# THE CONTRIBUTION OF CONTEMPORARY SENSORS TO THE MANAGEMENT OF NATURAL AND MANMADE DISASTERS - THE PRESENT AND THE FUTURE

I. D. Doukas [a], G. Retscher [b,] *

[a] Laboratory of Geodesy and Geomatics, Department of Civil Engineering, Aristotle University of Thessaloniki,
GR-541 24, Univ. Box #465, Greece - jdoukas@civil.auth.gr
[b] Institute of Geodesy and Geophysics, Vienna University of Technology, Gusshausstrasse 27-29, 1040 Vienna,
Austria. - gretsch@pop.tuwien.ac.at

**KEY WORDS:** Natural Disasters, Manmade Disasters, Disaster Management, Sensors, Geosensors, Smartphone Localization, Pervasive (Ubiquitous) Computing, Ambient (Spatial) Intelligence, Wireless Sensor Networks (WSN), Geosensor Networks (GSN)

## ABSTRACT:

There is a pretty large variety of all kinds of disasters (either natural or manmade). This established fact, in relation with the axiom that “disasters will always happen”, arguably is producing a numerous and extremely complex set of problems (social, environmental, economic and technical). The plethora of possibilities concerning applications of wireless sensor networks (WSN) and/or geosensor networks (GSN), which are a revolution in the physical world observation, forms a disruptive technology very beneficial for many (and different) fields and applications. In general, disaster monitoring, management and environmental observation are indisputably a wide and fertile field with enormous potential related with the advantages of network features such as e.g. densely deployment, dense sensing of the environment, large spatial coverage, robustness, no human intervention etc. The management of disasters demands competent decision support which, in its turn, asks for up-to-date information. WSN or GSN are by some means dedicated instruments which are capable to sample space-time processes and generate lots of real-time data that perfectly satisfies this urgent demand of up-to-date information (even support the frequent update of information for reacting promptly against crisis). For any kind of disaster, there is a five-phases life-cycle (i.e., response, recovery, mitigation, prevention, preparedness) known as Emergency Management and Disaster (Crisis) Risk Management Cycle (DRMC). In this paper, the diffusion of WNS and GSN into the management of disasters (natural and manmade) is briefly reviewed, since such networks are capable to offer their services to every phase of DRMC. Some thoughts concerning the future and “visions” are given by taking also into account their potential through their blending with other technologies/methods/techniques which belong to GIS, structural health monitoring, smartphone localization, pervasive (ubiquitous) computing, and ambient (spatial) intelligence.

## 1. INTRODUCTION

Nowadays, there are some bold attributes concerning the human society and its “home”, planet Earth. These attributes could be categorized as: *Change* (e.g. climate, resources, energy, communication etc.) and *Increment* (population, mobility, communication, information, consumption, disaster frequency etc.). Speaking especially about natural disasters, they do show an exponential increase (UNEP, 2011). Such a strong alarming increase easily can be detected also in the field of manmade disasters (from now on, the term “disaster” means any kind of, either natural or manmade, disaster). This fact could have causes, such as: the population growth and movements, the infrastructure development, the improvement in access to information, the climate change and so on. Generally, the quest for sustainable development is getting stronger, deeper and wider. A greater number of people tries hard to realize the “system” called Earth. Serious and “noble” targets have already been set, such as: the awareness, realization, understanding of the interactions between mankind (without excluding other living beings) and environment, enhancements in the field of disaster management (especially **D**isaster **M**anagement **S**ystems (**DMS**), which mostly mean Web-based systems), the Earth's protection and sustaining (issues like: monitoring, predicting, protecting of resources etc.), the humans adaptation to a dynamic environment etc. These targets try to find their combined expression in “an integrated Earth observation (monitoring) system” (Montgomery and Mundt, 2010). A lot of people in the world (organizations, institutes, academics etc.) are engrossed in this “dream-project”. The case is about a dynamic system, which should be stable and capable to serve in time depth, modular, expandable and always adaptable to new needs and the technological evolution. It is clearly understood that this system should: gather measurements from many different sources (instruments, devices), manage - assess data, offer easy interface, communicate with a large number of different users, advance research (also training, interaction, collaboration) and offer valuable decision support.

