A Spatio-temporal Surveillance Approach for Business Activity Monitoring

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Abstract. The SECAIR project provides an event-driven architecture for dealing with spatio-temporal requirements. It adopts a multi-sensor data fusion process to handle with event streams emitting continuously location based data regarding a vast number of different business objects. It is therefore well-suited for business activity monitoring, supporting managers at analysing and processing complex event streams in real-time. A prototype applied to the surveillance of situation awareness requirements for airport environments is presented, in particular to monitor ground movements in very congested areas for indoor and outdoor areas. Outputs are presented using an advanced Graphical-User Interface, addressing a collaborative environment for airport stakeholders to manage ground handling operational procedures more efficiently and in compliance with airport business rules.

Keywords: Situation and Context Awareness Services, Spatio-temporal data, spatial Data Warehouse, Spatial Dashboard.

1 Introduction

In today's highly competitive service-oriented business environment, it is essential to keep decision makers informed about which events are affecting business-critical operations. This requirement is even more relevant in much regulated environments, with a set of business rules which need to be continuously checked to minimize delays or reduce the likelihood of risky events [1]. This is the case of an airport, usually classified as a system of systems, which following the Advanced Surface Movement Guidance and Control Systems (A-SMGCS) recommendations need to encompass functionalities for unambiguous identification of all surface traffic (e.g., aircraft and vehicles) without reducing the number of operations or the level of safety [2].

The main concerns of levels I and II of the A-SMGCS concept rely on the improvements of safety, whereas the ground movement's efficiency is dealt with in levels III and IV. This means that the surveillance service is a pre-requisite for implementing all the other A-SMGCS services.

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In the airport environment, surveillance must be able to respond to an increasingly complex range of threats. It also requires the integration of multiple technologies to continuous monitor and effectively manage the processing of aircraft, passengers and cargo data. To reach such level of data integration for decision-making, we need an informational cockpit capable to graphically impart large amounts of relevant information into the screen. A feature typically assigned to corporate dashboards.

Indeed, one way to keep tabs on every tiny piece of airport situation awareness and simultaneously get a big-picture mosaic of the airport is through spatial dashboards. When combined with map viewers and human understanding, spatial dashboards also provide business users with the ability to make balanced decisions when monitoring business activities.

In this paper an innovative event-driven approach for monitoring daily operations is presented based on the prototype that is being designed within the SECAIR project [3]. The project makes use of a spatial data warehouse (SDW) and deals with complex event streams using multiple localisation technologies as sensor devices. It is therefore well-suited for business activity monitoring, supporting the decision-making process of business users at analysing complex event streams in real-time.

The remainder of the paper is organized as follows. Section 2 provides a short analysis of related work, outlining technologies used to continuously collect data about airport surface movements. Section 3 and 4 presents the system overall description, emphasizing the main points which make the proposed solution different from usual tracking systems. Section 5 shortly describes the chosen technology for the development of the control services, outlining the most relevant ones. The paper ends with conclusions in section 6.

2 Related Work

Airport surveillance demands security requirements to protect passengers, staff and critical infrastructure from serious safety infringements that may compromise airport operations [4]. The range of location–based and sensing technologies required to provide the early detection and intervention in an airport environment typically include a mix of many different systems. For instance, surface movement radar (SMR) and secondary surveillance radar (SSR) systems are quite common in large airports. However these solutions are extremely expensive to purchase and operate, and are subject to masking and distortion in the vicinity of airport buildings, terrain or plants [5].

The extensive deployment of satellite system and air-to-ground data links results in the emergence of complementary means and techniques. Among these, ADS-B (Automatic Dependent Surveillance-Broadcast) and MLAT (Multilateration) techniques may be the most representative [6]. However, current radar based systems have many problems to track surface targets, especially in very dense traffic areas, such as the apron area or the taxiways. On the other hand, most of the aircrafts turn-off their transponders after landing, compromising their identification possibilities. This means that such systems will not detect non-cooperative vehicles or aircrafts that are not equipped with such a transponder. Therefore there is a strong demand for a new sensing technology, in particular for smaller/medium airports. Such sensors include near-range radar networks, Mode 3/A, S or VHF multilateration [5], CCTV systems with video analytics [7], magnetic flux sensors [8] or D-GPS installed in vehicles [9]. Although none of these sensors is individually able to meet all the user's requirements for airport surveillance, the fusion of the information they give can achieve an acceptable solution.

