ARC – Airborne Minefield Area Reduction

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Abstract

This paper gives an overview of the ARC system (Airborne Minefield Area Reduction), a demonstrator system for airborne minefield survey for use in General Mine Action Assessment and Technical Survey (area reduction and as far as possible mine field delineation).

A description of the conceptual and the methodological aspects of the project and the developed system is given, followed by a summary of the operational steps in the use of the system and of the preliminary results of the trials and minefield tests performed during the demonstrator development.

1. Introduction

1.1. Background

Within the framework of the ARC project (Airborne Minefield Area Reduction) a demonstrator system is being developed for airborne minefield survey, for use in General Mine Action Assessment and Technical Survey (area reduction and as far as possible mine field delineation).

An important methodological aspect of the proposed approach is its pyramidal information structure, which is reflected in (i) the use of a helicopter UAV, flying at different heights, and (ii) the developed GIS data base structure. Technological and scientific challenges are also the full integration of the data chain from the optronics sensors to the detection of minefield indicators and subsequent analysis integrating contextual (minefield information), and the acquired data in a data fusion approach. These conceptual aspects of the developed system are the contents of the second section of the presentation, the third section describes the data flow and system operation in more detail.

The project has finalised the implementation and integration phases, during the last project phase minefield tests and the evaluation of the system results as well as system refinements are the main parts of the remaining work [1]. The fourth section of the presentation comprises an overview of the preliminary results of these tests which have been produced after the Minefield tests in Croatia in May 2003, followed by preliminary conclusions possible at the current stage.

1.2. ARC Objectives

The objectives of the ARC project, as given in the Description of Work, 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. The nomenclature of the terms related to demining work follow the definitions from IMAS 04.10 Glossary of Mine Action Terms and Abbreviations [2].

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, etc.) 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 system. 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 cost reduced repetitive surveys and (iii) providing accurate and reliable survey data (maps, aerial imagery, land cover, …).

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, including thermal imaging. The platform is an extension of current technology for survey applications; and the ARC system a full new methodology to be smoothly integrated into the pre-(Technical Survey) and possibility post-(Quality Control) mine clearance activity.

2. The ARC Concept

This section describes key elements of the concept of the ARC system – the hierarchical information model, the minefield indicators approach and the high level system architecture.

2.1. Pyramidal Approach

An important aspect for information systems is to provide the appropriate level of information detail to the user. In the case of a system addressing different user groups at different levels, this can be achieved using a pyramidal (hierarchical) information approach (Figure 1).

In the ARC system the pyramidal concept is implemented by modifying the general view sketched in the figure below in a way logically integrating 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. In this concept the data acquisition from a helicopter UAV is an important element, as this platform fulfils all of the following requirements:

- Small starting and landing area (important within potentially dangerous environment),
- Precise positioning system combining DGPS, INS, accelerometers and solid state gyros (important for both exact geo-referencing of the acquired data and for re-visits of areas of interest),
- Possibility to acquire data from altitudes between 10m and 1000m (see pyramidal data acquisition scheme),
- Remotely controlled operation,
- Autonomously stabilized: robust operation also under difficult weather conditions (wind),
- Pre-programmed to fly along pre-selected routes, and hence accurate repetitive scans (surveys)

