REAL-TIME SPATIAL ANALYSIS FOR DISASTER MANAGEMENT

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ABSTRACT:

Emergency and disaster management are, above all, time-critical tasks. Situations usually are in flux, rapidly changing, prone to surprises and thus have to be monitored diligently and in near real-time. The authors have leveraged the potential of distributed and open architectures for supporting real-time spatial analytics for time-critical demands of disaster management. This architecture has been validated through a prototype implementation tested in emergency exercises.
The main challenge was the technical integration of real-time remote sensing data and standardized in-situ sensor measurements to support first responders in the disaster mitigation and response phases. Concepts and workflows were developed and tested to integrate new pre-operational GMES services in emergency and disaster management (specifically, for measuring and monitoring physical and chemical hazards such as radioactive radiation and toxic gases) using location enabled tools for supporting rescue and recovery operations.
Open and internationally established standards are enabling a service-oriented workflow extending from sensor-data acquisition to information extraction, spatial analysis towards visualisation; facilitating ubiquitous provision and dissemination of ad-hoc generated information. Sensor measurements taken by human or robotic movements are verified, integrated and interpolated into an initial field view, which is then enhanced and densified based on situational demand.
The exercise presented in this paper demonstrates a real-time workflow from location-enabled sensor measurements (field tracking of gamma radiation) to analytical geoprocessing and rapid mapping, improving the effectiveness of time-critical emergency support. Results from this exercise confirm that the proposed approach significantly enhances the generation of a Common Operational Picture and in turn improves time-critical spatially explicit decision support.

1. MOTIVATION

Spatial analysis traditionally is considered part of a mostly linear processing workflow, translating data into information relevant in a given application context. This means that insights typically are available (long) after some kind of event has occurred which has triggered the collection of data.

In virtually all kinds of decision support scenarios, and particularly in emergency and disaster response contexts, gaining knowledge about 'what should be done differently next time' is a less than satisfactory analysis result. For successful decision support throughout any event cycle, analytically processed information is required in near-real time and has to reflect the dynamic nature of events as they evolve and as data are being gathered.

The essence of any Common Operational Picture (COP) is that it has to integrate and convey current information, ready for interpretation by all relevant actors. Presenting raw sensor readings rarely will be desirable, but key information items have to be dynamically extracted and effectively presented. Due to the not completely foreseeable nature of most incidents this is a huge challenge for analytical geoprocessing.

The authors are proposing to leverage progress in interoperable standards, with a particular emphasis on integrating Sensor Web Enablement and OpenGIS-conformant Web Processing Services (WPS) in a fully Services-Oriented Architecture (SOA) which by definition is cloud-ready and therefore highly flexible for adaptation to various incident and emergency scenarios.

It is fully anticipated that future decision support frameworks and 'control centre' – style dashboards will rely heavily on user interfaces presenting high quality real-time geospatial information in a condensed, contextualized and easy-to-comprehend manner for immediate translation into decision alternatives.

2. CASE STUDY

The above outlined conceptual approach has been developed, implemented, demonstrated and validated based on a prototype used in the '*Shining Garden*' exercise: within the G2real project framework researchers from the iSPACE Research Studio were hosted on November 17, 2010 at Seibersdorf Labs near Vienna. The exercise assumption was the impact of a satellite with a radiation source, and the spatial scope, distribution and levels of contamination had to be established quickly.

The entire exercise was framed as a live demonstration for decision makers, in order to solicit their feedback on the timely presentation of information required for mitigation measures. Within the exercise area, two low level radiation sources with different intensities were placed, and technicians were dispatched with mobile sensors to gauge and establish the overall spatial picture of radiation intensities.

These field technicians walked across the suspected contamination area with their sensors, and readings coupled with GPS positions along their path were transmitted in 5 second intervals. Values and positions were immediately integrated into an interpolated field ('value surface') which was continuously updated as new data were gathered.

Figure 1: Field Data Acquisition

These interpolation results, combined with sample points along tracks and an orthophoto basemap of the incident area were displayed life to the audience. Based on the emerging 'situational picture', dispatchers then directed the field technicians to more closely inspect (i.e., gather further readings) areas with high contamination, pay attention to additional locations and to scope the perimeter in order to verify the spatial containment of the contamination.

Not only the gathered data and processed information displayed as part of the COP, but also the entire flow of interaction among field technicians, dispatchers, experts and audience were collected as an empirical foundation for better design of processes and technologies supporting situation rooms and control centres.