In Europe, they already talk about **SISE** (**S**ingle **I**nformation **S**pace in **E**urope) for the Environment. Even better, since the Earth’s global system comprises many complex sub-systems, the resultant - even greater - complexity demands multidisciplinary and holistic views, integration of knowledge and information (Schouppe, 2008). The global vision goes to a higher level, which is **GEOSS** (**G**lobal **E**arth **O**bservation **S**ystem of **S**ystems) which has the following main targets: ‘to achieve comprehensive, coordinated and sustained observations of the Earth system in order to improve monitoring of the changing state of the planet, to increase understanding of complex Earth processes, and enhance the prediction of the impacts of environmental change. Finally, to enable all nations

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* Corresponding author.

to benefit from easy access to timely, quantitative, and high-quality long-term global data and information as a basis for sound decision-making' (GEO, 2007; Cragila et al., 2008). GEOSS deals with nine *Societal Benefit Areas*: Disasters, Health, Energy, Climate, Water, Weather, Ecosystems, Agriculture, Biodiversity. These areas do show the magnitude of the whole enterprise.

Disasters do carry the aforementioned attributes (*Change*, *Increment*) and play a key environmental role since they are having most significant effects on Earth. Several definitions of the terms disaster, hazard, risk, emergency, crisis, exist with a certain degree of synonymity among them. The United Nations defined a «Disaster» as:

> *'A serious disruption of the functioning of a community or a society causing widespread human, material, economic and environmental losses which exceed the ability of the affected community/society to cope using its own resources'.*

«Disaster» is a term which has its direct roots to the ancient Greek word «δυσαστρία», originally meant an unlucky constellation (or combination of temporal positions) of stars (Doukas and Retscher, 2011). A «Hazard» is 'a situation which poses a level of threat to life, health, property or environment'. When humans act, any of their action exposes them to hazards. A hazard does not necessarily put humans at risk. Most hazards are dormant or potential, with only a theoretical "risk" of harm. Where «Risk» is 'the probability and severity of loss linked to hazards'. However, once a hazard becomes 'active', it can create an emergency situation. «Emergency» means 'a sudden and unexpected occurrence which requires urgent attention', in other words 'a situation that poses an immediate risk to health, life, property or environment'. Finally, «Crisis» is 'a highly volatile dangerous situation requiring immediate remedial action'. In today's simplified words, a Disaster is 'the impact of natural or manmade (or a combination of both) hazards that negatively affects society or environment'. «Emergency Management» is 'the discipline dealing with risk and risk avoidance' (FEMA, 2011).

The axiom is that "Disasters will always happen". Therefore there will always be targets like: sustainable growth, development, minimization of losses and damages (human, economic, environmental). Generally, this means well-informed policies and effective decision making. For the accomplishment of these, environmental observations (even better, global Earth observations) are required (accurate, continuous, coordinated, comprehensive and sustained).

A strong contribution to the huge set of the global Earth observations is already made by "unusual" instruments and devices. Apart from human society and planet Earth, the attributes *Change* and *Increment* (mentioned above), expand their influence also on the 'Data-Domain' (Data acquisition and Data processing-delivery). Speaking about 'Data acquisition', there is a really massive production of data (unstructured data), since there are digital sensors … everywhere (satellites, mobile mapping, LiDAR, SAR, InSAR, medium-format and large-format camera systems, image sequences for monitoring purposes, sensors-geosensors, ubiquitous wireless communication, short-range radio-based communication, airborne- Unmanned Aerial Vehicles (UAV),...). Additionally, the cloud-computing is present (a representative product of the evolution in the ICT field), topics like automation, speed, storage, integration of acquisition and processing are just some of the fields they show rapid changes to the better.

The Data-Domain (with the so many different sources and types of observations) is a determinant factor for management of disasters. One of these sources, the sensors/geosensors and their contribution to disaster management, is the target for the investigation that has been carried out in this paper.

## 2. SENSORS, GEOSENSORS AND THEIR NETWORKS - USEFUL TERMS

### 2.1 Sensor Technologies and their Networks

The terminology below can be found in many (slight or not) variations according to different scientific views, books, Internet and other (analogue or digital) sources. In any case, here the selected terminology is fully consistent with the attached to this paper bibliography. Additionally, this bibliography is rich enough to allow the reader for deeper explorations of the extremely wide scientific field of Sensor Technologies. More specifically:

One of the most significant technologies in the 21st century are **W**ireless **S**ensor **T**echnologies (**WST**) which refer to **W**ireless **S**ensor **N**etworks (**WSNs**) and **R**adio **F**requency **Id**entification (**RFID**) based sensor devices (Garcia et al., 2009; Retscher and Fu, 2008; Zhu et al., 2009):

**(a).** **W**ireless **S**ensor **N**etworks (**WSN**). There are three types of WSN (Aboelaze and Aloul, 2005; Reis, 2005; Yick et al. 2008; Garcia et al., 2009):

*(a1). «Cellular networks»:* A typical sample of them is given by cellular phones.