Most of existing systems operate independently from each other [4], limiting the opportunity for providing automated decision support [10]. The function of tracking, correlating and forecasting operationally relevant data from the information presented, is left as a task for the business users. In recent work [11], it is already possible to find algorithms addressing the very stringent integrity requirements to support aircraft surface movement.

In the literature it is possible to find research projects (e.g., 2004: Airnet at *www.airnet-project.com* and ISMAEL at *www.ismael-project.net*, 2006: EMMA at *www.dlr.de/emma*, 2008: AAS at *www.aas-project.eu* and LOCON at *www.locon-eu.com*), with different technologies that have been developed and successfully tested for ground movements detection, providing real time analysis and presenting actionable data with a high degree of certainty or as a cost-effective solution.

Within the SECAIR project, one of the technical requirements is that all location–based technologies are coherently integrated using advanced data-fusion techniques in order to reduce installation costs and to address multipath effects reduction. The project advanced fusion techniques operating with high-performance Global Navigation Satellite System (GNSS) and improved radio based tracking, combined with video based technology will enable the accomplishment of an automatic and reliable prediction of safety events. This broad-level integration extends the state-of-the-art for the surveillance of airport surface traffic, enabling unique automated decision support capabilities, with new context aware services, that have not thus far been available.

3 System Description and Operational Scenarios

The SECAIR system is being designed to monitor ground vehicle and aircraft movement at airports. Tests have shown that the system can be used for surveillance, either as a complementary system for existing and future A-SMGCS at large airports or as a cost-effective stand-alone solution that uses commercial available location-based technologies for monitoring critical areas at medium and small airports. For instance, to track handling operations at congested areas for indoor and outdoor environments (e.g., boarding gates at the passenger terminal and aircraft parking areas at the apron).

The SECAIR system was defined assuming that video cameras are installed for a complete video surveillance and homogeneous coverage of the target area for daylight/good visibility conditions and operational situations. It also assumes that site tests are performed without any wireless data communication problems and that some resources (i.e., vehicles, equipment, and staff) are equipped with at least one localisation technology. The positions of surveyed objects are continuously transmitted and are coherently integrated using advanced data-fusion techniques to address multipath effects reduction and improve quality of location (QoL). The Data-fusion algorithm operates with the following localization technologies:

- Vehicle, GSE or person positions
  - A standalone GNSS, collecting a new position each second;
  - An indoor-outdoor tracking system based on radio frequency localization (IOTS), collecting at least 1 position per second;
  - A video surveillance and tracking system (VSTS), capable at providing a new position each 0.5 seconds;
  - IEEE 802.15.4a Ultra Wide Band (UWB) standard for a low-rate wireless personal area network.
- Aircraft (A/C), the point feature representing the position of the A/C corresponds to the A/C central point with a clearance defined by the A/C classification (i.e., wingspan and length).

To perform this correlation, and to present the results to business users in an easy to understand way, the system performs a WGS84 coordinate transformation to all location-based data. Non-cooperative objects positions and identifier (e.g., Aircraft and Staff) are provided by the VSTS in a vector format. The demanded result of this correlation (fusion) step is an only track for each mobile. The surface conformance monitoring capability will provide a notification to all connected business users when there is an event. When an event is detected, a timely response is required to reduce the impact on safety or efficiency. For instance, whenever a vehicle protection area intersects with another moving object or infrastructure, a collision avoidance event is triggered informing the driver to move to a safety distance. This scenario requires the vehicle to be equipped with an onboard unit, which includes a touch screen display and a radiofrequency (RFID) reader for an automatic login procedure that uses the airport ID card of the driver to simultaneously validate if the diver is authorized to operate the identified vehicle.

In order to validate the SECAIR system and outline its benefits at accurately detecting the presence of objects (i.e., persons, vehicles, goods), inside or in the surrounding area of predefined locations, a system prototype for a pilot test is being installed at Airport of Faro (AFR), Portugal. The implementation comprises the system deployment, the interfaces to heterogeneous localization technologies and a set of client applications with a self-configuring graphical user interface (GUI).

