Standardised geo-sensor webs and web-based geo-processing for near real-time situational awareness in emergency management

Guenther Sagl*, Bernd Resch,
Manfred Mittlboeck,
Barbara Hochwimmer and
Michael Lippautz

Studio iSPACE, Research Studios Austria – RSA,
Schillerstrasse 25, 5020 Salzburg, Austria
E-mail: guenther.sagl@researchstudio.at
E-mail: bernd.resch@researchstudio.at
E-mail: manfred.mittlboeck@researchstudio.at
E-mail: barbara.hochwimmer@researchstudio.at
E-mail: michael.lippautz@ researchstudio.at
*Corresponding author

Cornelius Roth

Centre of Geoinformatics,
University of Salzburg,
Schillerstrasse 30, 5020 Salzburg, Austria
E-mail: cornelius.roth@sbg.ac.at

Abstract: Up-to-date, accurate, and reliable information is fundamental for time-critical decision support and sustainable emergency management. In this paper, we show how standardised geo-sensor webs, in combination with web-based geo-processing, can enhance efficiency in emergency response and management, demonstrated in the field of radiation safety. We focus on end user and information requirements and show how 'live' spatial-temporal analysis results of near real-time and mobile radioactive radiation sensor measurements can enhance the situational awareness of rescue forces for near real-time decision support. We validated our approach technically and methodologically through a radiation safety exercise. The end user feedback confirmed that this 'live' workflow can enhance the decision support and the emergency information management through near real-time situation awareness during and after a damaging event.

Keywords: situational awareness; spatial-temporal awareness; live analysis; near real-time sensor data; decision support; emergency management; common operational picture; COP; standardised sensor web; web-based geo-processing.

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Biographical notes: Guenther Sagl is doing his PhD at the Doctoral College Geographic Information Science, University of Salzburg, Austria. Additionally, he is a Junior Researcher at the research studio iSPACE. His research interests include near real-time geo-analysis of mobile in-situ sensor measurements for environmental monitoring and time-critical decision support.

Bernd Resch is a Visiting Professor at the University of Osnabrueck, Germany, and a Research Scientist at the research studio iSPACE. He holds a PhD in Geographic Information Science. His research interests are in the field of mobile systems and geo-sensor networks, sensor fusion, and near real-time monitoring systems.

Manfred Mittlboeck is a Key Researcher at the research studio iSPACE. He holds a PhD in Geographic Information Science. His research focuses on GIS integration and standardisation technologies for spatial decision support systems.

Barbara Hochwimmer was, until recently, a Junior Researcher at the research studio iSPACE. She is now working as a GIS expert for an Austrian national park organisation. She holds a Master's in Geoinformatics. Her research interests are geo-design, geospatial web service development, and rapid mapping technologies.

Michael Lippautz was, until recently, a Junior Researcher at the research studio iSPACE. He is now doing his PhD in Computer Science at the University of Salzburg. He holds a Master's in Informatics. His research focuses on hard real-time application development for embedded systems.

Cornelius Roth is a Research Associate and Project Manager at the Centre for Geoinformatics, University of Salzburg. He holds a Master in Geography. His research focuses on the validation of standards and interoperability with respect to the geo-intelligence for security management.

1 Introduction

In the case of an emergency that requires the immediate attention of action forces, timely intervention is one – if not the most – significant component within the decision-making process (Si et al., 2008). Fast and correct decisions require up-to-date, accurate, and reliable information about the current situation (Tosti and Smari, 2010). Many emergency situations involve more than one rescue organisation, which makes instantaneous and effective communication of the current situation challenging. One major problem in order to generate and subsequently share a common operational picture (COP) is related to integrating data into heterogeneous emergency information and management systems (Demir et al., 2011).

Well-established emergency information systems in combination with sensors and sensor networks are used to measure and monitor various potential chemical, biological, radiological, and nuclear (CBRN)-related hazards such as the concentration of toxic gases, harmful chemicals, radioactive radiation, etc. even in real-time. Such (mostly proprietary and closed) systems can handle and analyse real-time data without major problems. However, the challenge still is the exchange of real-time data and its integration into heterogeneous systems across different rescue organisations such as the red-cross, fire brigades or specialist forces. Proprietary data formats and interfaces are often a major problem within this data integration step as this limits interoperability.

Up-to-date data and information can be seen from several perspectives. The term 'real-time' originated in the domain of computer science and refers to very strict and invariant time intervals (mostly in milliseconds) for deterministic data processing. In the context of geographic applications such as real-time environmental monitoring, however, 'real-time' mainly refers to the 'current' state of the environment or to the state of the environment as it is 'now'. A less rigorous term than 'real-time' is 'near real-time' as it does not impose rigid deadlines and the expression itself suggests the dynamic adaptation of a time period according to different usage contexts (Resch, 2012). In the context of this research, the terms 'live' and 'near real-time' are seemingly appropriate and used synonymously throughout the article.

In this paper, we present the results of our live analysis workflow, as well as lessons learned from the EraStar 'G2real' project, specifically from the radiation safety exercise 'Shining Garden'. Emphasis is put on end user and information requirements for near real-time emergency information management. We demonstrate how this workflow enables the creation of live spatio-temporal awareness of radioactive radiation dose rate and thus enhances the situational awareness for rescue forces. We provide an overview of the emergency management information system architecture used for near real-time geo-analysis. In addition, to demonstrate multiple web-client support, we show analysis results from the 'Shining Garden' exercise at a 'command and control centre'. Finally, we present and discuss the feedback received from the end users and domain experts during and after that exercise.

