3D GEO-INFORMATION IN EMERGENCY RESPONCE: A FRAMEWORK

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ABSTRACT

Providing geo-data to an emergency services is increasingly gaining the attention of developers and researchers. A variety of emergency situations have occurred in the last several years such as large fires (in cities, forests), flooding, terrorist attacks, road-side emergency, etc. The need for reliable systems helping rescue operations is urgently appealing. The word here is even not only about specialised systems helping rescue teams but also giving appropriate geo-information to the ordinary people in/around the area with emergency occurrence.

What is the underlying motivation for the concept outlined in this paper?

First of all, mobile devices such as portable digital assistants (PDAs) and mobile phones have become tools that one uses on a daily basis. Almost everyone possesses a sort of handheld device (cell phone, PDA, PocketPC, etc.) Currently, we observe a convergence: cell phones incorporate more and more functionality, which was once the domain of PDAs and ultra-portable computers, while later ones can be updated with communication abilities or have them out of the box. Even multimedia and 3D data are nowadays available on mobile devices or will be in the near future.

Second, GIS are in growing expansion and changing nature. The third dimension is getting more and more familiar. Many GIS already provide extended 3D visualisation although spatial analysis is still in the 2D domain. The traditional stand-alone, desktop GIS evolve to a complex system architecture in which DBMS play the critical role of a container of administrative, geometric and multimedia data. Integration, interoperability and ontology are some of the ‘hot’ issues of research and development.

What is the readiness of GIS systems for responses to the emergency situations? A number of systems providing two-dimensional (2D) geo-services (e.g. VisiCAD, ArcPad, InteliWhere), are already available on the market. However, functionality offered by such systems is often not sufficient for efficient management in time-critical applications such as emergency response applications.

This paper promotes geo-information and especially 3D geo-data in a support system for field workers and decision makers in case of emergency. Firstly, the paper provides an overview on the phases and basic characteristics of an emergency management and outlines the requirement to the supporting system with respect to different users (mobile, web/desktop, working in virtual environments). Secondly, the paper concentrates on the specific for geo-data requirements. Final discussion on required research concludes the paper.

KEY WORDS: Data structures, Data discovery and integration, 3D Visualisation, Positioning

1. REQUIREMENTS FOR TECHNICAL SUPPORT IN EMERGENCY RESPONSE

To find requirements for a useful support System for decision-makers in emergency management, it is necessary to know how to describe and characterise emergency management itself. The Federal Emergency Management Agency, USA divides emergency management into four phases namely: *Mitigation*, *Preparedness*, *Response* and *Recovery*. These phases are currently widely accepted by all kind of agencies all over the world. The fist phase is related to activities leading to a reduction of occurring emergency situations (e.g. construction specifications for building to resist at earthquakes, dykes to prevent flooding, etc.). Preparedness focuses the active preparation for occurring an emergency. The rescue forces (e.g. police, ambulance, fire brigade) are trained how to operate and cooperate in emergency situations. Response is an acute phase after occurring an emergency. Recovery is a phase after the acute emergency including all arrangements to remove arose detriments and long-term supply of irreversible detriments.

In any of these phases geo-information support can be very useful. As most of the important data and information necessary for a support system are spatially related, a GIS component in such a support system becomes of special relevance. Nowadays, there are many solutions for special scenarios in single phases of emergency management. Especially systems to support decision makers in the phases Mitigation, Preparedness and Recovery are in use. Examples for this are GIS based flood simulations and use of calculated results in further planning. Results of such simulations can be used to predict the risk and the potentially quantum of damages (Mitigation). But they are also necessary to develop useful and realistic scenarios to be used in trainings (Preparedness). In Recovery, there is often a high public and political interest to see a situation before and after an emergency and to set priorities for the rebuilding.

The number of systems for technical support in Response is quite limited. Here, emergency management is usual done with maps that are seldom digital. Useful systems to support decision makers in any of the phases are missing nearly complete. To improve to use of digital support of decision makers in this phase, two premises have to be archived:

- As you seldom know the point in time when a case of emergency occurs, the tools to support decision makers have to be integrated into overall architecture. This overall architecture covers all phases of emergency management so the tools are available whenever necessary. Additionally the architecture covers different cases of emergency. As it is also used before a case of emergency occurs, all data form there can be accessed and completed.