For field tests, ANA-Aeroportos de Portugal (ANA) - the main Portuguese airport's management company, will provide airport vehicles together with a wireless network covering all airport operational areas. The system deployment also comprises interoperability with existing airport systems, for instance, to collect flight information and data about Staff. This interaction brings to the forefront information requirements relevant to assist operational managers in responding more efficiently and on time to events requiring their immediate intervention.

4 Event-Driven Architecture for Spatio-temporal Data Analysis

The SECAIR project constructs the whole system according to a centralized event-driven architecture [12]. Fig. 1 illustrates the system multi-layer architecture, covering requirements ranging from levels of the data communication layer to the presentation layer of user interaction.

The architecture consists on a set of interconnected components, on the deployment of IP-based wireless communication networks, on a middleware platform responsible to integrate positioning data into accurate location information, on a business logic that acts as a gateway between the business requirements and the client applications, for instance, to provide semantic meaning to events triggered by the server, on a client Graphical User Interface (GUI) that act as a control center for end-users to interact with the system as a whole.

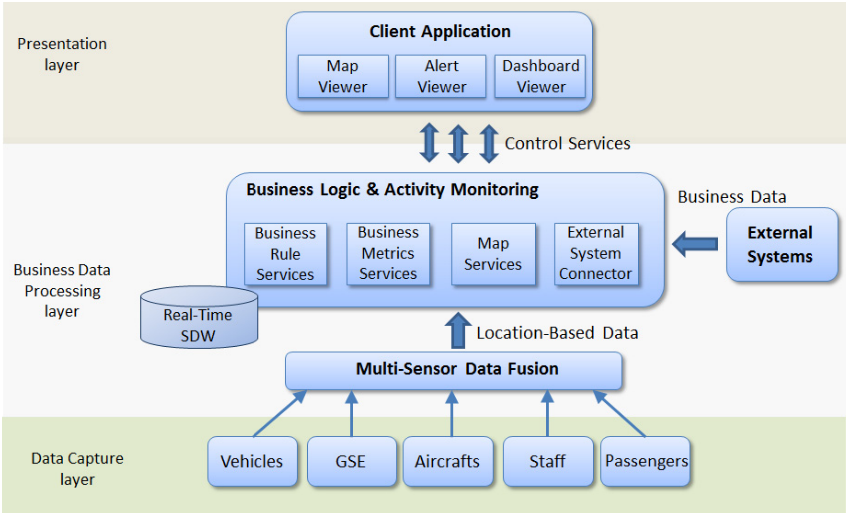

Fig. 1. Block diagram with a high level view of the SECAIR system

Since the system operates with heterogeneous sensors, prior to the data fusion process, it receives multiple positioning data from the Data Capture layer. But after the multi-sensor data fusion process, we obtain one computed position per object that is reliable. The Business Data Processing layer includes software modules such a role-classified multi-view of business rules, customized business metrics and the segmentation of the airport into multiple operational areas interacting with each other over a common stream of location-based data.

The Multi-Sensor Data Fusion module takes lessons learned from the LocON project [9] in relation to techniques for multi-target, multi-sensor tracking. The project advanced fusion techniques operate with improved radio based tracking and video based technology enabling the surveillance of non-cooperative resources (i.e., vehicle, GSE or personnel not equipped with a localisation device). At the server side, the system core functionalities are managed by the following software components:

- **Business Rule Services**, establishes the link between the definition and the execution of all business rules within the system [13], enabling organizational policies and the repeatable decisions associated with those policies, such as restricted areas incursions, to be defined, deployed, monitored and maintained centrally at the server side. When changes occur at the business level, this service also assists in finding the set of existing rules that are influenced by those changes. The Business Rule Services interacts with the SDW to store all incoming events with the right classification.
- **Business Metrics Services**, constructs a layered hierarchy of business indicators. It uses a decision dendrogram with its nodes weighted. Granular indicators are at the bottom (leaf) level and the derived indicators (usually more aggregated) are the nodes of the dendrogram. Updates to metric values have to be computed in almost real-time to enable a short reaction time. This means that for each inline data coming from the Data Capture Layer, the location-based data from each survived object has to be analysed to determine if an event (e.g., safety rule) occurred or if a business metric needs to be updated. For instance, a business user can configure the system to inform about how many safety incursions into stand areas were caused by a specific driver in a specific time period or day of the week.
- **Map Services**, in addition to the geovisualization of the survived objects, the specified scenarios also require geographical-related data for an accurate and detailed representation of the airport layout. Within the SECAIR project, the airport layout is represented with a set of overlapped layers in a standard format [14]. To efficiently support the spatial database workload and the degree to which spatial functions are required, a geographic information system (GIS) engine was specifically designed. This GIS engine copes with challenging requirements related to scalability and real-time representation of multiple moving objects and dynamic changes to the spatial context, without compromising the overall performance of the system.