This paper extends our previous work (Sagl et al., 2011), where emphasis was put on the implementation of live geo-processing tasks, particularly the spatial interpolation of a continuously increasing number of mobile sensor measurements, and the rapid service-oriented dissemination of the analysis results. In this paper, we demonstrate – in addition to detailed technical aspects within the service-oriented workflow – the added value of the analysis workflow for live situational awareness of rescue teams and, thus, for time-critical decision support. This also includes the support of several web-clients (e.g., laptop, tablet, etc.), accuracy assessment of spatial interpolation methods (IDW and Kriging), as well as evaluation and validation of the overall live analysis workflow by end users and domain experts (questionnaire).

2 Related work

A significant portion of the scientific literature is dedicated to sensor web developments (Reichardt, 2003; Zyl et al., 2009), which inherently include sensors and geo-sensor networks. Such geospatial sensor systems (Broering et al., 2011; Chen et al., 2010; Falke et al., 2008; Liang et al., 2005; Zyl et al., 2009) are applied in various domains, for instance, in health monitoring in urban environments (Resch et al., 2012), water quality surveillance (Ninsawat et al., 2008), or bomb threat scenarios (Stollberg and Zipf, 2007). Nonetheless, the sensor web concept faces several challenges in the disaster management domain, for example, with respect to vulnerable infrastructure as compressively discussed in Wang and Yuan (2010).

Recent research of sensor-data based geo-analyses in the field of emergency information management addressed several technical and scientific problems. Chuli and Nengcheng (2011) implemented the smart disaster emergency processing based on the sensor web framework in order to investigate landslide scenarios. The Code Blue architecture (Lorincz et al., 2004) is designed to wirelessly track and monitor rescue forces, as well as patients in highly dynamic emergency situations. Tosti and Smari (2010) introduced a grid-base 'sensing' architecture, which integrates the Web 2.0, in order to support emergency management. In addition to those developments we ensured a fully service-oriented live workflow along the entire geo-information value chain, from the mobile sensing device to the visualisation of analysis results on various web-clients.

Geo-information technology has been employed in order to ensure the effective and well-coordinated response of rescue teams, which was demonstrated on the case of a fire event (Demir et al., 2011). Yet, standardised services such as the open geospatial consortium (OGC) web processing service (WPS) in its current version (1.0.0) (Schut, 2007) shows clear weak-points such as its broad scope and lack of restrictions (Stollberg and Zipf, 2007; Michaelis and Ames, 2009), or the deficiency of its asynchronous processing approach and lacking input/output data description (Resch et al., 2010b). To allow distributed and cloud processing of the rapidly increasing volume of (near) real-time data, more comprehensive architectures will be required (Friis-Christensen et al., 2007; Schaeffer et al., 2009). Within current – and certainly future – geographic information service architectures, standardised services like the OGC web feature service (WFS) for vector data, the web coverage service (WCS) for raster data and the web map service (WMS) for data visualisation only (the data is not included in a WMS) are widely used (Friis-Christensen et al., 2009).

Aside from the scientific and applied research approaches discussed above, a near real-time analysis and fully service-oriented workflow that starts from a standard sensing device and ends at a web-based client is rarely addressed. We try to account for this shortcoming by demonstrating such a 'live' workflow, which flexibly integrates spatial interpolation methods, in order to create up-to-date emergency information layers beyond point measurements according to the end user needs.

3 G2real – near real-time geo-analysis for emergency management

The overarching aim of the FP6 ERA-STAR Regions project 'G2real: Galileo-based GMES real-time emergency support testbed, real-time exercise and development of services' was to establish and test new pre-operational global monitoring for environment and safety (GMES) services in the field of emergency response and disaster management. Of particular interest was the validation and verification of the services developed through two exercises – one related to Galileo-based navigation, the other to real-time GMES services. Herein, we focus on the scientific results of the latter exercise for radiation safety called 'Shining Garden'.

3.1 Near real-time GMES service exercise 'Shining Garden'

The assumed use case developed is about a 'small-scale simulation of a satellite crash scenario to demonstrate a GMES-based search and recovery mission'. The assumption for this exercise was an unplanned re-entry of a nuclear reactor powered satellite into the earth's atmosphere. The radioactive debris was assumed to be distributed over a wide area. In a traditional CBRN tracking scenario, the search for radioactive particles is divided into at least two phases: in the first phase, an airborne radiation detection results in a coarse localisation of radiation hot spots; in the second phase, special CBRN ground teams investigate these hot spots in order to localise the radioactive source and, if necessary, evacuate potentially affected citizens.

The user requirement analysis (see Section 4) led to the following task: within the second phase mentioned above, CBRN teams are equipped with a portable radiation sensor and generate live radioactive radiation maps based on near real-time sensor measurements and geographic analysis methods. Latest satellite imagery of this area should help to take the relief effect into account. All information layers are then provided as GMES services using open geospatial standards. This task was performed at the radiation safety test area (Figure 1) located in Seibersdorf, Lower Austria. Two sealed 137Cs radioactive sources with an appropriate radiation dose rate provided by Seibersdorf Laboratories were used to simulate the contaminated spent fuels. Since the Galileo signal was not available at the test area, conventional differential GPS was used for positioning. The main objective of the 'Shining Garden' exercise was the validation of the overall system performance and the development of a near real-time GMES dose rate web-mapping application.

Figure 1 Radiation safety test area at Seibersdorf Laboratories, Lower Austria (see online version for colours)

4 Assessment of end user requirements

This section presents the outcomes from two expert workshops dedicated to the requirement analysis of end users in emergency situations. In the first workshop, the end users and experts – in collaboration with the G2real project team – formulated, categorised, and prioritised their requirements. Issues discussed included essential (sensor) data sources, suitable communication protocols and standards, minimum positioning accuracy, level of generalisation of analysis results, appropriate cartographic visualisation and legend, etc. In the second workshop, these end user requirements were iteratively refined at a more detailed level and were categorised into information, communication, and positioning.

