A Multi-Mission Service Platform for Satellite-based Wide Area Surveillance

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***Abstract*—Contemporary satellite technologies in the fields of Earth Observation (EO), communications and navigation, augmented with terrestrial sensor networks, provide an invaluable toolbox for the development and deployment of integrated platforms for wide-area surveillance. The applicable use cases span across a wide range of application domains, from maritime and sea border surveillance to agricultural and environmental monitoring. This paper presents the design and development of a multi-mission service platform based on a generic core, able to aggregate data collected from multiple sensors and route monitoring information among processing modules and decision support systems. As the central point of a modular architecture, this service platform can be easily and quickly customized to serve multiple heterogeneous application domains. Its application for maritime surveillance is presented as an indicative use case.**

Keywords—service platform; wide area surveillance; earth observation; sensor network; workflow

I. INTRODUCTION

The topic of the integration of different space technologies - mostly in the fields of earth observation, satellite communications and navigation - for the purpose of effectively monitoring an extended geographical area has been repeatedly addressed by several R&D efforts worldwide. In Europe, such research efforts have been mostly supported by the Copernicus (formerly GMES) programme, as well as the ESA IAP (Integrated Applications Promotion) programme [2]. Recent activities also promote the augmentation of satellite monitoring data with information from in-situ sensors, using state-of-the-art data fusion algorithms, towards more efficient and effective surveillance.

As outcomes of such efforts, several integrated commercial surveillance platforms have been developed, addressing several application domains, including but not restricted to: Maritime monitoring, Land border monitoring, Environmental monitoring, Critical infrastructure monitoring, Agricultural monitoring, Urban area management and Emergency management (e.g. wildfire, flood or tsunami monitoring).

While the common approach up to now has been the development of a separate, dedicated surveillance software solution for each of the aforementioned applications, in this paper we present the concept and architecture of a universal, multi-mission software platform able to consolidate several of the aforementioned application domains in a single data processing and routing core. This common core should be seen as the "gluing component" among heterogeneous subsystems, bringing together sensor data sources, processing modules, decision support systems and user interfaces.

The paper proceeds as follows: Section II presents the motivation for the proposed multi-mission platform as well as key requirements. Section III presents the architecture of the platform and its integration with data sources and sinks. Section IV presents the adaptation and application of a very early prototype in the area of maritime surveillance and finally Section V concludes the paper.

II. A MULTI-MISSION SURVEILLANCE PLATFORM: MOTIVATION AND KEY REQUIREMENTS

The application domains mentioned in the previous section are indeed quite heterogeneous and address different needs and business cases. That is why up to now software platforms for surveillance have been domain-specific. Some indicative examples can be identified e.g. in the area of maritime monitoring [3] [4], land border surveillance [5] and wildfire monitoring [6]. However, despite the specific requirements of each specific application domain, almost all of these platforms share some common aspects such as:

- acquisition and processing of Earth Observation (EO) data
- leveraging information from in-situ sensors using data fusion algorithms
- leveraging satellite navigation systems for location-based services
- using satellite communications for collecting and disseminating information
- using Geographical Information Systems (GIS) for information management and representation

We argue that, after studying the aforementioned common aspects, a common intersection among all domains can be identified. This intersection can be the starting point towards a universal software solution which can perform all core functionalities of a surveillance system, such as information routing and translation, and which can interface with modular plug-in components for application-specific operations.

In addition to the arguments above, a couple of opportunities can be identified, which further enhance the motivation for a multi-mission solution.

First, there seems to be a general tendency towards the establishment of centralized repositories for Earth Observation data. Such repositories are expected to store a vast amount of images of various types (e.g. optical, multispectral, radar etc.) which would be widely available for service research and/or societal needs. Such an initiative is the Copernicus Data Access Portfolio, aiming at the (controlled) dissemination of data collected by the Sentinel satellite mission. In this context, a universal surveillance platform could acquire data from such repositories in order to use them in various applications. Significant economies of scale can be achieved in this sense, since the same satellite product (e.g. an optical image) would be reused across many application domains (e.g. urban management and environmental monitoring). Apart from the data itself, data processing as well as information fusion algorithms could be reused across domains, probably with some parameterization.

