ISMAEL – Intelligent Surveillance and Management Functions for Airfield Applications Based on Low Cost Magnetic Field Detectors

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***Abstract*— Against the background of aggravated capacity constraints at airports due to increasing air traffic, airports are in need of innovative systems enabling Air Traffic Controllers to precisely determine the position of vehicles moving on the surface, even under reduced visibility conditions. While this demand is addressed by the development and introduction of Advanced Surface Movement Guidance and Control Systems (A-SMGCS), technologies currently applied to A-SMGCS feature some weak points regarding coverage, robustness interference, and climate conditions. ISMAEL targets these weak points by developing an innovative detection solution based on magnetic sensing technology. Thus, ISMAEL will represent a valuable and cost-efficient complementary contribution to existing and planned A-SMGCS at small and large airports.**

I. Introduction

Despite temporary declines in 2001 and 2002 as a result of 9/11 and a number of European airline collapses (Swissair, Sabena, etc.) traffic volumes at European airports will continue to increase [1], leading to at least a doubling in traffic every 12 years [2]. For a considerable part this can be attributed to the huge growth in the low cost air traffic sector, which led to a rapid expansion of previously stagnant secondary airports such as London Stansted and Frankfurt Hahn [3]. The size of airports cannot be increased at the same rate nor will new additional airports significantly contribute to resolving this challenge.

As a consequence airport terminal areas and surface operations are increasingly recognised as important aviation capacity constraints. These constraints are particularly acute under adverse weather conditions, which dictate less efficient terminal area procedures to maintain safety and can result in delays that propagate through the regional air traffic system and beyond.

The constraints can be reduced if airports are equipped with systems that allow Air Traffic Controllers to determine precisely where each aircraft is located within the run- and taxiway system at all times, even under reduced visibility conditions. The precision and reliability with which aircraft type and position are identified directly determine the separation requirements, which must be allowed to maintain safety. Optimizing separation requirements allows higher throughput and thus improved usage of restricted airport capacities.

ISMAEL, a European R&D project funded within the 6th Framework Programme of the European Commission, targets this issue by developing an innovative detection solution based on magnetic sensing principles for improved ground traffic control and management at airports.

II. Objectives

Against the background of aggravated capacity constraints at airports due to increasing air traffic, ISMAEL aims at easing the situation by developing an alternative system for surface movement surveillance at airports improving safety and efficiency of ground movements. A new detector based on magnetic field sensor technology was developed for use within A-SMGCS. In this context, ISMAEL aims at improving existing installations of A-SMGCS at large airports as well as at enabling the installation of an appropriate form of A-SMGCS at small and medium airports in Europe.

III. Approach

As ISMAEL is a system development project it starts with the collection of user requirements as input to the subsequent detector development. Moreover, relevant aspects of system integration with respect to the targeted applications will be analyzed. The project concludes prototype tests at selected airports and the establishment of an exploitation strategy for the planned future introduction to the market.

Regarding the basic technical principle, the system is based on the detection of ferromagnetic objects (e.g. vehicle motors, aircraft components) from their interaction with the earth’s magnetic field. The earth's field acts as a biasing magnet, resulting in a magnetic signature (fingerprint) from ferromagnetic objects [4, 5]. This property can be used to detect and locate the objects, either using a single point sensor or an array of sensors.

Development work started with the specification and design of the scientific sensor head. The current approach of the scientific detector has certain advantages accounting for the risks involved in applying laboratory results to real life

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conditions. In this context one advantage is the flexibility of the scientific detector enabling to vary relevant parameters, in order to investigate the optimum settings for the execution of the aimed tasks. These experiences with the core properties of the magnetic field detector bring valuable insights for the development of the operational detector. Consequently the approach of the scientific sensor head contributes to the philosophy of a rapid prototyping environment.

Another focus is on the design and development of the SDF (sensor data fusion) server. The SDF server handles the following processes: it collects event data from various sensors and forms ground observations. The server filters them to form ground target tracks and finally presents the targets and the tracks to the user.

IV. INNOVATION

The local change of the earth's magnetic field is extremely small – less than 1 μT - but the new sensor prototype proposed can detect this reliably. The system can also be used to distinguish between different types of aircraft and vehicles based on the magnetic signature of each type. The information can be transferred to tower controllers for better airport management.

Within the scope of the project, a new series of sensor prototype is developed with the following features: Three magnetic field sensors in an x-y-z arrangement. Temperature compensation is integrated in the first of three amplification stages. A second order low pass filter is used to filter out high frequency noise. True differential output is applied to transfer data up to a distance of 1200 meters. Offset calculation and compensation and transfer of data and commands via RS485 at 19200bps are provided to operate multiple sensor heads within one thread and to transfer the specific configuration commands to the individual sensor heads. Waterproof solid cases for an under-earth deposit of the sensors are used.