4.1 Information requirements

In disaster management, the quality of information highly depends on the measurement data regarding quantity, availability, and accessibility. Data quality can be divided into two main categories, namely up-to-dateness and accuracy (Herrmann, 2007).

Table 1 provides an overview of the need of specific information layers (rows) used or generated within the G2real project and its respective user group (columns) in a matrix manner. Possible matrix field values are: required (green), optional (yellow), or not required (red). As one major outcome of the two expert workshops the number and definition of both the information requirements and the user groups are based on the end users' theoretical and empirical knowledge.

The four user groups represented as columns:

- *remote control room/disaster management leaders*: people in charge of rescue teams such as commanders directly giving orders based on spatially enabled decision support systems
- *mobile devices/rescue teams*: operation task forces on-site exploring, measuring, rescuing people or securing operation areas
- *information link to superior decision makers*: superior decision makers that are responsible for allocating resources that, in order to respond to the disaster effects, need to have an easy to understand overview of the overall situation
- *public, official information providers (TV or radio stations)*: all other people, whether affected by the disaster or not, to satisfy their information need such as warnings, a generalised map of the affected site, safety circles, etc.

The 12 information requirements represented as rows:

- *background maps*: information for orientation, e.g., aerial imagery
- *initial information*: information fostering the operational picture (e.g., points of interest, injury status, coordinates of each casualty, etc.).
- *real-time imagery*: a geo-referenced live picture of the area (air-borne camera picture or oblique imagery taken by rescue teams from the ground)
- *searched areas*: searched (secured) and not reviewed areas based on team tracking
- *biometric information*: vitality of rescue teams using body sensors
- *street and routing data*: street maps and routing service
- *environmental measurements*: telemetry data of additional sensors (e.g., temperature, wind speed and direction and/or weather situation)

- *processed maps*: processed map products (e.g., near real-time interpolated dose maps, residential areas and recent population, accessibility maps)
- *safe areas*: safe area map and an emergency pullback function
- *generalised COP*: operational picture generalisation to provide public/press information
- *thematic heat maps*: easy to read 'traffic light' maps showing phenomena such as radiation, exposure, or risk indices in three colours (e.g., green, orange, red)
- *raw data map*: raw data values and raw sensor measurements in a map.

Table 1 Overview of information requirements (see online version for colours)

	Remote control room/disaster management leaders	*Mobile devices/rescue teams*	*Information link to superior decision makers*	*Public, official information providers (TV or radio stations)*
Background maps	Green	Yellow	Green	Green
Initial information	Green	Yellow	Red	Red
Real-time imagery	Green	Yellow	Red	Red
Searched areas	Green	Yellow	Red	Red
Biometric information	Green	Red	Red	Red
Street and routing data	Green	Green	Red	Yellow
Environmental measurements	Green	Red	Red	Red
Processed maps	Green	Green	Green	Red
Safe areas	Green	Green	Red	Red
Generalised COP	Yellow	Red	Green	Green
Thematic heat maps	Yellow	Green	Green	Green
Raw data map	Green	Green	Red	Red

Note: Green = required; yellow = optional; red = not required.

4.2 Communication requirements

Within this project, a working transmission control protocol (TCP)/internet protocol (IP)-based communication was presumed. This was an essential requirement to enable the service-oriented data exchange between and within the test area and the internet. Such communication can be provided via wired or wireless communication technologies including telephone lines, ad hoc Wi-Fi (wireless local area network – WLAN) networks, global system for mobile communications (GSM), universal mobile telecommunications system (UMTS), or global satellite communication. These modern communication technologies are almost ubiquitously available and highly reliable but, however, not totally fail-safe. The requirement of a working TCP/IP communication therefore – in general – clearly limits the operational reliability of service-oriented architectures (SOA). However, the development of a totally reliable infrastructure is beyond the scope of this research [as mentioned in the related work section, see e.g., Wang and Yuan (2010)].

Long-range voice radio communication as another important communication media within and among rescue organisation is already well-established. Thus, internet access in and to disaster management facilities, as well as an independent radio network speech communication of staff and rescue teams is indispensable.

The need of reliable information and its exchange across different disaster management authorities can be argued at a technical level: the use of interoperable systems, and standardised information exchange (XML, GML) based on web platforms fulfilling three requirements:

1 ‘ad-hoc’ information integration through widely accepted interface standards

2 easily accessible information portals and information layers without technical or scientific knowledge

3 access to different types of spatially mapped information layers ranging from raw data values (to be interpreted by experts) up to intuitively readable ‘traffic light’ maps (green, orange, red).

4.3 Positioning requirements

A precise positioning within the range of 1 metre is required for time-critical localisation. The most widely used, freely available and fully operating global navigation satellite system (GNSS) today is the United States NAVSTAR global positioning system (GPS). The GPS’s native positional accuracy of about 5–10 m, which is freely available for public services, is therefore not sufficient to enable small-scale and accurate localisation. Galileo, as the new European GNSS, is designed to provide exactly such accurate localisation services to the public. These capabilities have been evaluated in the Bavarian use case and will be used in further scenarios where time-critical and exact positioning is necessary. However, a detailed evaluation the Bavarian use case is not part of this paper.