Figure 2: Presentation of dynamically evolving situational picture to actors

2.1 Research Project Context

This exercise supports the objectives set for the ERA-STAR Regions project "*G2real: Galileo based GMES real time emergency support testbed, real time exercise and development of services*". The entire project aims at the development and test of new pre-operational GMES services in the field of emergency and disaster management, as well as rescue operations.

The project is aiming at three outcomes: (1) organizational integration of end users and first responders; (2) definition, development, and validation of pre-operational GMES services with a focus on optimal levels of interoperability; and (3) validation and verification of a prototype through two real-time exercises – one analyzing Galileo navigation, the other one exploring GMES services. The latter exercise was implemented as '*Shining Garden*' within a radiation safety scenario.

3. ARCHITECTURE AND METHODOLOGY

The overall workflow design is based on the '*Live Geography*' approach proposed by Resch et al (2009). It targets the challenges arising in the data-to-information sequence through fully standardized service-oriented modules. The G2real workflow thus maximizes interoperability through established Open Geospatial Consortium (OGC) standards. Specifically, we employ the Sensor Observation Service (SOS) to request sensor readings, Web Processing Service (WPS) (Schut, 2007) to transform data into information, and Web Feature Service (WFS), Web Coverage Service (WCS), and Web Map Service (WMS), respectively, to disseminate and present analysis results on web-based clients.

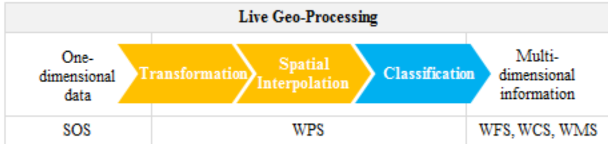

Figure 3: General Workflow

3.1 Sensor Observation Service

The overall workflow starts from one-(spatially speaking, zero-) dimensional observations ultimately aiming at multidimensional presentation across spatial and value domains. A multitude of sensing devices have the potential to serve as real-time data sources. Properties of physical or chemical phenomena – in this case the dose rate of radiation from radionuclides – are measured by an accurately calibrated sensor. Actually, for further use within a standards-based modular services infrastructure, these measurements needs to be pre-filtered, tagged with a current spatial and temporal position, and finally published via SOS. The technical framework developed for the complete sensor pod is fully compatible with already existing sensors and integrated through an embedded computing device.

This embedded computer manages pre-filtering of suspicious GPS fixes as well as improbable sensor readings. After first verification data are stored in an embedded SQLite database used to decouple the sensor reading phase from further processing steps. This loose coupling enables concurrent actions such as measuring, analysis and data delivery for presentation through asynchronous HTTP services. Services currently used include SOS, KML and GeoRSS. The entire functionality of this sensor pod approach conform withs OGC Sensor Web Enablement (Botts et al., 2007) and is described in detail by Resch et al. (2010).

While this discussion is illustrated with an example from mobile in-situ sensing, all conclusions would of course be valid for stationary sensor networks as well as for UAV-based remote or in-situ sensor technologies.

3.2 Analytical Geoprocessing

As a prerequisite for quantitative analysis across the entire study area, and of course for communication and interaction with analysts and actors in the incident management context, irregular point samples are converted into an area ('surface', or 'field') representation by interpolation.

Filtered and quality assured live in-situ measurements are spatially represented as points. These one-dimensional samples of mostly continuous phenomena (e.g. dose rate of radioactive radiation) can be transformed into multi-dimensional information either through IDW (Inverse Distance Weighting) as a deterministic, or e.g. Kriging as stochastic interpolation techniques.

An integrated modular geo-processing workflow is set up, leading from (1) transformations of input data from its current field spatial reference system (WGS84) to a projected coordinate system (e.g. UTM Zone 33); then (2) spatial interpolation of points into a continuous surface with IDW or Kriging techniques, including flexible parameterization which can be changed dynamically at runtime; and (3) classification (e.g. low, moderate, and high) of processing results according to user-specific thresholds for effective communication as a 'traffic-light symbology' with green – yellow – red.

Based on this generic workflow, and in compliance with distributed SOA architecture requirements and OGC specifications, online geo-processing services as described in Mittlboeck et al. (2010) were implemented for real-time support of analyses. More specifically, ESRI ArcGIS Server in combination with PyWPS acts as the geoprocessing engine. In the near future, due to the massive increase of real-time data, comprehensive architectures for distributed and cloud processing will be indispensable (Friis-Christensen et al., 2007; Schaeffer et al., 2009).