*(a2). «Ad-hoc networks»:* As a rule, they are established on a small geographical area in emergency situation(s). They are deployed without an existing infrastructure.

*(a3). «Sensor networks»:* A device that measures a physical quantity and then it converts it in a readable (by an instrument or an observer) signal, is a *«sensor»*. A sensor is a device which receives and responds to a signal. A sensor network is a system comprising "*nodes*" (see below), radio frequency (RF) transceivers, sensors, microcontrollers and power sources. A WSN (see Figure 1) consists of spatially distributed autonomous nodes that can measure characteristics of their local environment (monitoring, tracking, surveillance), perform computations, and communicate with each other over a wireless network. WSN are just small sensors combined with miniature computers. The combination of computing, communication and monitoring is the cause they are also called **W**ireless **S**mart **S**ensor **N**etworks (**WSSN**) (Quintero et al., 2009). There are great differences concerning the hardware platforms of sensors, a fact that makes impossible the creation of a common-to-all operating system. The key for the solution of this problem is *«middleware»* (in simple words, software between the operating system and application running on each node of the system) (Yoneki and Bacon, 2005). Middleware facilitates scalability, interoperability, deployment, and development of applications (Molla and Ahamed, S., 2006). There are five (5) types of WSN (Srivastava, 2010; Yick et al., 2008): *Mobile, Multi-media (WMSN), Terrestrial, Underground, Underwater*. In particular, 'WMSN are networks of wireless embedded devices that allow retrieving video and audio streams, still images, and scalar sensor data from the physical environment' (Akyildiz et al., 2008).

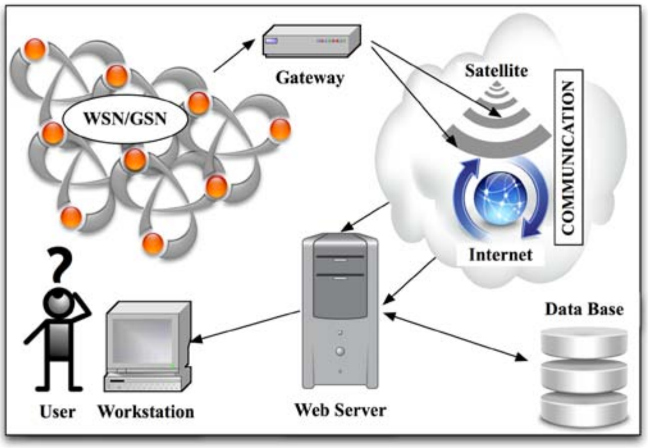

Figure 1. The concept of WSN/GSN

**(b).** **R**adio **F**requency **I**dentification (**RFID**) based sensor devices, a technology that uses wireless communication. These systems comprise three main components: the tag (transponder), the reader (transceiver) that reads/writes data to a transponder, and the computer containing database and information management software. RFID tags can be active, passive or semi-passive. The typical reading range of passive tags is between 10 cm and 3 m (Garcia et al., 2009).

The basic target of RFID was identification but a new range of wireless sensor devices based on RFID is appearing, as a result of the growing interest. The main difference between WSN and RFID is that RFID devices have no cooperative capabilities, while WSN permit different network topologies and multi-hop communication (“hop” - a computer networking term; in simple words, the link between two network nodes).

«*Sensor Web*» is ’a system of autonomous, wireless, intra-communicating, spatially-distributed sensor pods that can be deployed to monitor and explore new environments‘ (Delin, 2002). This means “a smart macro instrument for coordinated sensing”. The sensor web concept is also being explored in terms of cooperating, interoperable satellite platforms and sensors, sometimes called “*satellite webs*” (Teillet, 2010). In a generalized aspect, Sensor Web is a type of sensor network(s) especially well suited for environmental monitoring. From a contemporary point of view, it could be also a ‘sensing system’ with its operation strongly based on the World Wide Web (where a web application works as a gateway between the WSN and Internet). Using standard protocols and **API**s (**A**pplication **P**rogram **I**nterfaces), such a system is formed by web-accessible sensor network(s) and archived sensor data, both discoverable and accessible. Some researcher call it “*Sensor Grid*”, others “*electronic skin of the Earth*” (Botts et al., 2006; Craglia et al., 2008; Karim et al., 2009). So, while WSN comprises sensors that are collecting data, Sensor Webs gather and share data, even modify their behavior (on the basis of gathered data) (Teillet, 2010).