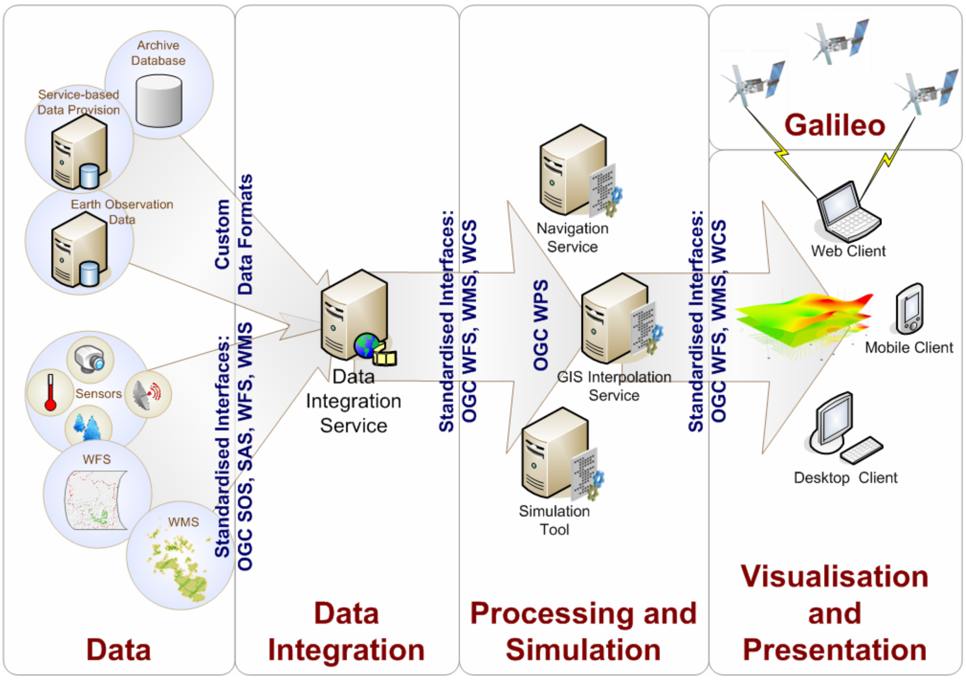
Since the positioning system in the ‘Shining Garden’ exercise was based on GPS, the networked transport of RTCM via internet protocol (NTRIP) was integrated to correct positional data ‘on-the-fly’. This ensures a positional accuracy of the GPS receivers of < 1 m, which is – according to the end user – at least necessary to localise the radiation source within the radiation safety test area.

5 Architecture of the emergency management information system

The G2real workflow ‘starts’ at ordinary sensors, includes sensor data fusion and (spatial) data processing, and ‘ends’ at selected desktop- and a variety of standard web clients such as any internet browser or Google Earth. At the client, which can also be a command and control centre, the newly generated spatial information was integrated and visualised for decision support.

Following the SOA principals, the overall workflow design (Figure 2) was based on the ‘live geography’ approach introduced by Resch et al. (2009). In order to maximise interoperability of the service-oriented workflow with other systems, we used a number of well-established OGC standards: the sensor observation service (SOS) for near real-time sensor data acquisition ('data'); the WPS for geo-analysis tasks ('processing and simulation'), and the WFS, WCS, and WMS for rapid mapping and dissemination of both sensor measurements and geo-analysis results ('visualisation and presentation').

Figure 2 Modular and service-oriented workflow for near real-time geo-analysis (see online version for colours)



5.1 Standardisation enables interoperability between inter-organisational systems – SWE

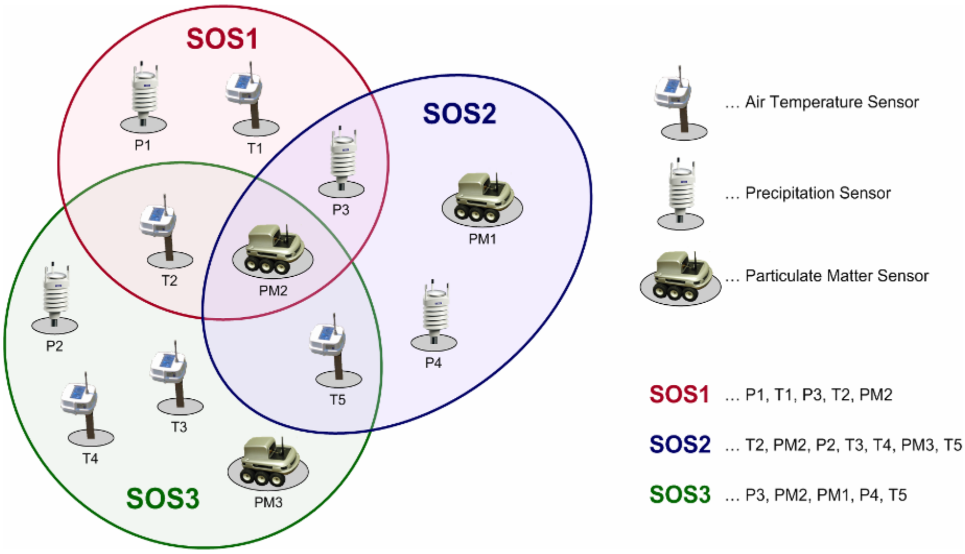
A fundamental prerequisite for sensor networks is interoperability, which concerns data structures, measurement transmission, sensor queries and alerting functionality. Thus, the OGC sensor web enablement (SWE) initiative was chosen to assure interoperability in the G2real workflow. This choice was made due to SWE's comprehensiveness (it serves the entire process chain), its broad development support from both academia and industry, its rapid advancement and introduction as official standards, and its maturity, which it has mainly gained through the last two years.

The most essential SWE standards for monitoring applications are the SOS for sensor data provision, observations and measurements (O&M) for encapsulating the measurements into a standardised XML-based format, and the sensor model language (SensorML) for describing the sensor platforms. Furthermore, the sensor alert service (SAS) plays an important role for sending event-triggered alerts, e.g., in case of threshold transgression.

The actual implementation of the geo-sensor web is highly application-specific according to the unique requirements of every single deployment. Thus, the live geography approach only suggests broad interoperability, which is achieved by the extensive use of the OGC SWE standards, whereas other sensor network challenges need to be solved as the case arises.