- To give the data to the user, the user himself and his technical environment have to be considered. To respect the technical environment of the user, we have to contemplate the local value of mobile devices nowadays and in the future. Since they are essential tools in everyday life, it will be necessary to integrate them in a useful support system for decision makers. To respect the user, means to estimate the stress of the user have to be provided. Among all an intuitive visualisation is critical. Including 3D visualisation is a good way to make visualisations more intuitive in stress situations.

A system assisting in disaster avoidance and disaster relief situations should be able to provide information to planners and rescue workers and has to fulfil the following generic requirements:

- Intuitive, taking into account work in high stress environments. The field workers usually will not have the time to investigate complex graphics user interfaces, maps overloaded with information or unclear symbolisation.
- Covering areas non-known to user and providing appropriate guidance. The rescue forces are trained in special environments or particular training areas. In general, they are not familiar with the specific environment of the disaster occurrence. Very often they have to access areas (e.g. factories, back yards of public institutions, storage places) that are unknown to them. Furthermore, the usual environment might look completely changed due to smoke or damages caused by flooding or earthquake. In such cases, the need of appropriate guidance is especially appealing.
- Able to trace the most appropriate information and provide to different teams and to the public. Much of geo-information is stored in different information systems (GIS, CAD, geo-DBMS) and all this information should be investigated and, if appropriate, delivered to the rescue teams. For example, data about the construction of the buildings can be available with a construction company (responsible for the erection of the building), data about utilities (electricity, gas, water) are hosted with corresponding institutions maintaining the utilities, property data are usually maintained by the cadastral offices. Depending on the type of risk situation, different information might be needed. The system has to be able to decide which type of information is needed and where to find it (e.g. data discovery).
- Easy to combine various data for a variety of clients. As it is described in the next section, several different of groups (having different equipment) might be involved in the response phase. Different equipment should not create delivery problems. The data has to be scalable and adaptable for the type of the equipment.
- Integrated automated quality control of data. Very important aspect of management in the response phase is the input of field data. Updated information about the development of the disaster will greatly improve the decision-making process. However, the quality of supplied field data has to be strictly controlled. Apparently, new data will be expected and delivered by all the groups in the affected areas. All these inputs have to be estimated, and evaluated (prior combining with other data) to be used as supplementary and not contradictory sources.
- Real-time, fast at all levels. A very important aspect of systems for emergency support, is the speed of communication (request sending and response delivery). The clients especially on the field hardly have sufficient waiting time Investigations amongst Internet users (in on-stress situation) show that acceptable waiting time (for displaying of a web page) is less than 15 sec. In case of emergency, the information has to be supplied within 5 seconds and even less.

2. OVERALL ARCHITECTURE

Figure 1 shows our view about the overall architecture for efficient emergency management. The components of a particular interest for us can be separated into four general levels: end-users, networks, middleware and database.

End-users: To address all decision-makers in emergency management with the system, different groups of Clients are provided: high-level decision-makers, mobile clients, desktop clients and web clients. The high-level decision-makers are usually responsible for technical management and have to coordinate all the arrangements necessary to fight the situation. These clients will be provided with elaborated VR environments (e.g. auditoriums), in which they will be able to observe last developments in 3D large screens, discuss possibilities and give orders to the rescue teams. Desktop clients are any other specialists located in a variety of organisations that are asked by the headquarters to provide specialised data and expertise. They are sitting behind their desktop systems. Mobile clients are both rescue teams, lower level decision-makers that have to give information to people that are on the way into the area of emergency (e.g. external specialists); and people with handheld devices (that can receive directions on their own). Fourth client is the Web client, i.e. this is the general public and media that seeks for information regarding the disaster. They are also using desktop systems. These four group of client are represented at the top of Figure 1 as subdivision is made with respect to the used technology (mobile, VR and Web/Desktop). Variations in needed technology are apparent. While mobile users have small devices with limited characteristics (screen, power, memory, hardware acceleration), wireless connection and need to be located in space, Web/Desktop users have power computers, wired connection and their location is not of interest. In contrast to these two, VR environments require several computers for parallel processing to be able to render several images at once (e.g. in case of a 6-wall CAVE, six parallel computers are required)

Middleware: Within the system middleware level have to be organised for communication with the front-end and the database. Conceptually, we distinguish between communication middleware and database middleware. Depending on front-end technology used, the risk management phase considered, scenarios and organisation involved, the system has to be able to recognise the ‘user profile’ and forward it to the database middleware for search of information. The Communication middleware has to be able to recognise the type of front-end and the current status (e.g. capacity of the battery and memory available), the bandwidth of the communication channel (wired or wireless) and the position of the mobile users. For each particular request for connection to the database, the midlleware has to be able to create a user profile on 'the fly' and maintain it only within the time of disaster management. The profile will be used to introduce intelligence in the system. For example, if the request is coming from a mobile phone allowing only text display, the system should be able to recognise the situation and generate only text answers.