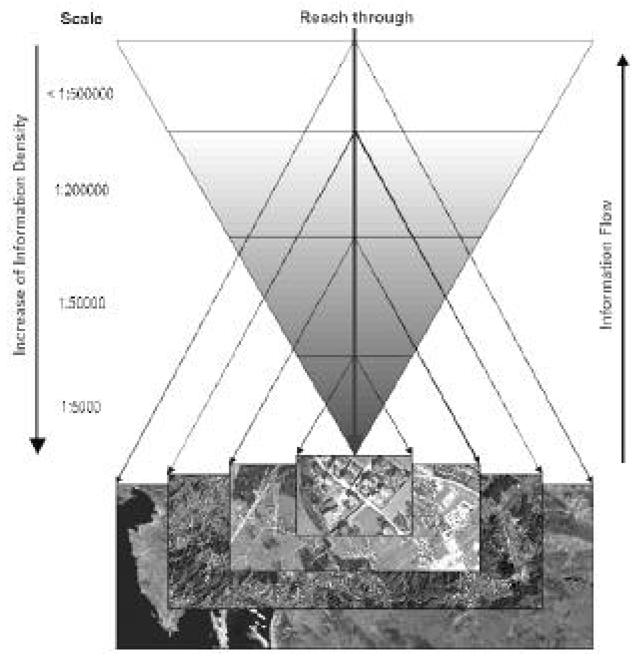

Figure 1: Schematic view of the pyramidal information structure applied in ARC.

The Information System developed within the ARC project provides additional information from new satellite data (e.g. IKONOS), external sources and the results of the ARC project. The currently collected information is restricted to the study 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. Field maps prepared from 1 meter IKONOS data almost comparable to 0,5 – 1 meter aerial orthophotos will bring additional improvement for operational purposes.

In its final version the Geographic Information System will be an integrated multifunctional system which fulfils series of tasks, e.g. Collection and dissemination of all minefield related information, support for decisions about priorities of minefield clearance, operational tool for selection of strategies and operational decisions, supplier of specific field information, steering instrument for an

ARC survey and ground survey, source of base maps for level 3 - quality control works.

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

- Level 1 – The government level,
- Level 2 – Regional Level,
- Level 3 – Local / Community Level,
- Level 4 – Operational Level.

The design of the system and the implemented data-base with the specially adapted GUI of the GIS allows the upper levels to zoom into the higher resolution information of the lower levels. Main focus of the implementation of the demonstrator system is the Operational Level. Table 1 gives an overview of the data specifications of the different levels used.

Level	Acquisition Height	Platform	Products	Resolution
Global 50x50km	700km	Landsat TM, Spot	Maps, Satellite imagery	30 – 10 m/pixel
Regional 20x20km	700km	IKONOS, Quickbird	Orthophoto Maps, frontline maps	1m/pixel (panchro-matic)
Local 10x5km 2x0,5km	3000m - 500m	UAV (Camcopter ®) Optronics Sensors	Orthophoto Optronic Imagery	0,5 – 0,2 m/pixel
Minefield 200x200m	1000m - 30m	Camcopter® Optronic Sensors	Optronic imagery	30 – 1 cm/pixel

Table 1: Specification of information levels.

2.2. System Architecture

The ARC system architecture has been set up in a highly modular way both with respect to hardware and to software structure, allowing for easy adaptation to changed environments and requirements.

On the highest level the main components are

(i) the airborne data acquisition system comprising the UAV platform and the camera systems, and

(ii) the ground station with all components required for the preparation of missions, analysis of the acquired data and production of the results

In the current configuration the implemented sensors comprise a VNIR camera (DuncanTech - red, green, NIR) and a thermal infrared camera (FLIR SC3000 QWIP).

All information in the system is stored and managed within a RDBMS, from where it is accessed and visualized by a GIS. Image pre-processing modules as well as the modules responsible for image processing and data fusion are integrated using a common GUI and accessing data from the common geo-database.

Figure 2 gives an overview of the logical structure of the GIS components and the database as well as the integration of the image processing modules.

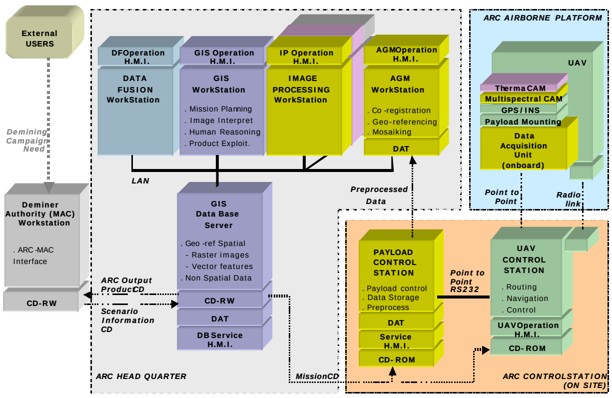

Figure 2: ARC System Deployment View

3. The System in Operation

The following section gives an overview of the information flow and the operation of the system from the planning of missions to the delivery of results to the users.