Generally, the SOS provides a service to retrieve measurement results from a sensor or a sensor network. Furthermore, the SOS can group a collection of possibly heterogeneous sensors, as exemplarily illustrated in Figure 3 (SOS1, SOS2, and SOS3), and provide their measurements of, e.g., air temperature, precipitation, and particulate matter via a standardised service interface.

Figure 3 General SOS usage concept (see online version for colours)

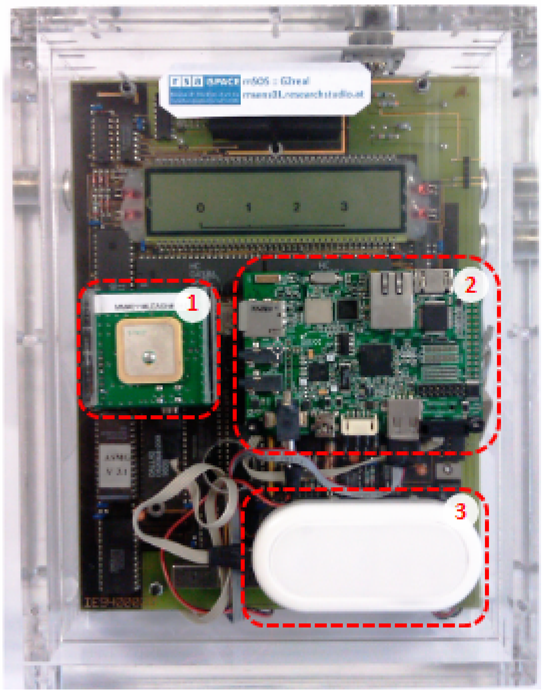


Source: Adapted from Na and Priest (2007)

5.2 Near real-time sensor data provision via SOS

A variety of high-quality sensing devices, which measure the physical or chemical phenomenon of interest, can serve as (near) real-time data sources that are accessible as a service via the internet. Therefore, we developed a sensor pod framework that is fully compatible with already existing sensors – a detailed discussion of that framework is given by Resch et al. (2010a). As described in Sagl et al. (2011), we combined the SSM-1[1] standard sensor, which is also used by Austrian emergency institutions to measure the radioactive radiation dose rate, with an embedded single board computer (Figure 4). The application running on that embedded computer pre-filtered the SSM-1 measurements, assigned the GPS position and time stamp to these measurements, established an internet connection, acted as an SOS server instance and hence managed incoming web-service requests. This intelligent sensor pod was therefore the 'starting point' of the overall service-oriented geo-analysis workflow. The sensor pods' services are fully compliant with the OGC SWE initiative (Botts et al., 2007).

Figure 4 Sensor pod (see online version for colours)



Notes: (1) GPS receiver, (2) IGEPV2 single board computer, and (3) UMTS modem on top of SSM-1 (circuit board only).

5.3 Data integration into spatial decision support systems

The fastest possible data integration, rather than data import, into heterogeneous information systems is a key challenge, especially if such data ought to support the time-critical decision-making process. Among other data quality criteria such as accuracy, completeness, consistency, etc. the 'topicality' parameter, i.e., the up-to-dateness of the data, has received particular attention. Since the near real-time integration of up-to-date data into spatial decision support systems (SDSS) often requires pre-processing steps such as format conversions, an efficient data fusion mechanism was required. Therefore, we developed 'live-data-source-plug-ins' for both open source and commercial software packages [for example, GeoServer (http://www.geoserver.org), or ESRI ArcGIS Server (http://www.esri.com/software/arcgis/arcgisserver)]. As a result, this data fusion mechanism enabled the use of near real-time SOS data for advanced geo-processing routines (Sagl et al., 2011).

5.4 Geo-processing – adding value to data to achieve user-tailored information

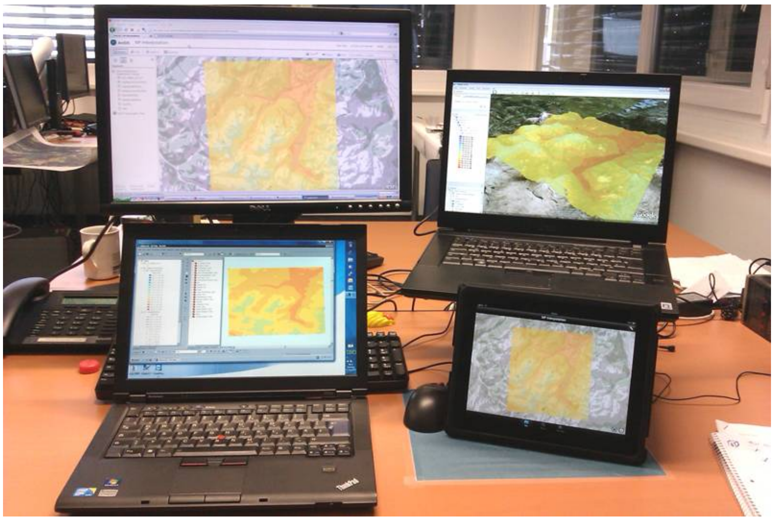
To estimate the value of continuous phenomena such as air temperature or radioactive radiation dose rates at locations with unknown values, the sensor measurements – which are geometrically represented as points – can be spatially interpolated. We used inverse distance weighting (IDW) as a deterministic spatial interpolation method and Kriging as a stochastic method. To dynamically generate new spatial information layers from near real-time sensor measurements we developed a modular processing workflow.