V. BENEFITS

The major benefits of the planned solution are derived from the fact that it constitutes an efficient low-cost complementary position technology to be included in existing and future A-SMGCS. Furthermore, it is easy to implement due to its small size allowing for installation at almost any location, such as integration in existing ground lighting systems. Unaffected by weather conditions, interferences and shadowing effects the system provides reliable position, velocity and direction information. In addition, a general classification of passing vehicles is intended. Moreover, the system does not rely on secondary transponders or other on-board equipment, such as multilateration or ADS-B (Automatic Dependant Surveillance Broadcast). Based on a passive detection principle no interference with other systems like aircraft radios is given. In general the solution is characterized by low energy consumption and a modular architecture that allows for easy system upgrades and extensions accounting for the heterogeneity of different airports. In this context another strong argument for this new detection technology is its flexibility. The system can be integrated into existing A-SMGCS and served as an efficient augmentation for special areas and/or special tasks.

VI. APPLICATIONS

The following six applications were analysed with respect to their potential for improvement resulting from an introduction of the planned detection solution:

1) Airport Surveillance,
2) Runway Incursion,
3) Fleet Management,
4) Docking Monitoring,
5) Gate Management,
6) Taxi Management.

Within the scope of user requirement analysis Airport Surveillance, Runway Incursion and Gate Management turned out to be the most promising applications to be targeted by ISMAEL in first instance.

A. Airport Surveillance

The surveillance function is one of the key tasks for airport ground operation. In order to establish safe and efficient planning and routing, the controller must have a clear picture of the current traffic situation. This situational awareness is necessary to execute the control task and give clear guiding instructions to aircraft and ground vehicles. Under good visibility conditions this task can be fulfilled through visual control, but when the level of visibility decreases some form of technical assistance is required.

The most well-established technique for airport surveillance is the ground movement radar. At larger airports it may be necessary to install multiple radar systems, because complex building structures cause shadowing effects or multiple reflections. In this case the radar may also be augmented by multi-lateration, an alternative surveillance technology that relies on signals from the mode-S transponders fitted to most public transport aircraft (increasingly multi-lateration data and radar data are combined in an A-SMGCS to provide a single integrated display). However, multi-lateration is subject to interference caused by reflections, and it detects only targets equipped with an operational transponder. Equipping small and medium-sized airports with radar or multi-lateration is often too expensive, so that these airports have to reduce or stop operation under low visibility conditions.

This represents the background for identifying potential applications for new surveillance concepts based on magnetic field detectors:

1) a low-cost alternative to radar or multi-lateration at

smaller airports,

2) a “gap filler” for areas where existing surveillance techniques are not effective (e.g. due to buildings),

For the application of the magnetic field detectors to airport surveillance two approaches can be taken:

a) Radar-like Functionality

The radar-like functionality meets the most likely expectation of users having experience with radar-based surveillance equipment. The whole area for ground movements is covered by magnetic field detectors, in order to provide continuous detection and location of targets as they move across the airport.

The physical principle of radar enables it to monitor a large area, such as an airport, with just one installation. In contrast the magnetic field detector is a point device covering only a relatively small area. Complete coverage of the whole airport would thus require a very large number of detectors.

The radar-like approach fits well with existing airport operation schemes, and is certainly a potential solution for larger airports that aim to provide further redundancy in critical areas, or require system augmentation for areas of the airport that may become blocked by new building construction for example.

b) Block-wise Functionality

The radar-like approach is preferable in terms of meeting most users’ expectations of surveillance, but there is a strong risk that the economical benefit suffers by the large number of detectors required. Thus a second approach is proposed to reduce this risk. The block-wise functionality divides the airport movement area into blocks and at the beginning and the end of each block a line of detectors is installed to detect aircrafts or vehicles entering or leaving this block. Thus, intersections of taxiways, exits from runways, etc. represent nodes that constrain a block. Through this approach, the cost of hardware, installation and maintenance could be reduced by 90%, but a change of operation must be accepted as well.

The block-wise approach is ideal for small and medium-sized airports that do not have an existing surveillance function because of high costs. In this context the block-wise approach can improve the situational awareness to a certain extent and thus may provide an acceptable trade-off between operational and the economic requirements. The block-wise approach could also be used at larger airports to provide additional high-integrity monitoring of critical locations such as stop bars.