Second, when it comes to in-situ sensor data, the establishment of standardized open interfaces and APIs such as the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) [7] promotes the dissemination and interfacing of sensor information in an open, standardized manner. By exploiting OGC standards, a multi-mission service platform can easily connect to a wide variety of application-specific in-situ sensors, possibly from various vendors, in order to be tailored and customized, without being restricted by vendor-specific interfaces.

In order to be open/universal and at the same time competitive and commercially attractive, a multi-mission platform should fulfill certain key functional requirements such as:

i. Provide open, standardized interfaces so as to connect to multiple data sources

ii. Provide a common data repository service for all data exchanged

iii. Support multiple data processing units to be invoked on-demand

iv. Support multiple protocols for communication and data formatting

v. Support multiple graphical user interfaces and provide a common map service to be used by all GUIs

vi. Provide a Workflow Engine that can support the runtime of several macro workflows representing decisional, operational or support processes across different modules

vii. Effectively and efficiently route the information among connected subsystems according to pre-defined workflows.

III. Multi-Mission Surveillance System Architecture

A. High-level system view

Taking into account the requirements set out in the previous section, a generic multi-mission surveillance system architecture can be defined, as shown in Fig.1. The architecture comprises several data sources and sinks and data processors, linked and orchestrated by a core service platform. The aim is to adopt a fully modular and reconfigurable architecture, by using "pluggable" mission-specific services and modules, yet maintaining the core platform as generic as possible.

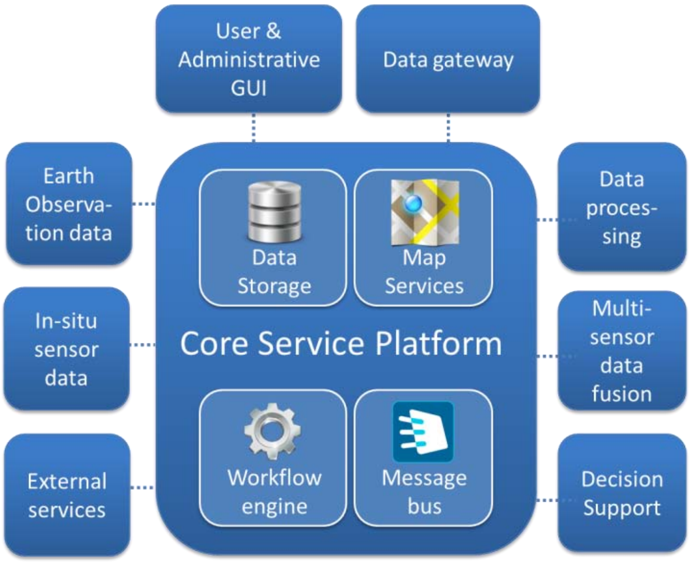

Fig. 1. High-level system architecture of a generic wide-area surveillance system

Apart from the core service platform, which will be described in the next sub-section, the following system components are identified:

- *Earth Observation data.* It is common for wide-area surveillance applications to utilize earth observation images, in various formats (e.g. optical, multispectral or radar/SAR). These data are expected to be provided by an external EO service provider.

- *In-situ sensor data.* In order to augment satellite observation and also achieve much shorter response times, many application domains also involve the usage of in-situ sensors, such as cameras, radars, detectors etc.

- *External services.* Effective surveillance may require also other information, in addition to the data provided by EO and sensors, such as e.g. weather information, environmental data etc. Such data are also assumed to be provided by third-party service providers.

- *Data processing modules.* These components process raw data collected by sensors (incl. raw EO images) in order to extract information. Such processing e.g. may include extraction of environmental data from EO images, target detection/identification in in-situ camera images etc.

- *Multi-sensor data fusion modules.* These modules are used to analyze already processed sensor data in order to correlate information coming from different data sources i.e. correlate targets detected in EO images with targets detected in in-situ cameras etc.
- *Decision support systems.* These implement complex algorithms, mostly based on machine learning approaches, analyzing processed sensor data in order to provide high-level recommendations and propose decisions (decision support, hence their name) to the platform user with regard to handling a specific situation. Such decisions may refer to e.g. assessing a risk or a hazard, alerting the population, allocating and distributing on-site personnel etc.
- *User and Administrative GUI.* The final product i.e. the domain-specific Integrated Situational Picture (ISP) is presented to the user in a graphical interface, leveraging state-of-the-art Geographical Information System (GIS) technologies.
- *Data Gateway.* It is used to export the products of the platform to external stakeholders, i.e. public authorities, alarming systems, the wide public etc., possibly adapting its format and content to match the recipient stakeholders' requirements.