This processing workflow consisted of three consecutive steps. Firstly, to allow metric computation in the two-dimensional space, the input sensor data was transformed from its original spatial reference system (WGS84) to a projected coordinate system (UTM Zone 33 North). In the second step, the point measurements were spatially interpolated to isolines, classified polygons, and a continuous raster surface. The IDW or Kriging interpolation methods and their parameters, for example, the exponent of distance for IDW, or the semi-variogram model for Kriging were selectable and adjustable at run-time[2] by the user. The third step was the classification of the interpolation results according to user-specific thresholds. This final step reduced the information to its essence in order to allow fast and sustainable decision support. In combination, these three consecutive geo-processing steps, which are described in more detail in Sagl et al. (2011), formed the live-analysis workflow. Based on that SOA-compliant geo-processing workflow, we established web-based geo-processing services using the ESRI ArcGIS server platform. Available geo-analysis output formats included lines, polygons, and raster surfaces.

5.5 Dissemination and visualisation of 'live' emergency information

The dissemination of live emergency information and its correct and easy recognition is fundamental for sustainable decision-making. We therefore prepared such complex information as standardised services and put emphasis on the simple visualisation.

Figure 5 Multi-level decision support through visualising geo-information on different web-clients (see online version for colours)



As shown in Figure 5, analysis results were integrated in near real-time into various decision support applications running on different clients: ArcGIS Explorer online at a standard desktop personal computer (top left); Google Earth on a standard laptop (top right); ArcGIS Explore Desktop on another laptop (bottom right); customised web-application on an Apple iPad tablet (note: visualisations show live spatial interpolation results of air temperature measurements in a German national park).

6 Results

The results shown herein are outcomes of the 'Shining Garden' exercise performed in the radiation safety test area Figure 1. Professionals placed two ^{137}Cs radiation sources within the test area for localisation. Prior to the exercise the sensor pod shown in Figure 4 was used to measure a radiation dose rate of 6.3 μ Sievert per hour (μSv/h) (western source), and 4.7 μSv/h (eastern source). We thus minimised potential systematic measurement errors.

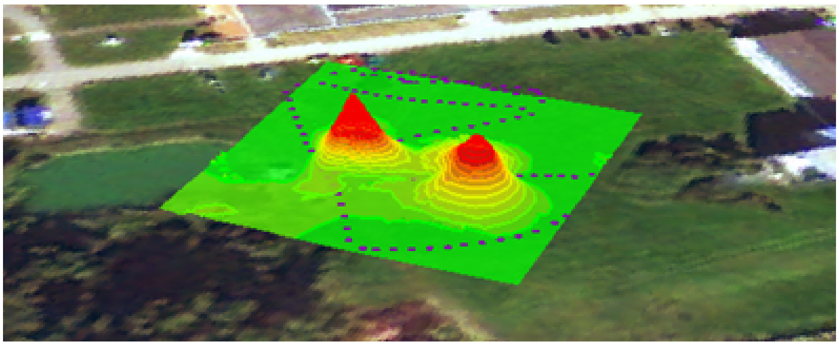
6.1 Near real-time geo-analysis during the sensing exercise

Figure 6 shows the 'command and control centre' and the near real-time web application during the first phase of the sensing scenario. This application was run on a Mozilla Firefox standard web-browser. The sequence of points in the centre of the screen represents the locations of the sensor measurements, which represents the path taken by the person carrying the sensor pod. The latest live geo-analysis result based on the ordinary Kriging interpolation (with spherical semi-variogram model) is shown as a continuous two-dimensional surface.

Figure 6 'Command and control centre': the near real-time web-application demonstrates live Kriging interpolation of the sensor measurements (see online version for colours)

Figure 7 shows a screenshot of the final geo-analysis result at the end of the second phase of the exercise. The client used (ESRI ArcExplorer), which enables an enhanced visualisation of multidimensional information, which includes isolines, as well as a continuous raster surface on top of point measurements.

Figure 7 Enhanced emergency information visualisation: Kriging interpolation result as isolines and continuous surface (see online version for colours)



6.2 *In-depth geo-analysis and visualisation after the sensing exercise*

Figure 8 shows the final IDW and Kriging interpolation results of the exercise's phase one and two in a matrix manner (white triangular symbols show the actual location of the two radiation sources).

Figure 9 shows the difference between the interpolation results. To best possible cover the test area, the dose rate measurements from both phases were combined and both spatial interpolation methods were applied. Subsequently, the difference of the IDW result minus the Kriging result was computed.

Figure 8 Comparison of IDW with Kriging interpolation results from Phases 1 and 2 (see online version for colours)