3.1. Mine Information System & Contextual Data

The first information introduced in the ARC GIS, is the Mine Information System, consisting of reference maps, orthophoto maps, suspected minefield polygons (vector layers), Minefield Records (vector layer, including type of mines, type of minefield, drawings and reference geographical points), mine incidents (vector layer), separation lines (conflict maps). This information has been improved by collecting contextual information e.g. digital elevation model, land cover and land use (agriculture information, soil maps), assessment of the Mine Information by considering the history of the conflict within the suspected area, visits to the suspected area, and taking photos of the landscape and visible indicators. Moreover satellite images have been considered also for change detection and land cover. The considered satellites are:

- Landsat TM / ETM with a ground resolution of 30m (multispectral) and 15m (panchromatic)
- Spot XS / Pan with a ground resolution of 20m (multispectral) and 10m (panchromatic) for Spot 1-4, and 10m (multispectral) and 5m (panchromatic) for Spot 5
- IKONOS with a ground resolution of 4m (multispectral) and 1m (panchromatic)
- QuickBird with a ground resolution of 2.4m (multispectral) and 0.6m (panchromatic).

3.2. Mission Planning

At the beginning of each ARC survey the mission is planned in the Head Quarters, taking into account background information described in the previous section. For the detailed flight plans ARC provides the Mission Planner, an extension developed on basis of ESRI's ArcView 3.3.

Based on the available information, the survey area is defined using the GUI of the Mission Planning module. With the additional specification of flight altitude and speed, degree of overlap, pitch, roll and opening angle of the camera's, etc., the flight coordinates of the UAV are calculated and exported to the UAV control station in form of a waypoint file containing also the commands for the data acquisition system (start/stop acquisition, acquisition rate, …).

Figure 4 shows flight paths generated for a test field, the colours of the different paths indicate the flight altitudes (red: 30m, blue: 300m, yellow: 900m above ground).

3.3. Data Acquisition and Pre-Processing

Once the mission plans have been generated they are transferred to the UAV control station and the flight mission can be started (Figure 5). The data acquisition process is fully automated, including also flights to calibration points (markers) which allow for the acquisition of both calibration data (mainly for the infrared sensors) and of quality assessment data (geo-referencing accuracy).

After the acquisition of data and landing of the UAV, the data are transferred from the on-board storage facilities and integrated into the ground station data structure.

The first pre-processing step is the calibration of the data, based on the information collected from the calibration markers. After that, the geo-referencing parameters are calculated in two steps: (i) the GPS/INS information is evaluated, providing geo-referencing with an accuracy in the range of meters, (ii) the AGM (Automated Geo-referencing Module) is applied to refine the geo-referencing to an accuracy in the range of a few pixels using an image-to-image rectification procedure (see Figure 6). The first step provides image mosaic for visual interpretation. The second step provides the 3D transformation matrix (pixel – world coordinates) which allows to geo-reference each image/pixel.

3.4. Image Interpretation and Processing

The aim of visual interpretation and (automatic) image analysis is the detection of minefield indicators for establishing mine-suspected areas. The (non exhaustive) minefield indicators used are: tracks, unused paths/roads, protective walls, trenches, embankments, bunkers, agriculture areas not in use, demolished buildings, …[4]

The detected (visually or automatically) minefield indicators (features) are stored vector layers in the ARC GIS. These features are later used by the Data Fusion module and the Human Interpreter to create evidences of suspected minefield.

Several Image Analysis routine have been implemented and tested for the extraction of minefield indicators. Among them we can site:

- Anomaly detection
- Linear Feature extraction[5]
- Land cover/land use classification
- Building detection[6]
- Diurnal Thermal Analysis (anomaly detection)[7]

These modules are integrated in the system both on the user interface side and on the data side, i.e. they access the common database for retrieving the input data and for storing the resulting feature layers.

