Fusion of Real-Time Remote Sensing Data and In-Situ Sensor Data to Increase Situational Awareness in Digital Earth Applications

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Abstract. The term “real time” regarding remote sensing applications can only seldom be found in recent literature. In the course of the German Aerospace Center (DLR) project VABENE, an airborne monitoring system has been developed which is able to preprocess remotely sensed images in real time by an on-board computing system and directly transfer it to a ground station via a microwave data transfer system installed on the aircraft. This paper identifies chances and possibilities that arise from the availability of real-time remote sensing data in combination with geodata obtained from in-situ sensors that are for example acquired by mobile devices such as smartphones or by stationary environmental sensors. It is shown how this information can be integrated in ubiquitous DE applications and in which way they could be used in real world use cases.

1. Introduction

Digital Earth (DE) as introduced by Al Gore in 1998 experiences currently an evolution from a predominant static representation of the real world to an anytime up-to-date toolbox for science and the public consisting of a high amount of various data and data streams. Many of the geospatial data are requested and required in real time which has recently led to new research fields like geo-sensor networks. The term “real time” regarding remote sensing applications is seldom found in recent literature as remotely sensed data typically require a particular time span to be available for further processing. This is mainly due to a) recording platforms like airplanes, unmanned aerial systems (UAS) or satellites, which so far have not been able to transmit data in (near) real time to the user, and b) the time consuming pre-processing steps (e.g. georeferencing and orthorectification) which are required to continue processing and further information extraction. In the course of the project VABENE of the German Aerospace Center (DLR), an airborne monitoring system has been developed that is able to preprocess the remotely sensed images in real time by an on-board computing system and directly transfers it to a ground station via a microwave data transfer system installed on the aircraft.

Based on the above technological developments, this paper presents opportunities that arise from the availability of real-time remote sensing data in combination with geodata obtained from in-situ sensors that are, for example, acquired by "human sensors" equipped with mobile devices such as smartphones or by stationary environmental sensors. Furthermore, it is discussed which obstacles have to be overcome to gain additional geoinformation from the fusion of the remote and in-situ sensor data. Finally, this paper shows how the extracted information can be integrated in ubiquitous DE applications of real world use cases.

2. State of the Art

The state of the art has to be reviewed regarding data used for real-time sensor fusion. Speaking of data in this context, the broad range of possible data sources is narrowed down to remote and in-situ sensors. The real-time remote sensing system of the DLR is presented in the next subsection followed by a subsection on in-situ sensors which is divided in two parts depending on whether the sensor is stationary or mobile, with the latter part focussing on smartphones.

2.1. Real-time Remote Sensing – The Project VABENE

VABENE (German acronym for traffic management during major events and disasters) is a DLR project with the goal to develop efficient tools for agencies and organizations with security functions and traffic agencies in case of major events or disasters. The scientific focus is divided in three main areas: traffic research, information processing and data distribution concepts [1].

The airborne monitoring system with optical and radar sensors is an outstanding attribute of the VABENE sensor technology. Three digital high-resolution cameras record images with different viewing directions at a repetition rate of up to 3 images per second. These pictures are then orthorectified in real time using a Digital Elevation Model (DEM) and can be analyzed using the on-board system. Due to the on-board processing and analysis of the images in real time, the gained information reflects the actual situation on the ground which is very important for a huge amount of real world use cases. So far, a number of algorithms for advanced traffic analysis have already been implemented.

Another important part of the VABENE real-time system is the data link. An optical data transfer system based on the work of [2] was developed to transfer the large data volumes in sufficient time via optical terminals on the airplane and ground stations. The ground stations are available as Transportable Optical Ground Stations (TOGS) as a mobile version. The combination of on-board processing and analysis as well as the optical data transfer enables a wide variety of applications and further processing on the ground.