B. Runway Incursion

The ability to detect vehicles passing a specific location is also very appropriate for the prevention of runway incursions, which is a critical task in assuring airport safety. Applying accordingly located magnetic sensors each runway exit can be controlled for intruding vehicles. This could prevent severe accidents, like the one in Milan in 2001, when two aircraft collided during take off due to limited visibility under foggy conditions and an inoperative ground radar.

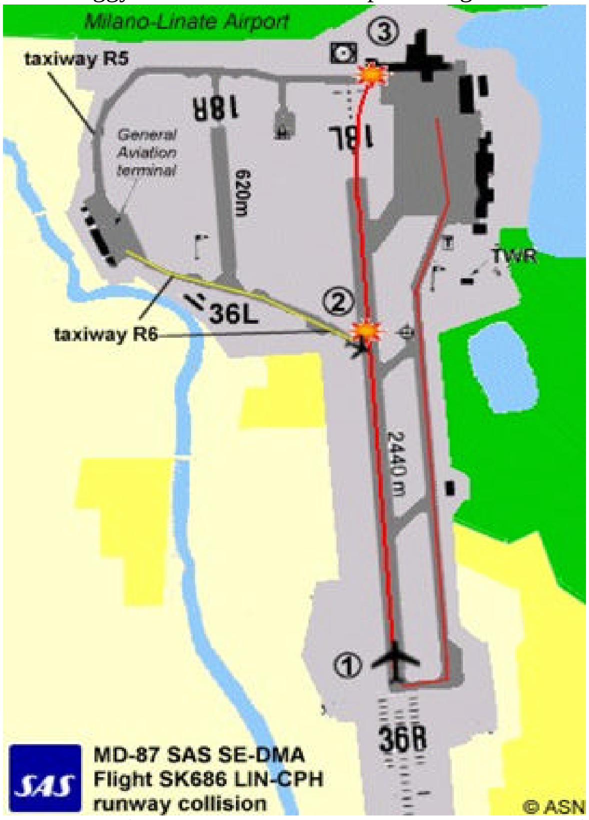

Fig.1. Map of the accident at Milano-Linate Airport on 8th of August 2001[6].

Figure 1 shows the airport layout and the routes of the aircraft, which occurred under poor visibility with a runway visual range of approximately 225m. As a MD-87 taxied to runway 36R for departure, a Cessna 525A Citation Jet 2 received instructions to taxi north via taxiway Romeo 5 and to call back at the stop bar of the runway extension. This instruction was acknowledged by the Cessna pilot. Instead the Citation Jet took a route east via R6. Despite further communication via radio, the disorientation of the Cessna pilot and the misunderstanding of the received instructions were not detected. The tower is located at a distance of approximately 580m from the stop bar, which prevented direct visual confirmation of what the pilot was reporting. 114 fatalities on board and on the ground resulted and Milan-Linate airport has lost permission to operate under a runway visual range below 500m.

Certainly appropriate equipment is available now to enhance safety and avoid such fatal errors during runway and taxi procedures. Milan-Linate airport even has a Surface Movement Radar installed, but this was out of service and could not support the controller at the tower. In this context a simple detector system based on ISMAEL could have been used to create a redundant and independent warning system.

The magnetic field detector is well suited to stop bar monitoring. A line of detectors at a stop bar could easily indicate when any vehicle or aircraft crosses the bar.

However, this would need to be presented as a confirmation of position rather than a warning, unless the system is integrated with other information to determine whether a collision risk exists (i.e. a RIMCAS system (Runway Incursion Monitoring and Collision Avoidance System)).

According to existing RIMCAS systems on the market, two levels of alert should be implemented. Stage one triggers when an aircraft approaches the runway and stage two comes into force when the aircraft overruns a stop bar and intrudes onto the runway. The application of a two-stage detector line will be investigated for runway incursion within the further activities of ISMAEL.

This concept fits well with the block-wise approach for the surveillance, but of course it is also possible to apply radar like coverage using a complete detector net structure over the whole Movement Area or at the approaches to the runway.

C. Gate Management

Not only moving vehicles can be detected by using magnetic field sensors, but also static vehicles. This property enables the identification of the occupancy status of all equipped parking positions. The magnetic sensing technology offers an easy way to provide reliable sensor information serving as platform for appropriate management tools.

The capacity of an airport is defined not only by the number of movements that can be handled by the runways, but also by the number of gates that are available. Effective gate management means knowing precisely when a particular gate becomes available so that it can be assigned to a new arrival as quickly as possible. Moreover, airlines are billed by airports for the length of time that they occupy gates. For these reasons an automated system for detecting when a gate is occupied would be preferable over relying on stand staff to report the gate status as at present.