«*Sensor node* (a.k.a. *mote*)» is a node in a WSN that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. Motes enable environment sensing together with data processing. A mote is a node but a node cannot always be a mote. Its main components are: a microcontroller, transceiver, external memory, power source and one or more sensors (Karl and Willig, 2003). A node has four attributes: sensing, processing, communication and actuation (Arampatzis et al., 2005). Nowadays, it is attainable to obtain sizes like 1 mm$^3$ for the nodes and 0.001 mm for the sensors, respectively. Thanks to the advances in nanotechnology, biomedical engineering and physical chemistry, in the (near) future, such amazingly small dimensions will be considered … as huge, when there will be compared with the expected 1x10$^{-6}$ mm sizes!. An excellent metaphor is given by Nittel (2009): ….if a remote sensing instrument is a ‘telescope’ and a traditional sensor platform is an ‘eye’, then a GSN is an ‘environmental microscope’. Such a microscope delivers observations with a spatio-temporal resolution never met before….

A typical classification of sensor types could be (Exner et al., 2011):

- Sensors for state variables and material properties (temperature, density, viscosity, content of dust, humidity, smoke / fire gases, pH- value);
- Sensors for geometrical and mechanical parameters (length, position, angle, speed, acceleration, pressure, vibration, acoustic-ultrasound, recognition of 3D shapes);
- Electromagnetic and optical sensors (magnetic field, current, ionizing radiation, visible light, infrared, image capture using CCD sensors, color sensors, OCR or barcode, possibilities for image processing).

In the WSN, the nodes are **MEMS** (**M**icro-**E**lectro-**M**echanical-**S**ystems) and/or **MOEMS** (**M**icro-**O**pto-**E**lectro-**M**echanical-**S**ystems).

**«MEMS»** are tiny, untethered, battery-powered, low cost devices, with limited on-board processing capabilities, storage and short-range wireless communication links (based on radio technology). Furthermore, they have sensing capabilities which arise from micro-sensors and sensor materials (Xu, 2002; Garcia et al., 2009; Nittel, 2009). MOEMS are just MEMS merged with Micro-optics which involve sensing or manipulating optical signals on a very small size scale using integrated mechanical, optical, and electrical systems (from now on, the term MEMS includes also MOEMS). The chips of MEMS are capable not only to sense the real word but even to react. By integrating the sensors and actuators, the measurement of physical parameters and actuating are now feasible (Arampatzis et al., 2005). Although MEMS have “military roots”, their lower cost and downsizing is favouring a lot of civilian applications (Khemapech et al., 2005). MEMS offer inherently device miniaturization and a wide spectrum of applications in sensors and actuators, robotics, accelerometers, micro-valves, flow controllers, global positioning systems (GPS); also a host of other sensors and actuators for many applications to vehicles (space, air, land, sea) and electronics (industrial, biotechnology, consumer).

Nowadays, on the one hand such tiny devices can be implanted into most of humanmade devices, on the other hand infinite-device networks are easily accomplishable and their automatic operations makes the participation of users unnecessary in order to perform their scheduled tasks. The above mentioned incredible new MEMS-dimensions allow for the so-called “*PicoNodes*” (Duckham and Bennett, 2009) and make the vision of the «*Smart Dust*» system (a hypothetical system of many tiny MEMS, robots, or other devices - introduced, developed, and funded by DARPA - which are usually networked wirelessly and are distributed over some area to perform tasks, usually sensing) to be very close to reality (Warneke et al., 2001).

A «*Geosensor*» is any device receiving and measuring environmental stimuli (e.g. GPS, total stations, digital cameras, laser scanners, satellite-based sensors, air-borne sensors, LiDAR etc.) and can be geographically referenced (Craglia et al., 2008; Villa et al., 2007). The technological evolution (MEMS, etc.) "upgraded" the geosensors and they usually are considered as a sub-set of WSN (see Figure 1, above).