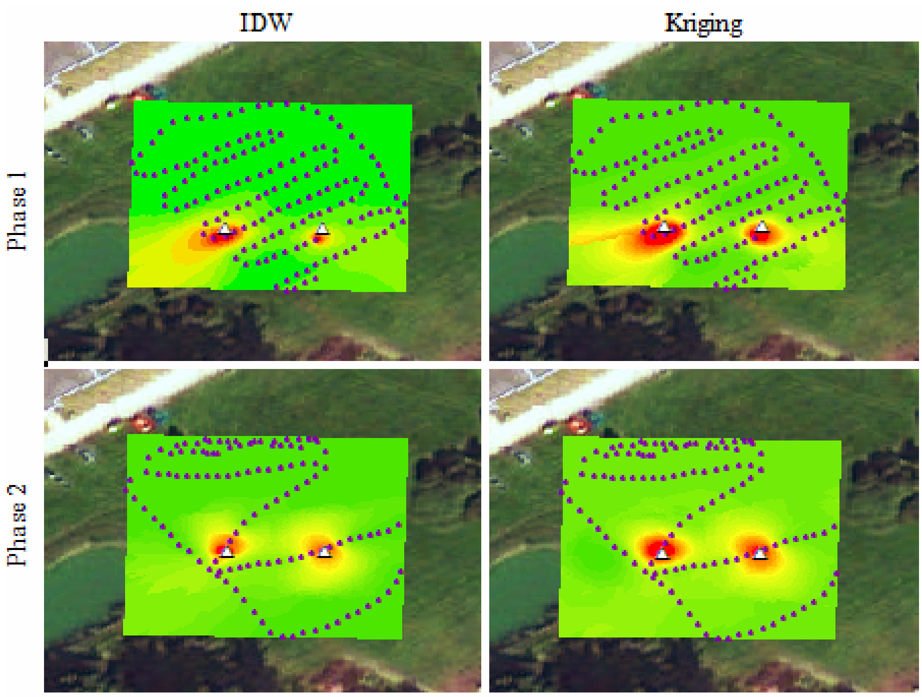
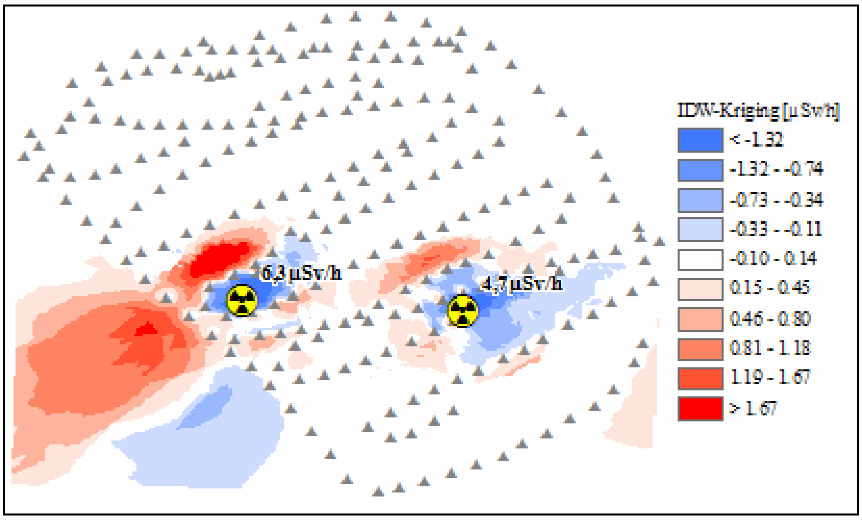


Figure 9 Difference of IDW minus Kriging interpolation results in absolute values (see online version for colours)



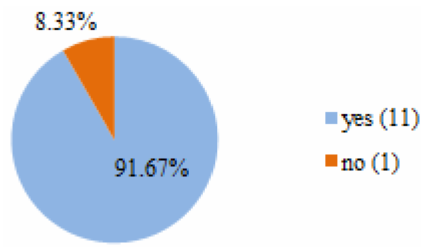
6.3 *End user validation*

We validated the overall live geo-analysis approach presented with the experiences and comments made by the end user and domain experts. About 30 people in total participated in the 'Shining Garden' radiation safety exercise. This group included emergency managers, researchers, officers, decision makers, as well as representatives of the fire fighters, civil protection agency, and federal rescue agency. Four of these people, who were involved in the previously held workshop about the user requirements (refer to Section 4, assessment of end user requirements), were not included in the end user validation in order to avoid biased statements.

This end user validation was based on a questionnaire distributed on-site before the exercise started. After the exercise, 12 end user and domain experts filled out the questionnaire and provided the following anonymous feedback.

Q1 In your professional opinion, can the overall system introduced, which integrates sensor measurements in near real-time to generate up-to-date and intuitive cartographical visualisations, enhance the coping strategy in the case of a damaging event?

Figure 10 Can near real-time maps enhance your coping strategy? (see online version for colours)



If yes, please explain which enhancements:

In Figure 10, reasons for ‘yes’ were: better overview of the situation; enables history of the sensing scenario for documentation; improvement of time-critical decision support; fast localisation of the radiation source; fast access to information; possible changes in the situation are easier and recognisable faster; enhanced actuality of the data, enhanced planning for further actions; improved coordination of rescue forces; platform independence, time-saving.

Q2 What type of real-time geo-data or sensor measurements do you need in the action phase of a damaging event?

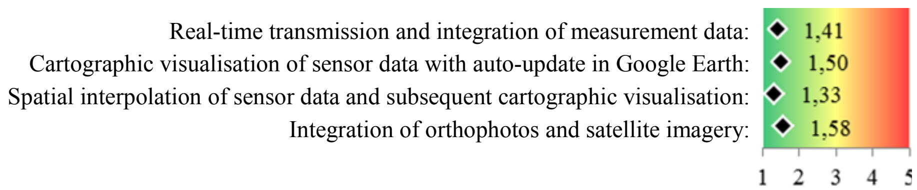
Meteorological data such as air temperature, wind speed and direction, rainfall, air pressure, etc.; measurements of harmful substances; coordinates of the event; positions of rescue forces; direction of propagation and concentration of toxic gases; probability of change of the current situation; status and position of rescue vehicles; biometrical data of rescue forces such as pulse and heart rate;

Q3 What are your suggestions for improvement in the overall workflow presented and in the operational phase in general?