3.5. Data Fusion

In the final step of the data flow the available information is combined in the Data Fusion module. This module uses a set of knowledge-based rules to derive higher level information from the features obtained from visual interpretation, image processing and contextual information. The most important subset of rules integrate spatial reasoning, e.g. by evaluating the distance between features of different types.

Ultimate goal of the data fusion process is to discriminate between areas of reduced and those of increased probability to be minefields.

Figure 8 shows a preliminary example of a data fusion result – the red area displayed on top of the aerial orthophoto denotes the area with higher probability of mine contamination as derived from the combination of a number of feature layers in the system.

3.6. Presentation of the Results

An important part of the system is the reporting of the results to the users, which is done in several ways:

1) The results of the ARC system are 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 suspected minefield are indicated. The digital maps contain:

- the original suspect minefield area boundary,
- the danger map (delineated contour) produced by the ARC system

2) The ARC-GIS contains all the collected data: maps, satellite images, geo-rectified optronic sensors images, results of the image analysis and Data Fusion, and Contextual data including minefield records and historical data.

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

Product exploitation capabilities are based on the functionality provided by the (ESRI ArcGIS) ArcCatalog8 application as well as on the procedures and the customisations elaborated on the basis of the ArcMap8 application in order to facilitate these task.

The gathered set of layers – including the danger map - are arranged and configured in the most informative way, allowing the user to modify the presentation to obtain the most appropriate and convenient view of the situation.

4. Preliminary Results and Conclusion

First preliminary results on the applicability of the presented concept and the demonstrator system based on this concept have been collected during field trials and minefield tests during the project lifetime. Preliminary results are promising and have shown that the pyramidal approach is an important element of the success of the project. This holds for both data acquisition (geo-rectification) and the planning and interpretation. Detailed evaluation of the tests is ongoing.

The helicopter UAV platform has proven to be very reliable and stable; deviations from the programmed flight path were found to be small compared to the predefined overlap between two flight paths.

During the Minefield Tests the potential of the system for an efficient cartographic survey of suspected areas from different altitudes using different sensors has been demonstrated successfully – the remaining errors of the geo-referencing procedure are in the range of a few pixels (i.e. a few centimetres for a flight altitude of 30m). With the subsequent visual interpretation valuable information for prospective demining actions could be found and geo-referenced very precisely.

Image processing algorithms have been applied successfully both to the multi-spectral visual data (pattern recognition, classification) and to the thermal infrared data (diurnal analyses). In the next step the derived features are integrated in the Data Fusion module to combine them to a high level dataset on the mine threat. First results of this procedure are promising and highlight the importance of suitable and well-defined minefield indicators and of their optimal representation in the data fusion rule sets.

To summarize, with the ARC System a demonstrator system for information gathering and exploitation in the context of humanitarian demining has been developed based on a helicopter UAV, visual and infrared camera systems, and on a GIS based mission preparation, image processing and analysis ground station.

During minefield tests the demonstrator system has been working operationally, employing all major components in a successful manner.

The basic data collection and mapping functionalities of the system with the automated geo-referencing and mosaic generation, and the subsequent use of the data for visual interpretation have been demonstrated almost in their full extent.

More work remains to be done for two important fields: (i) the extension of the list of suitable minefield indicators, and in close connection with this, (ii) the extension of the set of rules for the data fusion module.

Final conclusions on the developed system will follow from the Evaluation and Validation phase, which will be finalized with the end of the project by the end of 2003.