We recognise two types of profiles to be supported by communication middleware, i.e. wireless and wired. The wireless profile has to contain information about:

- Position of the mobile client and the direction of movement (tracking)
- Type of mobile device, including screen resolution, memory capacity, OS, rendering engine (if 3D rendering available), etc.
- Status of the mobile device (battery charge, available memory)
- Network for data transmission (GSM, GPRS, WLAN, Bluetooth, others) and the corresponding bandwidth
- Requested data with an indication about emergency of the case
- Data input of field data into the system. The profile has to initiate a separate connection to the data middleware that will decide on data update.

The wired profile is relatively simple compare to the wireless since position and mobile parameters are not required. The wired profile has to maintain data about:

- The front-end, i.e. desktop or VR. As it was mentioned above, VR environments may require two or more parallel processes to be run at once.
- The cable bandwidth (that may vary within different networks)
- Requested data
- Data to introduced in the system for use by the rest of the users.

The data middleware has three important responsibilities:

- Routing the front-end data to the database(s). In this respect, an important issue to be resolved is the discovery of the most appropriate data sources. As one do not know what data will be necessary, external data source has to be accessible via the Internet.
- Establishing semantic (geo-) data translators based on ontologies to be able to compare and evaluate data. Furthermore, the data may be stored in different software packages such as GIS, CAD, DBMS. The system still have to be able to cope with the different structures and representations.
- Adapting fetched data to the type of the front-end

Database: Major responsibility of database is to manage the own data and include data from or connect to other data sources. To efficiently structure all this data, a geo-DBMS has to be considered as a basic component of the system. The geo-DBMS integrates all data into an integrated spatial model. This allows a spatial evaluation of the data that is necessary for the analyses during use. It is impossible to have all data necessary or useful for managing emergency within one system all the time. Usually, one does not know the point in time when a case of emergency comes up or what data will be useful or even necessary during the next case of emergency. Therefore the system should provide different ways of accessing or integrating data to the system. All incoming data has to structured with respect to well-known models (based on ISO/TC211, W3D, etc) to be analysable by all parts of the system.

This overall architecture allows a support of decision-makers in all phases of emergency management and even in different cases of emergency. To make it really useful, it has to sure the system fits the high efforts of emergency management – especially running in real time. To demonstrate how the system will operate in the Response phase, we will use three different scenarios: flooding, terrorist attack and fire is urban areas.

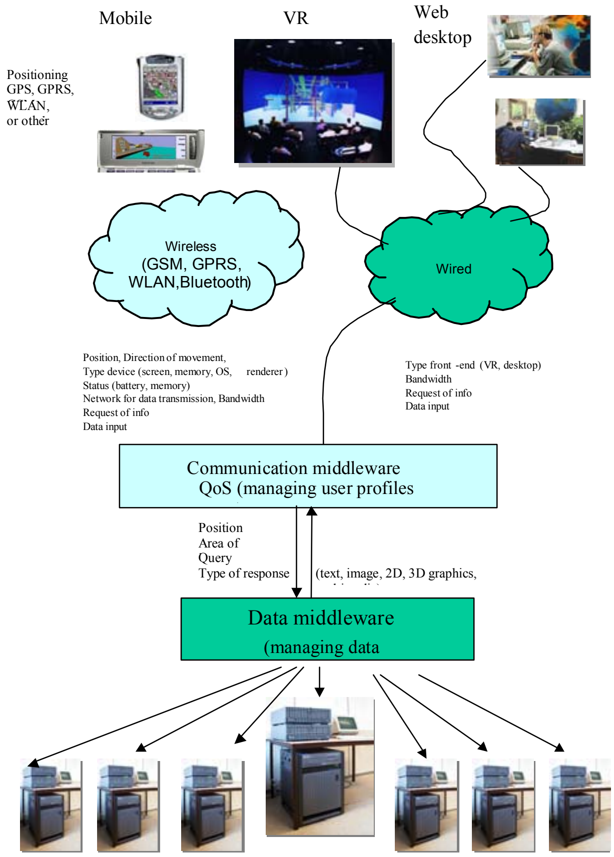

Figure 1: Overall architecture of the proposed system

3. SCENARIOS:

The system for support of risk management has to be able to respond to a variety of situations. This section describes three different scenarios hat can be managed by the proposed system.

