and last but not least (6) operational requirements.

Based on the acquired knowledge the system development work was one of the main focuses of the second project year, in detail the finalisation of the System Design and the subsequent implementation of the designed system. At the end of the second project year the system implementation is mostly finalised, and a significant part of the system integration work has been done. During Trial III, which was performed in Croatia, a wealth of valuable data was collected, which is used in the development of the image processing as well as of the data fusion modules. Moreover, in this trial for the first time the complete airborne system (Camcopter® and cameras) was used successfully.

For the geo-referencing of the acquired data, a core element of the ARC concept, a major technical change had to be made to account for difficulties in the development of the originally planned stabilized gimbal. The alternative solution with an unstabilized gimbal and GPS/INS together with a software module evaluating the geo-referencing information proved to solve these difficulties.

This modification, together with the extended data collection phase, which was required in order to obtain a sound basis for the development of the **ARC** demonstrator system, made it necessary to make minor deviations from the work plan by shifting some of the project budged as well as some deadlines. Therefore the Minefield Tests were made in May 2003, followed by an extensive evaluation and assessment phase.

The analysis of the Minefield Tests data has proven the general concept of the ARC system, with respect to both the operational aspects and to the data acquisition and evaluation part of the project. Although only a part of the acquired data could be analysed within the project lifetime, valuable insight into the related problems has been gained.

Further work has been identified to be required in the following areas:

- increase of the degree of integration of the system components
- further elaboration of the list of minefield indicators
- more extensive elaboration of knowledge models used for the data fusion process.

For the developed system and its components, which at the end of the project are available in different states of maturity.

A wide range of potential applications have been defined also beyond the original issue of humanitarian demining – generally this comprises all applications, where fast, accurate and cost efficient mapping of smaller areas is required. Further work within sub-groups of the ARC consortium will concentrate on the continuation of the development of the system for specific applications in these fields.