References

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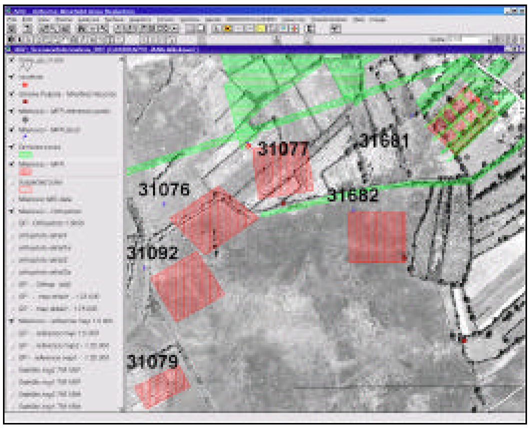

Figure 3: Screenshot displaying minefield information used for the preparation of missions.

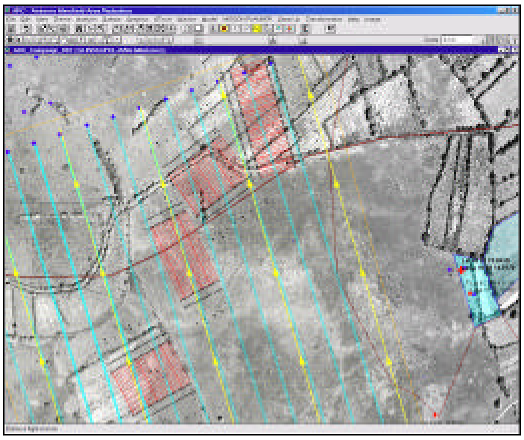

Figure 4: Screenshot with flight paths generated for missions over minefields in Croatia.

Figure 5: The ARC data acquisition system at take-off.

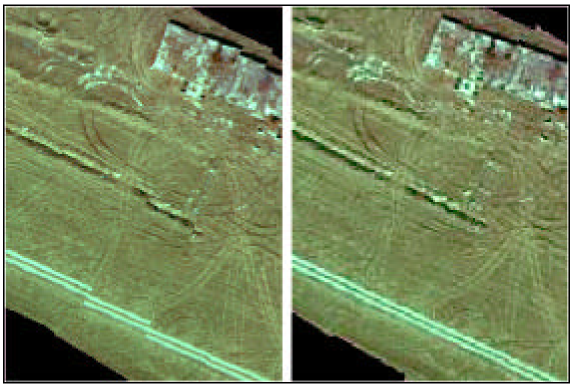

Figure 6: Georectification results after GPS/INS correction (left) and the application of the AGM (right).

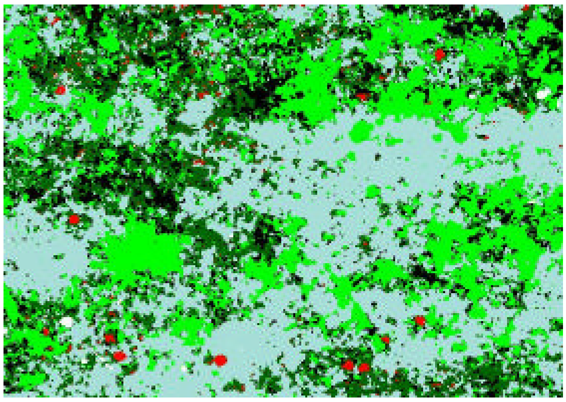

Figure 7: Classification results: dark circular objects (RED), bright objects (WHITE), vegetation (GREEN), debris grassland (DARK GREEN) bare soil (CZAN) and dark soil (BLACK).

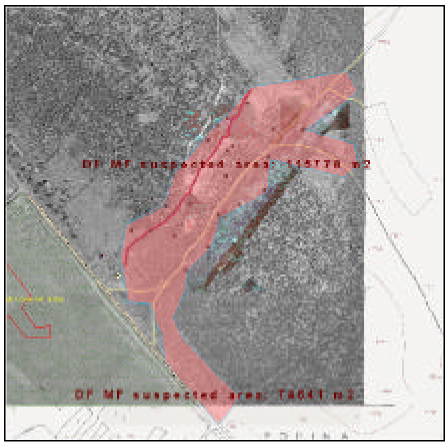

Figure 8: Preliminary data fusion result showing an area with enhanced probability to find mines (red).