2.2. Stationary In-Situ Sensors

In contrast to remote sensors, in-situ sensors are "related to point locations or to transects" and "are either immersed in, or at least touch, the object(s) of observation and measurement" [3]. In-situ data are always sensor and object specific, which means that it depends on the measured natural phenomenon regarding recorded values and units as well as the sensor's characteristics. Typically, in-situ sensors provide time series data with a definite temporal resolution for a specific geographic location. Usually this location is exactly measured via GPS or differential GPS and is static for every measurement data gathered by the sensor. Due to this fact, these types of sensors are called "stationary" as they do not vary in their geographic location. Representative sensors of this type are water, snow or rain gauges, air quality sensors, thermometers or seismometers.

To utilize stationary in-situ sensors for real-time issues, the sensors must be equipped with a communication device which is able to transfer the data on demand or on a regular basis. Recently, the amount of sensors which can be used for real-time applications has risen due to the development of the OGC Sensor Web Enablement (SWE) standards, which offer the possibility to discover and access sensor data via the Web [4]. For Germany, the German Weather Service (DWD) is currently developing a Web service called Climate Data Center (CDC), which should provide all climate data of the DWD to researchers, teaching staff and governmental institutions. Apart from that, several other services are available for Germany offering sensor data, e.g. river gauge data [5].

2.3. *Mobile In-Situ Sensing Via Smartphones*

As the name implies, a mobile in-situ sensor is not fixed in one location but is installed on or within a carrier with which it can measure specific phenomena for different geographic locations. Hence, any stationary sensor can be converted into a mobile sensor by simply combining it with a carrier object, which can be any moving object like a car, a boat or a person. In principle data gathered by mobile in-situ sensors therefore are similar to data recorded by stationary sensors. In this section, we will focus exclusively on smartphones because they combine all essential segments for real-time in-situ sensing: mobility, location awareness, multiple built-in sensors as well as wireless connectivity to add additional sensors and to transfer the sensed data via Internet.

A smartphone differs from a regular cellular telephone basically in its computational capability which makes a smartphone a combination of a mobile personal computer and a mobile phone. The majority of definitions for smartphones point out its extended functionality by built-in applications and its ability to access to the Internet [6]. In the third quarter of 2012 worldwide sales of mobile phones were recorded at almost 428 million with around 40% smartphones [7].

The variety of built-in sensors in smartphones has significantly increased: “Today, a smartphone or a tablet might integrate a MEMS microphone, an image sensor, a 3-axis accelerometer, a gyroscope, an atmosphere pressure sensor, a digital compass, an optical proximity sensor, an ambient light sensor, a humidity sensor and touch sensors” [8]. Studies about accuracy and precision of smartphone sensors are very rare and focus mostly on specific smartphone models with varying sensor products. An evaluation of accuracy of attitude data, images and 3D coordinates for photogrammetric coastal monitoring was conducted by [9]. The study showed standard deviations of 0.33° to 2.04° for the heading angle calculated by using the accelerometer and magnetometer. [10] presented classification accuracies of physical activities for sanitary issues using smartphone motion sensors with satisfying results for activities like walking, jogging and sitting but less satisfying results regarding three-dimensional activities like upstair and downstairs movements.

Concerning external sensors connected with smartphones, many studies have been carried out for wired and wireless connections. Especially scientists in the field of health and medical innovations work on combining medical devices like ECG with smartphones via Bluetooth [11]. Smartphones in this connection offer a convenient way to add the geographic position of the user and transmit the whole data via Internet.

In the past years, smartphone sensors have quite often been used in studies including participatory sensing (PS), a volunteered approach for sensing data with smartphones originally introduced by [12]. Early examples for PS also named in the same study were public health issues like air quality, urban planning with the monitoring of noise and ambient sounds or natural resource management like the gathering of semantic metadata by field scientists. Scientists recently use PS in diversified approaches varying from road surface monitoring [13] to fuel-efficient navigation services [14]. Like in every research field dealing with location data, participatory sensing has its own privacy debate leading to various approaches to satisfy privacy needs [15] [16].

3. Related Work

First, we present a brief overview of general aspects of sensor fusion. Second, recent works regarding geo-sensor networks and geo-sensor fusion are presented which is followed by examples for real-time applications in this field. Finally, the current research gap is presented based on the previous review.