Flooding. A flood arrives X-town. As the administration has been informed as early as possible the arrangements to fight the flood are already in process. Parts of the city have been evacuated. To inform the citizens a special Web site is in use. Here the users can choose between a numerical visualisation of the floods high and a visualisation basing on a 3D city model. Since this is much more intuitive to the citizens, calls to the call-centre are significantly reduced. The city council and part of the decision-makers are sitting in an Auditorium observing on a 3D display affected parts of the town with the simulation of the flood. The simulations are synchronised with the data updates coming from the field. The decision makers in the main office discuss actions to be taken.

Some of the decision-makers and mobile forces are on the field to do measurements. All these are equipped with mobile devices sending data. Since mobile action forces can always access the most actual data and insert data themselves, the system always represents the most actual data to most of users. These data are of great help at any decision level. Using special mobile Graphics User Interface (GUI) for data input, many errors are avoided. Mobile GUI will consist of a positioning part to allow fast updates and possibilities to alert the mobile workers for existing danger or people needing help. The positioning is possible in any situation, efficiently switching between GPS, GMS, GPRS and WLAN.

Avoid terrorist attacks. An important person visits a city. Terrorist attacks are expected. A special route for his/her transportation has to be provided. The entire trace of the route is 3D analysed for dangerous points (e.g. high buildings near to the street). In addition, an optical control basing on a 3D visualisation is possible. Thus points with special danger are identified and an optimal route (excluding the most dangerous points) can be chosen.

Fire: Fire alert in a large building in a city. While the fire fighters are already on the way to the fire, the leader and decision-maker uses his Mobile IS to get a view of the building and its neighbourhood. There he sees small streets in the surrounding of the fire. So he starts a query to calculate the best position of the ladder-car, so the ladder can be used and the large car can reach. He gets three possible positions for this and decides to choose the second one. Immediately this information is integrated to the system. The driver of the ladder-car gets a navigational support to the position. As it is a stress-situation for anyone, the co-driver decides to have a look to the more intuitive 3D navigational support. The fire fighter driving another car gets a message to move his car to another position not to block the ladder-car. When the ladder-car arrives the fight against the fire can start immediately. Further, some people are still captured by the fire in their offices on the 15th floor. A group of fire fighters is on the second floor. How to get to the their offices? The detailed technical breakdown of the navigation goes as follow:

- Initial positioning of the device, i.e. topological search in database to locate the device
- Negotiate with the device for the optimal output, i.e. evaluating the complexity of the surroundings and negotiating for possible output, e.g. 3D navigation or map of one floor and the stairs.
- Create an optimal route to the offices
- Process and present the route, i.e. re-structuring the data with respect to the negotiations on the previous steps.
- Periodically get device location, i.e. tracking the position with respect to the current data set available, topological query, e.g. ‘point-in-body’
- Compare the planned route with the current position: e.g. 3D overlay ‘point-on-line’.
- Compute work-around if obstacle is discovered or data are exceeded: new shortest way, or new data set.

Could be that the time need to get to the 15 floor is too long. Instructions have to be given from the system directly to the people in danger. The System sends a message to some of the group to access the System (name and password) and begin negotiating with the mobile device (e.g. mobile phone). The safe route has to be adapted to the current status of the telephone cell. The battery is too low to receive long messages, i.e. the system should convert the navigation into short instructions.

4. RESEARCH QUESTIONS

To be able to respond in a way similar to scenarios described above, several groups of research questions related to geo-information have to be addressed, namely positioning, database systems, data discovery and integration and visualisation and navigation. Each of these comprises a large range of problems related to the third dimension. These will be briefly described bellow.