Currently, a number of initiatives are underway to improve the exchange of information between airlines, airports and air traffic controllers. An automated Gate Management system could provide valuable contributions by giving precise indications on the departure and arrival of the aircraft at the gate.

ISMAEL can provide a rather low cost means of detecting an aircraft at a gate or stand. ISMAEL will be less expensive to install than inductive loops and can distinguish between an aircraft and a ground vehicle (moving or static). ISMAEL can thus signal the actual situation at the gate in real time and on a reliable basis.

VII. First Results

At the time this paper is written the elicitation and analysis of user requirements have been completed. First results primarily relate to insights on users' perception of the proposed solution. From the viewpoint of potential users, i.e. air traffic controllers and airport operators, ISMAEL represents a valuable contribution to existing and future A-SMGCS provided the system accounts for the following key requirements:

- Being noncooperative, i.e. not requiring a transponder for position determination, enabling complete detection of all vehicles regardless of their equipment, as a major requirement for an independent control mechanism.
- Acting as complementary solution being able to fill gaps in the coverage of existing detection systems or to provide additional cover in critical areas.
- Determining the actual position of an aircraft, vehicle or obstacle on the surface within a radius of 7.5m it shall be available at least for 97% of the time.
- Differentiating between target types and retain identification and labelling of authorized movements.
- Featuring sufficient redundancy, fault tolerance or failure mitigation to enable operations to continue or be downgraded without affecting the required level of safety; in case of a failure of a system element the status of the system has always to be in the "safe" condition.
- Being reactive to hazardous situations, to anticipate and prevent their development.
- Placement of sensors with a minimum disruption of airport operations during installation and maintenance; enabling remote calibration of the sensors.
- Being unimpaired by radio interference, adjacent high power cables, and adverse weather and topological conditions.

Regarding technical developments, first results on detector and system development can be described as follows: Input has been generated for the interface control document between the analogue sensor head and the digital processing unit. The identified constraints, established achievements and gained know-how for the production of a first series of prototypes of the scientific sensor head have been discussed and consolidated to meet all above-stated requirements and become a basis for the execution of the development tasks.

The sensor head prototype is an important tool, to support the development phase of this project. By maintaining the research facilities and capabilities and explore them outside the laboratory under environmental conditions of the targeted application field, the sensor head prototype allows detailed research activities to form the core functions to form the later detector. Several steps have been taken to design the sensor head prototype. The focus for the sensor head prototype is on a high degree of flexibility and on the feasibility limits of the applied technology, by using high quality components. Up to now, two generations of sensor head prototypes have been designed and produced.

Core functions of sensor head prototypes have been tested under well-controlled laboratory conditions (laboratory test) as well as under airport conditions (field test). Several characters, such as sensitivity and noise levels, of both generations of sensor prototypes have been tested in laboratory. These results represent a useful basis for the design work of the next generation sensor prototype. Current work also includes the function tests of the various available magnetic sensors to define the most suitable one for ISMAEL. Sensor prototype function tests at airports of Saarbruecken and Zweibruecken, Germany have been carried out aiming at investigating the functions of the prototype in real life measurements including sensing distance, noise level, sensor location and direction. Test results will be applied to further detector development and hardware/software adjustment. After initial tests using mobile setup to check signal amplitude and noise level, it is decided to build up a fixed test site for field tests. Several sensor head prototypes have been installed at different locations close to a taxiway of airport Saarbruecken. They are connected through a simple bus system to a connection box, through which signals from all sensor head prototypes can be fed into mobile measurement system. Also, sensor head prototype status like communication and temperature can be obtained simultaneously. Parameters including amplification, and offset can be adjusted during operation time. Initial field tests on passing-by-aircrafts have been carried out, and data collection is on going.

A typical test result from a passing by Boeing 737 aircraft is presented in Fig. 2. The sensor head is installed in the middle of the taxiway, one meter below the surface. The presented field direction shown in this figure is perpendicular to the aircraft moving direction as well as perpendicular to ground. Signal peaks can be explained to from gear and engine part. Further data analysis will be performed after regular field tests and data collection. Other reference methods including optical video camera monitoring will be provided to carefully investigate position, resolution, and response time which are the key factors for applications.