Searching the literature for related work in sensor fusion one will quickly notice a broad range of terms describing almost the same topic. Examples are “data fusion” [17], “information fusion” [18], “image fusion” [19] or “multi-sensor fusion” [20], just to name a few. Early approaches concerning the term “sensor fusion” were made in the fields of robotics [21], medical science [22] and remote sensing [23]. All these terms describe the combination of data or information from multiple sources to gain enhanced or improved information about the measured object. Regarding “sensor fusion” these data, as the name implies, can be derived by any kind of sensor. The upcoming work on, and the establishment of, geo-sensor networks as an explicit research field among environmental scientists [24] brought up new research potential for the fusion of geo-sensors.

[25] present a new framework to create "Sensor Network as a Service" (SNaaS) which is based on the usage of so-called "virtual sensors" which are a "product of spatial, temporal and/or thematic transformation of raw or other virtual sensor streaming data". An extension of the virtual sensor is the "virtual geo-sensor" which holds explicit geospatial properties defined via GML.

A non-monolithic sensor network approach for urban air quality has been developed and presented by [26]. Open standards are used within a modular infrastructure with the focus on flexibility and portability to establish pervasive environmental urban monitoring. This work is followed by the introduction of the 'Live Geography' approach by [27] as a ubiquitous technical infrastructure for urban monitoring applications.

[28] introduced their development of a dynamic web mapping service using Earth observations and in-situ sensor data. In this near real-time application, MODIS 250 m daily surface reflectance data are combined with meteorological data from sensors of a SWE server by the Royal Dutch Meteorological Institute (KNMI). The information of the two data sources is used in an environmental model to estimate the vegetation productivity for the Netherlands.

A real-time workflow for geo-sensor information analysis is presented by [29] which is based on portable self-made sensor pods. The development focuses on fast geo-processing as well as rapid information distribution and visualization as it is used for time-critical emergency support for radiation protection. A concept and an implementation of a sensor fusion service (SFS) for the real-time integration of sensor measurements were introduced by [30]. The proposed solution is based on an open-source GeoServer and offers the possibility to fuse heterogeneous sensor data into common WMS/WFS output for visualization and analysis issues

Researchers in the field of computer vision and mobile computing recently utilized data fusion of smartphone sensor and image data. [31] presented an augmented reality algorithm to generate panoramic images on-the-fly by sweeping the camera over a scene. The algorithm is mainly based on information resulting from image processing techniques which are combined with the user's orientation derived from the inertial and magnetic sensors of a smartphone. [32] introduce a similar approach by combining video and movement sensor data to show the potential for smartphone-based indoor navigation on wheels and by foot.

The literature review clearly shows that the integration and combination of various data sources and sensors is an on-going research topic with a number of problems already solved. However, the use of smartphone sensors in combination with remote sensing data as well as its possibilities and opportunities are widely unexplored. Smartphone sensed data on the one hand are often used in closed systems like augmented reality applications [31] or indoor navigation [32] but is merely used for universal and cloud applications mostly due to privacy concerns. Remote sensing data on the other hand are used predominantly for traditional issues like monitoring and data analysis but are rarely combined with non-remote sensor data (e.g. [28]). Especially the term "real time" regarding remote sensing is not comparable to the common interpretation of "real time", as daily or hourly applications are often referred to as "real time" or "near real time" by remote sensing scientist.

The data delivered in the course of the project VABENE by the DLR redefines the understanding of "real time" for remote sensing applications and therefore opens a completely new direction of research.

4. Integration in Digital Earth Applications

The research gap for the real-time fusion of remote sensing data and in-situ measurements is obvious. In the following, the advantages and disadvantages of the two data types are described briefly which subsequently leads to the concept of the further research on this topic.

Remote sensing data are normally provided for large geographic areas, especially for hard-to-reach regions (e.g. earthquake damaged or flooded areas). However, optical remote sensing is generally dependent on weather conditions during data acquisition. For example, regions which are covered by clouds are therefore not accessible. Beyond that, remote sensing data provide no information on occluded areas, e.g. under bridges or in buildings, and always have a limited resolution which varies depending on the sensor quality and the used sensor carrier.