Positioning and communication: Two critical questions can be outlined (also Zlatanova and Verbree 2003): 1) tracking of rescue workers everywhere (outdoor and indoor, providing their 3D coordinates) and 2) ability to exchange data over wireless network. Several additional aspects influence the way of positioning and communication:

- (3D) accuracy. The required positioning accuracy depends on a particular situation and may vary from 500 meters (locating a hospital) up to 5 meters (locating and safe exit in a building with reduced visibility).
- availability of networks. The system has to be aware of the possible networks. The configuration for a given region may change. For example, in case of fire in a building, a mobile WLAN can be configured only for the area of the fire (thus positioning and communication will based on WLAN).
- bandwidth of used network The bandwidth is of major importance for transmission of 3D geo-data (often reaching GBs).
- urgency of situation. Last, the system should be able to detect what king of situation appears and selectively decide on the preferred way of positioning (depending on the availability of networks).

Several positioning possibilities should be under considerations: global positioning systems (GPS, Galileo), Mobile networks (GSM, GPRS), WLAN of hybrids of them. In general, the navigational (design) accuracy of GPS for consumer devices (i.e. single frequency) is 30 metres. The accuracy of GPS even goes bellow 30m, due to natural phenomena (atmospheric affects) or problems with satellite configurations. In dense built-up areas, the GPS positioning even may fail due to lack of satellite visibility. Furthermore, the GPS receivers are not operational within closed spaces (buildings, tunnels). The global positioning systems are the only ones providing true 3D coordinates. However they cannot be isolated from the mobile networks, since a communication channel for user data exchange is lacking. Currently, GPS coordinates have to be sent to the server manually.

Telecommunication networks can trace a mobile phone almost everywhere but the accuracy is very low. In most of the cases mobile phone be can related to a network cell, which correspond to 100-500 m accuracy. The urban areas are again problematic. A mobile phone can be easily connected to a transmitter (e.g. on a high building) that is 2-3 km far way from the current position of the user. A number of hybrid systems, e.g. combination of mobile networks, GPS and additional information (i.e. postal code) are already in use.

The progress in the Wireless Local Networks offers yet another alternative to position a user in close ranges (30-40m). First systems for 3D positioning in a building are already reported, e.g. by *Ekahau Positioning Engine* (www.ekahau.com). This is a solution available for 802.11 and HiperLAN2. The positioning is based on a priory accomplished calibration map created by collecting sample points of the area. Each sample point contains received signal intensity and related map coordinates (for the current floor). The accuracy achieved by such positioning is up to 1m.

Apart from these technologies, alternative approaches for tracking have to be investigated. Examples may come from augmented reality systems, which also need accurate tracking of the user. Very appropriate for outdoor tracking are some of the vision systems reported in the literature (Behringer 1999, Davison 1999, Harris 1992, Zillih et al 2000)

Having many possibilities for positioning and communication, a challenging research and technology issue is switch between them to be able to provide accurate positioning at any time.

Database systems: In the last few years, management of geo-information and spatial relationships progressed to a stage at which they are maintained directly in the database, without a need for any specialised applications (having different file formats and requiring a variety of viewer). Such a solution provides integrated dynamic topology and spatial analysis to any wireless handheld device or desktop system. Although current DBMS made a large step toward maintenance of spatial data, many 3D issues remain to be addressed. The support of 2D objects with 3D coordinates is already almost a standard (Oosterom et al 2002, Zlatanova et al 2002). The offered functions and operations are, however, still only in the 2D domain (Stoter and Zlatanova 2003). Concepts for 3D objects and prototype implementations are already reported (Arens et al 2003). Furthermore, no a 3D topological structure is currently available in any of the commercial software (Oosterom et al 2002) but a lot of research is done (Coors and Flick, 1998, Zlatanova and Heuvel, 2002). This means that currently, no system can compute the shortest or safest route to the ground level of a building. Appropriate data structures, indexes and generic spatial functions have to be investigated and developed. The base system has to be ready to switch between 2D and 3D analysis, if this is requested by the application.

Data discovery and integration: A lot of geo-information exists in different information systems (CAD, GIS, Geo-DBMS). How to find the most appropriate data for the particular situation? Most of the problems are pure semantic one. A representation of a building may exist in one system as a complex CAD model and in another only as a simple box but with a lot of information about utilities. How to match these two data sets to get information about, e.g. gas pipe lines that may explode. The two databases, created for different purposes, may have used completely different terms and descriptions. Semantic translators, metadata, ontology, data integrity are only few of the research questions that have to be addresses. Moreover, offline data mining process can highly contribute to the efficiency of the system. Whether some data have been already requested and have been useful (i.e. highly ranked) will give indications which data sets first have to be traversed. Creating history (data mining) of most used data will speed up the search.