B. Service Platform components

As aforementioned, while the data source/sink/processing modules may be application domain-specific, the core service platform is meant to be universal and mission-agnostic, allowing the on-demand interfacing with various heterogeneous modules in order to adapt to the needs of each domain.

The main services provided by the Service Platform are the ones which are common in all wide-area surveillance application domains and specifically:

i. *Component Orchestration.* The successful implementation of each surveillance scenario is associated with a specific business logic, i.e. a conditional sequence under which data is retrieved from sources, processed and sent to the system outputs. For this purpose, the Service Platform includes a *Workflow Engine*, which runs a specific process in order to pool data from sources, adapt them, invoke processing modules and integrate the final product. This process is application-domain specific, yet it is easily reconfigurable and can be edited even via graphical editors. It is expressed in a business process modelling language, such as BPEL [8], assuming that most external components are implemented using Web Services (WS) interfacing.

ii. *Data Repository.* The Service Platform is assumed to store all raw and processed data in a central repository, thus acting as "information hub" for all interconnected modules. In order to be able to easily accommodate various types of sensor data and easily interface with heterogeneous services, the platform needs to expose a standards-compliant interface for communication of sensor data, such as the OGC Sensor Observation Service (SOS).

iii. *Message Routing, Forwarding and Adaptation.* Since data have to be exchanged among modules, the SP needs to enable the communication among them in a unified way, acting as a mediator, also adapting the information as well as the interfacing protocol, according to the specification of each module. In this context, the SP should also allow the communication of information according to the publish/subscribe paradigm; an external module should be able to subscribe to specific information and receive a notification when such information becomes available. For all these purposes, a dedicated *Message Bus* is the most appropriate component, leveraging technologies and functionalities from commonly used Enterprise Service Buses (ESBs), such as WSO2 [9] or Apache Synapse [10].

iv. *Map/Geospatial service.* A map service with common base map data is necessary for the visualization of the platform product. The adoption of a standardized data and communication format, such as the OGC Web Map Service (WMS) facilitates the interfacing with standards-compliant applications. In addition, the service can be extended to accommodate data produced within the system in either raster or vector format, such as processed maps, contours etc.

IV. Demonstrated Use Case: Maritime Surveillance

In this section, we present a very early proof-of-concept implementation of the aforementioned architecture and its application in the domain of maritime surveillance. The overall user need is the detection and identification of vessels in the open sea as well as in coastal areas.

The system developed (Fig.2) is essentially a domain-specific instantiation of the generic architecture presented in Fig.1 and discussed in the previous section.

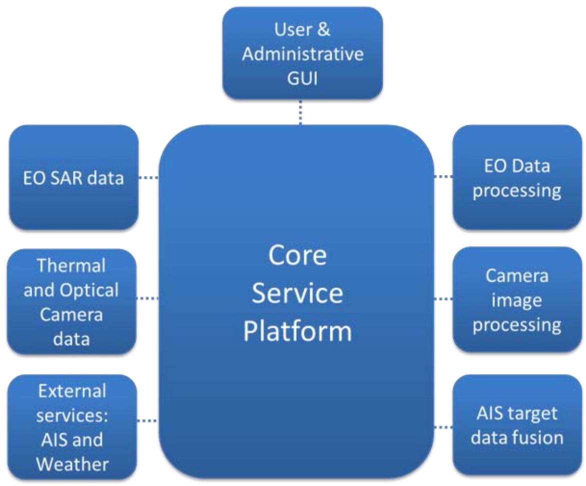

Fig. 2. Instantiation of the generic system architecture of Fig. 1 for the maritime surveillance domain.