At the Presentation layer, the surveillance capability of the SECAIR system is presented to business users in three different ways. The Map Viewer represents moving objects as colour coded point features with a timestamp and a set of descriptive data (see Fig. 2); this may include additional data (metadata) about aircrafts, vehicles, drivers, flight data, and descriptive data about the airport operational. The Alert Viewer presents a textual description of the alert messages, with indication of start and end time, plus a set of additional descriptive data related to each event. The Dashboard Viewer expresses in a graphical layout, the values of spatio-temporal business indicators enabling each Client Application to provide a clear picture of the airport status. In Fig. 2, the three vehicles visualized with a colour coded labelled outline different levels of alert messages presented at the Alert Viewer.

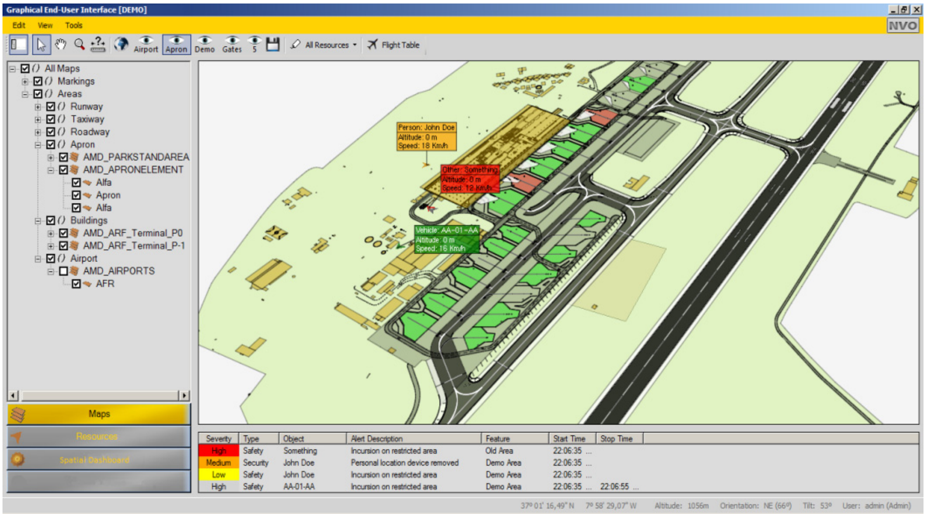

Fig. 2. Prototype version of the GUI layout

By default any client application connecting to the system automatically subscribes the Locations control service to start receiving the location of all ObjectIDs being surveyed. In parallel the location of each ObjectID is checked to validate if an alert message needs to be trigged to the presentation layer and consequently assign the proper semantic and risk level to each alert message. Infractions caused by each ObjectID need to be classified at the server side before passing the information to the presentation layer, otherwise the end-user will not understand what is being presented at the Map viewer. To provide this service, a database storing business rules, policies and additional relevant data for each map feature is required.

5 Data-Flow between Layers Managed by Control Services

Within the SECAIR project, Windows Communication Foundation (WCF) provides an explicit support for service-oriented development with a unified programming model for rapidly build service-oriented interfaces. Built on .NET Framework 4, WCF is implemented primarily as a set of classes on top of the .NET Framework's Common Language Runtime (CLR). WCF doesn't define a required host, allowing creating clients that access services running in different context environments.

The WCF cope with most of the communication requirements because the interface must be remotely accessible as the GUI can run on a different hardware/technology than one where the business logic or the external systems are. The interface is mainly event driven, with the business logic and the external systems continuously sending events to update the GUI after a successful login.