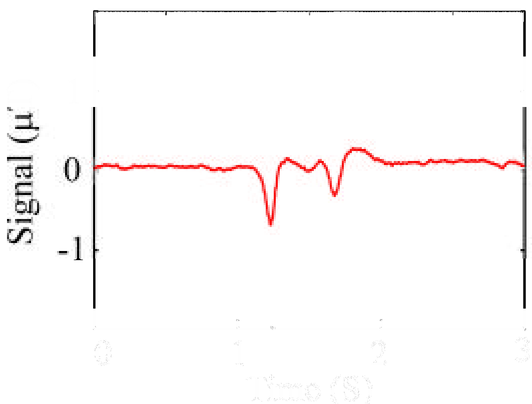

Fig. 2 Magnetic profile of Boeing 737 detected by a sensor head prototype at airport Saarbruecken, Germany.

The reliability among different sensor head prototypes has been checked as well. If sensor heads are positioned at the same location to the aircraft, outputs from them give the same results. Tests on the same aircraft after a certain time give also the same result. Another interesting result is that, signals from the same type of aircraft have the same characteristic features. This result builds up the basis for later classification of aircrafts. All these test results give us a promising concept for further system development. Design of next generation sensor heads is currently the focus based on field tests.

Theoretical calculations of the magnetic field change due to the presence of airplanes are undertaken to support sensor head prototype development. These calculations are important for the choice of sensor head prototype parameters as well as optimum sensor position and direction. Initial calculations are done based on simplified parameters for various aircrafts.

Several types of aircrafts are chosen for the calculation in this stage. Most important parameters of the modelled aircrafts include those components which are made from ferromagnetic materials. Parts of turbine engines as well as of gears are included in the calculation. The calculation employs a simple model to speed up the simulation.

The magnetic field change caused by a Boeing 737 is shown in Figure 3. As expected, close to gear or engine parts, strong magnetic field changes are produced. From this, ideal locations of magnetic field detectors can be concluded. If the sensor is installed directly under plane’s gear part, the strongest signal will be detected. Sensors can also be installed along the border of the taxiway. In this case, the signal level decreases significantly.

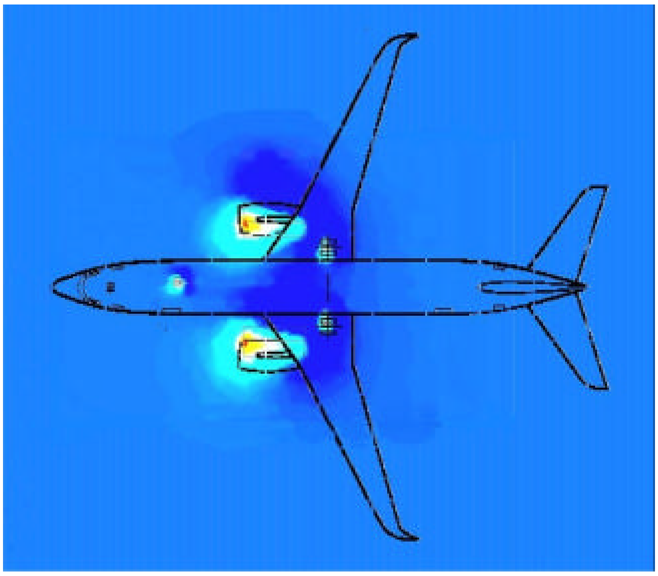

Fig. 3 Magnetic field change due to the presence of Boeing 737 based on theoretical simulation. Field range is from 51 µT (dark blue) to 135 µT(red).

Calculated values will be adjusted according to subsequent field test results. This process will reduce field test numbers as well as costs. Further research on bus-concepts and system-on-chip design will make the whole system complete.

Regarding the selected applications, airport surveillance had to be split into two scenarios to account for the differing requirements of large opposed to small and medium-sized airports. While the formers will apply the ISMAEL system as backup or as gap filling module in combination with other technologies, the focus of the latter will be on a stand-alone solution at affordable cost to provide at least a minimum functionality to the controller. Thus, different operation modes have been identified to account for the heterogeneous needs of large compared to small and medium-sized airports.

VIII. Conclusion and Outlook

First development steps and feedback from potential user groups have shown that the magnetic sensing solution developed within the ISMAEL project seems to be a reasonable and promising detection system to be incorporated in existing and future A-SMGCS or to be applied as stand-alone alternative for smaller airports. Unaffected by weather conditions, interferences and shadowing effects the system provides reliable position information of whatever type of vehicles moving at the airport surface. Yet, its operational feasibility has to be validated by means of real-life tests at selected airports. For that purpose detectors will be installed at the airports of Frankfurt and Thessaloniki to examine the actual contribution to and impacts on ground traffic management and control. Expected results are rather promising as the first sensor head tests at Saarbruecken airport indicate.

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