Due to the in principle (and practice) virtually "unlimited scope and nature of OGC WPS" (Michaelis and Ames, 2009), only the functionality required in any given specific application context is implemented as a service supporting this particular service. Depending on the data and information model required by the client, the geoprocessing output includes both vector and raster elements as needed.

This approach results in an entirely service oriented 'live geo-processing workflow' using a suite of OGC standards: SOS to request one-dimensional in-situ data, WPS for geoprocessing on-the-fly, and WFS, WCS, and WMS, respectively, for multi-dimensional information output.

3.3 Communication and Interaction

Fast and flexible communication of results to all actors and in particular to decision makers certainly is a cornerstone on the path to achieving a short feedback loop and facilitating real-time command and control. The presentation of a current situational picture can be done in a control room, on a mobile tablet or with other media, with a dedicated display client or a generic one like Google Maps, as long as it supplies operational decision makers with the information required to initiate next steps and adequate action.

Essential for the requisite flexibility again is a web-based and thus services-oriented architecture. By avoiding any kind of stovepipe architecture element it is possible to present a situational picture in any relevant context: a field data acquisition technician will operate in a different context and will have other objectives than a strategic decision maker acting on a higher level.

The main criterion for acceptable visual (geospatial) interfaces of course is a correct, but even more so contextualized design. A mobile field worker will typically always have her or his display centred on the current location, while a dispatcher or emergency manager will want to roam more freely. Offering the adjusting of symbology and classifications has to be carefully weighted against distractive and disruptive effects.

Ease of interpretation, and unambiguity of interpretation are essential: information has to be clearly presented for possible further action. One example again is interpolation, where a choice of Kriging as a method facilitates the highlighting of areas with low confidence in interpolated values, which might be candidates for revisiting to improve results with additional samples.

Overall, visualisation should not (any more) be considered as the presentation end of a processing workflow. Rather it is the human interaction step in a control cycle, enabling actors to direct and manage all further measures towards achieving the goal at hand.

4. RESULTS AND OUTLOOK

This prototype has been successful in demonstrating in a simulated incident and disaster manage context, that distributed and services-based architectures supported by open standards provide the foundations for real-time geoprocessing in mobile and highly flexible contexts.

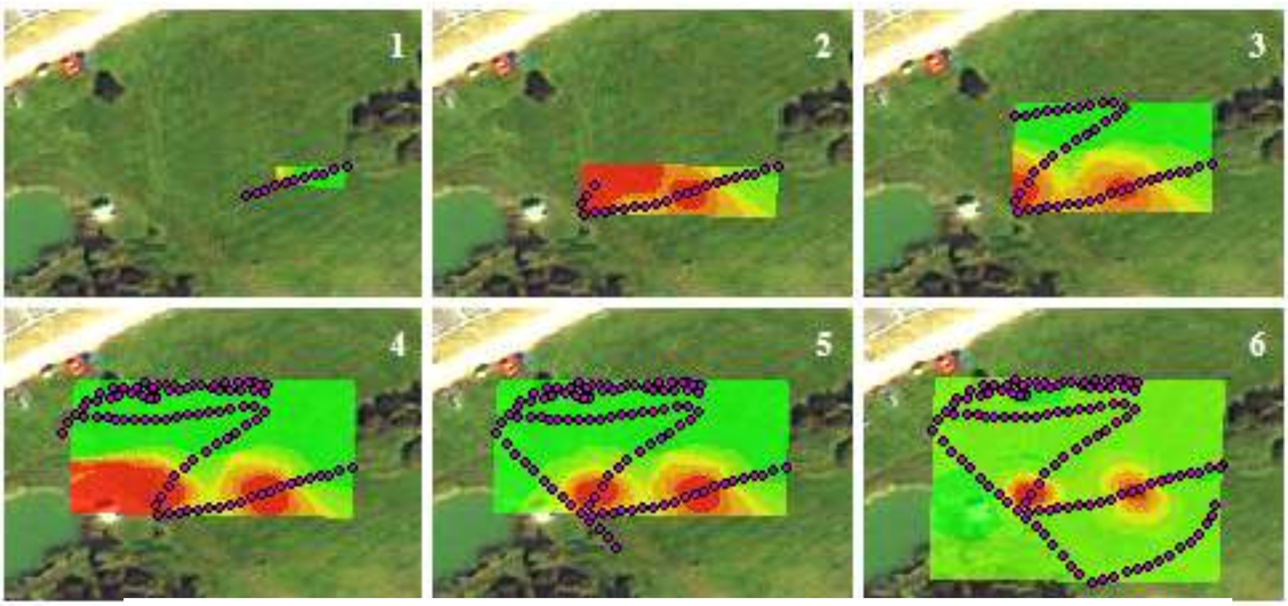

Figure 4: Stepwise interpolation of sensor data as field workers move with sensors across affected area