In contrast, in-situ sensors are generally independent of the weather conditions, can deliver data for hidden areas as well and deliver detailed information albeit depending on the position accuracy (GPS, DGPS, etc.). In addition, in-situ sensor data might deliver information that cannot (or at least barely) be derived from (optical) remote sensing data, like temperature, soil moisture or orientation and moving directions of people and cars. A limiting factor is that in-situ sensors generally deliver punctual information only, which reduces the coverage of the investigation area significantly. Besides, they are exposed to phenomena on the ground like vandalism or destruction due to natural impacts.

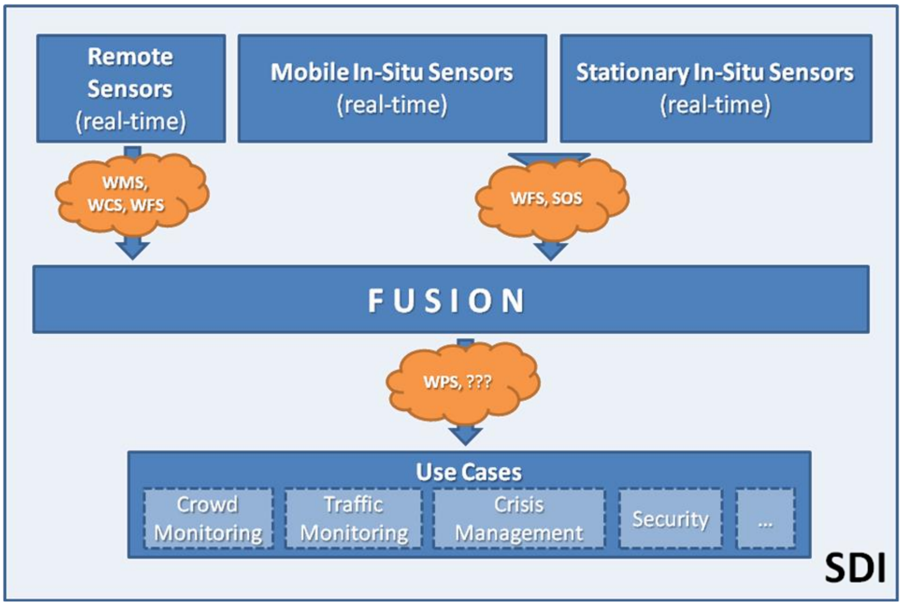

Figure 1. Concept of integrating the fusion of remote sensing data and in-situ measurements in real-time DE applications via a spatial data infrastructure (SDI).

Thus, the idea of this work is to use the advantages of the two data types to eliminate the mentioned disadvantages for real-time applications. This leads to the concept of integrating the fusion of remote sensing data and in-situ measurements in real-time DE applications via a spatial data infrastructure (SDI) as outlined in figure 1. Remote sensors as well as mobile and stationary in-situ sensors are integrated in a fusion process via standardized interfaces. The fusion results then should be tested and evaluated in real world use cases.

These use cases might range from crowd or traffic monitoring applications, to expert support systems for crisis management or security issues. In a first step, the combination of smartphone sensor and remote sensing data will be tested for crowd monitoring during major events. During a music event in Germany in 2010, 21 people suffocated and over 500 people were injured due to an unexpected high number of people streaming towards the same, narrow spot. In an upcoming field study it will be shown that the fusion of smartphone movement data and information derived from remote sensing data can avoid such disasters. Therefore the amount of people in a crowd will be estimated from the image data using image processing algorithms and shall be combined with arbitrary distributed smartphone movement data. The assumption in this case is, that one person in a crowd has to flow with main movement direction of the crowd as a whole and cannot move to a different direction. Consequently, the movement data of one smartphone can be assigned as the flow direction of the entire crowd. With the number of people within a crowd, estimated from the remote sensing data, and its moving direction, derived from the smartphone sensor data, the future positions of the crowd can be predicted and “trouble spots” like narrow points can be recognized early.

5. Conclusion

This paper states the opportunities that arise from the availability of real-time remote sensing data in combination with in-situ sensed data. Furthermore, it presents the opportunities of the extracted information for real world use cases and shows a way to integrate this information in Digital Earth applications via OGC standards.

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