Control services are the building blocks to implement business logic, enabling business users to dynamically manage and interact with the target environment, changing the status of the business context as well as to obtain detailed information about the moving objects and receive automatic alerts about events. Client applications can subscribe to different events, receiving also in an event-driven way all information, which can consist of location data and other business or device related data. Control Services perform a background job for the client applications without adding more than a slight delay of a few milliseconds, so it can likely be regarded as negligible.

Within the scope of the field tests to be performed at ARF, an integration is established with the airport operational management system common to all ANA airports (GO system). The GO system enables the study and analysis of the schedule for each season, the configuration of infrastructures and business rules, planning, monitor and manage daily operations in subsystems like, parking positions, embarking and disembarking gates, baggage belts, Check-in to each flight, taking into account the requirements of safety and security.

Effective management and integrated complexity of the operation would not be possible without the input and output interfaces, the GO system states with very different systems / applications, allowing the exchange of information between stakeholders.

To conclude this section, Table 1 presents the multidimensional database structure of the Spatial Data Warehouse (SDW) that will hold the analytical processing capabilities of the SECAIR system. The matrix lists at the columns the dimensions used to describe business logic and at the lines the events (facts) related to the different domains of business activity monitoring. The intersection between lines and columns defines the star schema for each fact table. Any dimension (column) with more than one "X" implies that this dimension must be conformed across multiple fact tables (lines), forming a constellation.

Table 1. The SDW Matrix of the SECAIR Data Structure

Dimensions / **Granular Facts (ROLAP)**	Airport Layout	Aircrafts	VehiclesGSE	Stakeholders	Flights	Staff	Tasks	Alerts	Time Hour	Time Day
Ground Movements	X	X	X	X	X	X	X	X	X	X
Safety Security Events	X	X	X	X		X		X		X
Vehicle Services	X		X	X	X	X	X		X	X

The Airport Layout dimension is a spatial dimension storing the thematic layers which characterize the airport layout in conformity with the ED119 std. [14]. It also stores metadata about each operational area. For instance, airport circulation constraints on areas related to ground traffic movements include speed limits for different types of moving objects (e.g., operational vehicles and A/C), constrains for specific vehicles categories (e.g., auto-stairs, high-loaders, passenger busses), data related to the airport operational status (e.g., normal or low visibility operations). The other dimensions are non-spatial in the sense that they only store business data obtained through interoperability with the GO system.

The three fact tables store specific events related to ground movements, therefore classified as spatial facts with a new coordinate position stored for each object being monitored. The Ground Movements is the most granular and detailed fact table, classifying each movement in relation to any business rule infringement. The Safety Security Events stores aggregated data related only to safety and security events. Finally the Vehicle Services fact table is particularly adjusted for fleet management.

The SDW is accessed by all software components from the Business Data Processing Layer. The External System Connector is configured to connect to the GO system to collect operational data in a format usable by SECAIR. At the Presentation Layer, the user profile determines the level of detail established to access the information stored in the SDW. The goal is to provide business users with the required information to remotely monitor/coordinate on-going operations or to analyse historic events.

6 Conclusions

The paper presents an event-driven architecture, with a multi-sensor fusion algorithm and GIS functionalities to support spatio-temporal data processing of numerous continuous event streams. The proposed event-driven architecture is a pragmatic and reliable way to ensure fast response times, meaning that any occurrences are shown immediately (within fractions of a second) and, as far as possible, dealt with automatically.

The system adopts a multi-layer approach with heterogeneous localization technologies and a multi-sensor data fusion process to handle with event streams emitting continuously location-based data for each surveyed object. It is therefore well-suited for business activity monitoring, supporting business users at analysing and processing complex event streams in real-time.

The proposed system is being designed to deal with spatio-temporal requirements, including scalability and security of data. A SDW was specified to hold a very high volume of fine-grained events, which must be processed and analyse individually before taking appropriate control actions. The innovative mix between geovisualization functionalities, the treemap approach for the spatial dashboard and the use of control services also introduce new challenges to the data fusion process contributing to improve situation awareness and situation management capabilities for coordinating apron operations and monitor, in real-time, the compliance of ground traffic operations with airport business rules.

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