Since geospatial standards have evolved from data models and data transfer towards visualisation and now include full analytical processing capabilities, it is now easily possible not only to have even complex processing sequences contributing to a rich and timely situational picture in a control room, but information can just as well be brought into a mobile, location-centric context of work. Just about any display client will do – the heavy lifting of processing is done by servers 'in the cloud' anyways.

Figure 5 showcases the main service elements integrated into an architecture supporting the objective of real-time geoprocessing for improved situation awareness. The requirement of simple interaction even when analyses are complex can thus be fulfilled – '*do not give me the data you have, but the information I need - here and now'* is a statement demonstrating the urgent need for moving from huge streams of data towards clearly focussed contextualized information for decision support.

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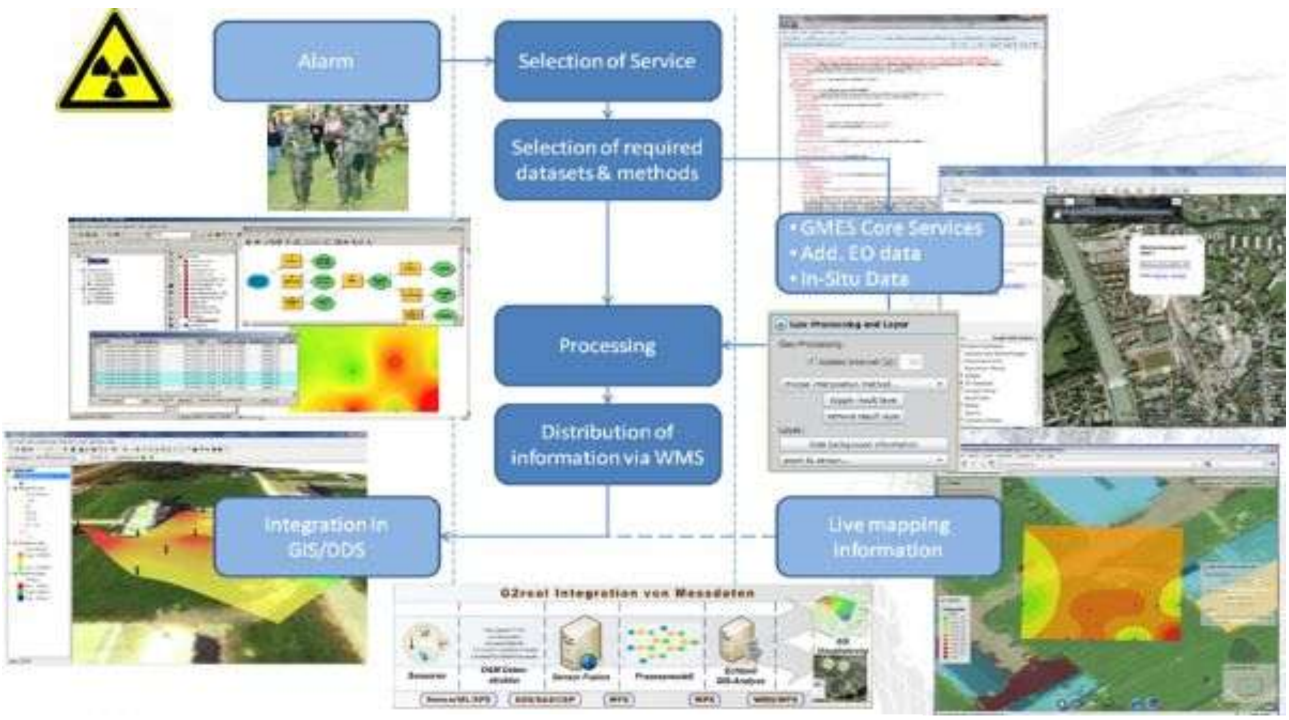

Figure 5: Real-time sensor integration workflow