Visualization and interaction: Appropriate visualisation of information is the most critical aspect for the success of the rescue mission. The way to represent the information (text, graphics, image) has been always a topic of investigation (Verbree et al 1999, Pasman et al 1999). How to represent information to a user under stress is one of the major questions in disaster management. Some initial experiments already give indications that the user reacts better on graphics navigation compare to text navigation (Kray et al 2003). Furthermore, the user orients better in 3D view compare to 2D (Rakkolainen and Vainio 2001, Holweg and Jasnoch, 2003).

One of the most critical aspects in the proposed system is the provision of 3D graphics on mobile devices. The 3D capabilities of mobile devices are largely restricted in several aspects: dedicated 3D hardware chip, floating point units (floating point calculations are done by the software), hardware division circuits (for integer division), memory bandwidth (3D rendering needs large amounts of texture to be read from the memory) and CPU speed (Jacobs, 2003). Besides, visibility scene management algorithms have to be adapted for the low-resolution screens of mobile devices. Breakthrough in 3D rendering on mobile devices are observed in several directions: faster chips, many operation systems, APIs for 3D graphics, standards for 3D visualisation on mobile. However, many perception aspects still need to investigated.

For the preparation of 3D visualisation, similar principles as for the design of conventional maps are valid. The 3D visualization has a model character, i.e. the shown objects shall be represented in a geometrically correct way and at the right position. Furthermore, the visualisation used as communication instrument demands an adequate degree of readability. Several principles are valid:

- Geometrically exact design. 3D visualisation has to be very close to the real view. In contrast to maps, where a lot of symbology used, 3D view should convey by realism and not by abstraction.
- Keep the important, leave out the unimportant. To emphasise on important information in the 3D view, new approaches to attract attention have to be used. For example, usage of a textured building amongst shaded ones.
- Emphasise the characteristic, exclude the fortuitous. 3D models may be represented with plenty of details but in most of the cases this may lead to overloading with information. In this respect it is very important to keep the balance between important and fortuitous.
- Objects must have a minimum size to be visually perceptible. Very small objects are not well recognised by users
- The graphic refinement must come up to the needs. It is practically impossible to represent all the details but too few details may create unrealistic views.
- The graphic density must not be too high. High graphics density does disturb the users and understanding of the message.

These principles are partly contradictory. For instance, a geometrically exact representation of all geographic objects of a city model automatically leads to a high graphic density. This makes the graphic differentiation of single objects nearly impossible. This problem applied to 3D models is solved by using a graphic abstraction, but unlike the cartographic generalisation, an interactive 3D visualisation allows a directed refinement of the model. It has to be taken into account that a model refinement respectively a scale modification is possibly to be done via network. This requires adequate techniques to avoid long waiting times. On the other hand, the destination of the user can be identified, because the visualisation always follows a concrete request, e.g. a routing. This explicit user intention should be considered in the graphic abstraction.

Data update: A very important aspect of risk management is provision of update information about the development of the emergency situation. It can be critical for taking appropriate decisions and guiding the rescue teams, people trapped in the area and mobile workers collecting information. It is also important to update the appropriate data sets. The data before the disaster occurrence should remain untouched to be able to make estimations of the damages in the Recovery phase. A solution would be to have a temporal 3D model of the current situations that would be available to all the users of the System and accessible for updates. The update of the temporal model should be very strictly controlled. Different priorities of access have to be created for the different users.

5. CONCLUSION

In this paper we have presented our concept for a System to be used in emergency management. We consider the role of 3D GIS critical for providing advanced 3D visualisation, analysis and interaction to all the users involved in the disaster/risk occurrence. Practically the research question to be addressed are core 3D GIS questions (3D data structures, DBMS support of 3D topology, indexing, metadata, consistent update) complicated with additional requirements for short time response and appropriate graphics user interface for work in stress situations and data. Another important aspect of using geo-data for disaster management is utilisation and integration of data, based on ontology and geo-semantics. A breakthrough in 3D geo-display on mobile devices is of particular importance. Positioning of mobile users needs further research to become flexible to be able to support users in any environments (indoor and outdoor).

It should be noticed that we have discussed only issues related to utilisation of information and not hardware issues (graphics accelerators, possibilities to increased memory, bandwidth, reduce power consumption, range of devices, networks and communication protocols). We believe that parallel to the technology developments, a serious progress has to be made in structuring, analysis and visualisation of information and more specifically geo-information.

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