Common up-to-date knowledge about the current situation, across all rescue forces involved; combination of different technologies to enable monitoring, COP, etc.; optimisation of processes; fast and reliable measurements; reduction of complexity of systems; real-time integration of existing measurements;

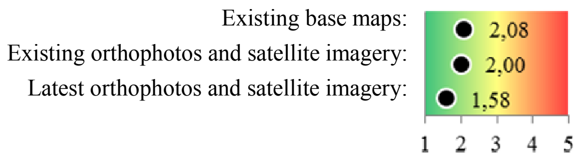
Q4 What is your estimation of the added value of the ‘Shining Garden’ exercise for your particular rescue organisation? (1…high to 5…low)

Figure 11 Added value of the ‘shining garden’ exercise (see online version for colours)



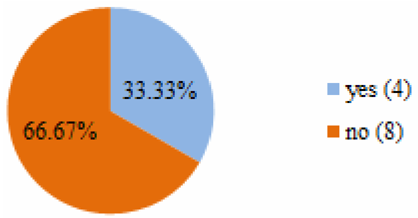
Q5 How supportive is the availability of up-to-date background data? (1…high to 5…low)

Figure 12 Importance of up-to-date background data (see online version for colours)



Q6 Within your particular institution, do you prepare or provide base data or sensor data conform to open and international standards?

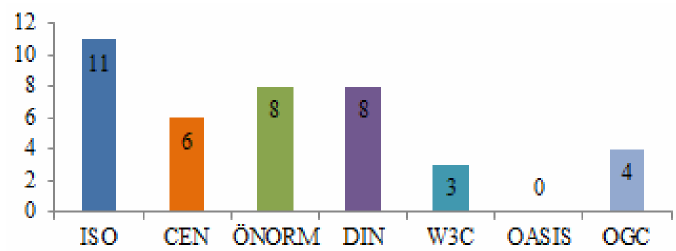
Figure 13 Institutions preparing or providing standards-compliant base data (see online version for colours)



Q7 Which standardisation bodies are you aware of?

Possible choices included the International Organisation for Standardisation (ISO), European Committee for Standardisation (CEN), Austrian Standards Institute (ÖNORM), German Institute for Standardisation (DIN), World Wide Web Consortium (W3C), Organisation for the Advancement of Structured Information Standards (OASIS), and the OGC.

Figure 14 Awareness of different standardisation bodies (see online version for colours)



Q8 Which components of the G2real project could be of interest for your particular institution?

Real-time COP; documentation and reporting of distance travelled; live and rapid mapping; automated acquisition of measurement data, history of sensor data as a piece of evidence; hand-held sensor devices; OGC-add-on for standard sensor devices; live analysis of sensor measurements;

7 Discussion and conclusions

In this paper, we demonstrated and verified our approach of a live workflow for geo-sensor data analysis though a near real-time radiation safety exercise. This workflow was based on standardised geo-sensor webs and web-based processing. The results presented clearly showed the significance of up-to-date and reliable information for time-critical decision support. Near real-time sensor measurements in general, and their live spatial interpolation results in particular, created situational awareness for rescue forces time-critical decision support across various institutions. The domain experts and end user feedback confirmed that the up-to-date situational knowledge achieved based on that approach significantly enhanced the decision-making process.

We validated – technically, as well as methodologically – the overall near real-time emergency information system through the 'Shining Garden' radiation safety exercise: following our live-workflow shown in Figure 2, the near real-time radiation dose rate measurements from mobile and intelligent sensor pods (Figure 4) were analysed using the IDW and Kriging spatial interpolation methods (as discussed in Section 5.4). These live geo-analysis results were instantaneously disseminated as standardised services and visualised on several web-clients (as demonstrated in Section 6.1).

From a technical point of view, we validated the real-world functionality of the system through the 'Shining Garden' exercise. Due to the use of open and international standards, the live analysis results could be shared among the heterogeneous systems of different rescue forces. Furthermore, this enhanced the efficiency, optimised the communication, decreased the time for intervention, and thus enabled a live situational awareness of rescue forces and decision makers in emergency management.

From a methodological perspective with respect to the spatial interpolation, the analysis results showed that IDW was the appropriate interpolation method during the sensing exercise. Immediately after the scenario, i.e., when all point measurements were included, however, the geo-statistical Kriging interpolation technique obtained the most accurate spatial assessment of the radiation dose rate (Figure 8, and Figure 9). This is in full agreement with Mabit and Bernard (2007).

Live results obtained during the exercise show the path taken by the professional (reporting purposes), and the gradually growing spatial-temporal analyses from the near real-time measurement (Figure 6). The advanced visualisation shown in Figure 7 increased the spatial awareness of the rescue forces. Both figures clearly show the most probable locations (red spots) of the two radiation sources displayed for detection.

Post-analysis results indicate that the direct comparison of final interpolation results shown in Subsection 6.2 takes the two different paths into account. It clearly points out for both phases that Kriging rather than IDW fulfils an accurate localisation of radiation sources. Furthermore, the enhanced visualisations enable an accurate reconstruction of the field exercise.

The feedback received from end user and domain experts during and after the exercise confirms that the live information layers generated from near real-time sensor measurements allow rescue forces to react immediately as the situation at the emergency site changes. This situational awareness could be further improved by integrating, for instance, sensor data about the on-site weather conditions such as precipitation, wind speed, wind direction, etc., and the current position and vital parameters (e.g., heart rate) of rescue forces. These sensor data fusion aspects allow for a more comprehensive COP and will therefore be considered in detail in a follow-up project. Although the effective communication of such a COP among the different rescue institutions involved requires a 'common language', the availability and accessibility of the underlying data via standardised interfaces and web-service is rather low (Figure 13: only 33% of the institutions involved in the 'Shining Garden' exercise prepare or provide standards-compliant data). The end user and domain experts see both the need and benefit of live information layers in emergency response.

We conclude that standardised geo-sensor webs and web-based geo-analyses can contribute to the field of emergency information management. We showed that the standards-based live workflow presented in this paper, which started with near real-time measurements from ordinary sensor devices and ended with the live information visualisation at the 'command and control centre', can enhance the situational awareness of rescue forces for time-critical decision support.

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Notes

1 'StrahlenSchutzMessgeraet Version 1' (German language).

2 Running tasks are not affected, changes take effect when the next geo-processing task is triggered.