The aim is to maintain the generic applicability of the core SP, while interfacing it with mission-specific components. Data sources include:

- EO data: It is well admitted that the use of Synthetic Aperture Radar (SAR) satellite images is the most appropriate remote sensing method for vessel detection, compared e.g. to optical images. In our setup, we use SAR data from the Cosmo-SkyMed satellite constellation.
- In-situ data: for monitoring of vessels in proximity to coastal areas, we use coastal cameras (both optical and thermal). Coastal radars can also be easily integrated.
- External services: in addition to weather services (weather information is used in SAR processing and also included in the integrated picture presented to the user), a maritime surveillance system makes use of AIS (Automatic Identification System) data. Vessels periodically broadcast AIS information, declaring their identity and current data, such as location, speed and heading. These data are collected by a network of terrestrial receivers and aggregated by an AIS data provider.

Data processing modules include EO data processing (for detecting vessels in EO SAR images) as well as camera data processing (for detecting vessels in thermal or optical camera streams). The data fusion procedure involves temporal/spatial alignment of processed sensor data (detected targets) and their correlation with AIS information. In this way, the identity of a specific vessel detected in an image can be specified. Targets which are not associated with a valid AIS identity can be marked as unknown.

The final product of the platform is visualized in a GIS-based graphical user interface. The following figures depict screenshots from the application GUI. Fig.3 depicts a camera-detected target correlated with AIS data, while Fig.4 shows targets detected in a satellite image, also identified via AIS.

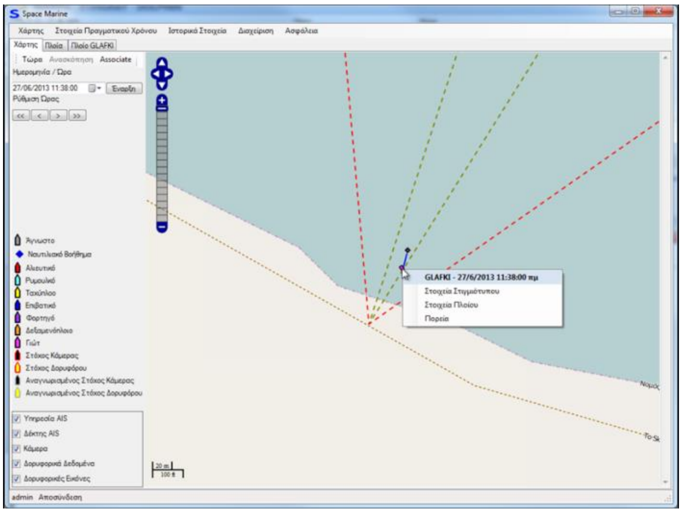

Fig. 3. GUI snapshot showing a camera-detected vessel as well as AIS information

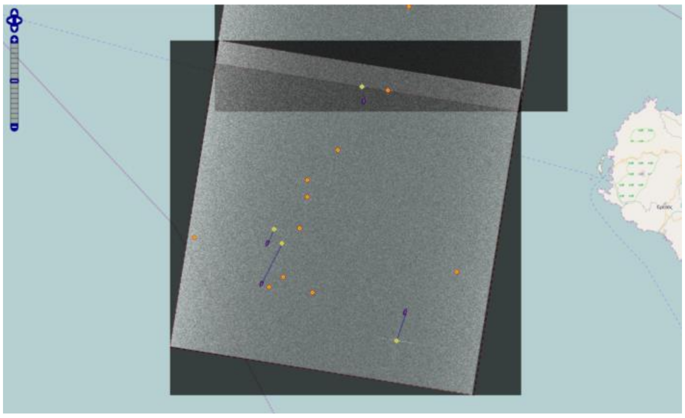

Fig. 4. GUI snapshot (cropped) showing vessels detected in EO SAR images.

It must be noted that this setup involves a very early implementation of the SP, which i) uses a proprietary REST interface for communicating with modules instead of a standardized one and ii) uses a hard-coded workflow rather than a reconfigurable one.

The next steps in implementation involve the support of OGC SOS and WMS standards for information exchange as well as the integration of a flexible workflow engine so that BPEL-defined workflows can be loaded and instantiated on-demand, according to the requirements of each surveillance scenario.

V. Conclusions

In this article, we presented the design and early implementation of a multi-mission service platform for wide-area surveillance. We demonstrated that it is feasible to establish a common generic core which is able to accommodate a wide variety of application domains via the interfacing with the appropriate sensors and processing modules. The benefit gained is the capability of rapid customization and reconfiguration thanks to the modular nature of the system and the open interfaces used, as well as the re-use of sensor data and basic processing algorithms (e.g. for target fusion) across multiple application domains.

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