**The** *«**G**eo**s**ensor **n**etworks (**GSN**)»* belong to the super-set of WSN and they are dealing with the geographic space (which can range in scale from the confined environment of a room to the highly complex dynamics of an ecosystem region), as they are intending to detect, monitor and track phenomena and processes into that space (Reis, 2005; Nittel et al., 2008; Nittel, 2009). A GSN needs at least one 'positioning sensor node' (e.g. a GPS receiver) as part of the overall network. Consequently, the rest of the nodes can derive at least their relative geographic position (Winter and Nittel, 2006). The nodes in the network could be static or mobile, or could be attached to mobile objects or used by humans (e.g., wearable sensors/motes, cell phones/smartphones - i.e., advanced mobile phones with multi-roles such: mobile phone, personal digital assistant, portable media player, camera, web browser, GPS navigator, Wi-Fi and mobile broadband access) (Arampatzis et al., 2005). Analysis and event detection in a GSN may be performed in real-time by sensor nodes, or off-line in several distributed base stations (which are in-situ or centralized) (Nittel et al., 2008). When the infrastructure is impossible or too expensive or not needed to be fixed, then the "proper" solution is based on WSN/GSN (Sester, 2009). GSN have many commons with ad-hoc networks, but there are also differences because GSN are: application specific, energy akin, self configurable, data centric. They also offer: environment interaction, dependability and **QoS** (**Q**uality **o**f **S**ervice in network traffic), simplicity and they scale potentially (Karl and Willig, 2003). The more modern networks are bi-directional, enabling also to control the activity of the sensors (Akyildiz et al., 2002; Römer and Mattern, 2004).

A rough categorization of geosensors could be:

a. Satellite-based sensors providing multi-spectral information about the Earth´s surface;
b. Air-borne sensors for detailed imagery but also for laser scans (LiDAR) of physical or manmade structures; and
c. Near, on, or under the Earth´s surface sensors measuring anything from physical characteristics and phenomena to the tracking of living beings, vehicles etc. (see Craglia et al., 2008).

From another relative point of view, such sensors could be: wearable, ambient, remote.

The most important common feature of all types of WSN is the fact that they can be embedded in the real world. Sensors can detect the world's physical nature and actuators can affect the world in some way (e.g. toggling a switch, making a noise, or exerting a force). Under the scope of "normal" computing, such a close relationship with the physical world is a serious contradiction (Elson and Estrin, 2004).

The most important benefits and challenges regarding GSN are (Nittel et al., 2008; Craglia et al., 2008; Sester, 2009):

**GSN Challenges**: Have to be unattended, Heterogeneity (data, quality, coverage, data types), Integration with existing large "classic" sensors (e.g. remote sensing instruments), Needed geographic location, Node programming, Power limitations, Prone to failures.

**GSN Benefits**: High resolution spatial and temporal sensing, Multi-purpose use of data (beyond original acquisition purpose), Pervasive and non-intrusive sensing, Proactive sensing (nodes are proactive and intelligent sensors rather than passive data collectors), Real-time information, Redundancy - fault tolerance (system does not depend on one sensor), Scalability - densely deployed.

The significance and success of GSN, easily justifies the emergence of a newborn "dedicated" science called "geosensorics". From now on, for convenience reasons the generalized term in this paper will be WSN/GSN.

## 2.2 New Paths and Visions

All the evolution of technology (WSN/GSN, MEMS, miniaturized devices, consumer electronics, telecommunications, computing etc.) described briefly above, pushes the world towards most important new paths and visions, beyond the "conservatism" (!) of personal computers. The most important new visions, related with the philosophy and the target of this paper, are as follows:

«*Pervasive computing'* (a.k.a *'ubiquitous computing'*)» stands for the concept that almost any device can be imbedded with chips to connect the device to an infinite network of other devices. Then a combination of synergies concerning network technologies, wireless computing, voice recognition, Web capability and artificial intelligence (AI) can be achieved. The ultimate goal is the creation of an environment with inconspicuous and always available connectivity.

*«**Am**bient **I**ntelligence* (***AmI***)» means sensitivity and responsiveness to the presence of people's "electronic environments" (Zelkha et al. 1998; Aarts et al., 2001; Duckham and Bennett, 2009). An ambient intelligence world is based on collaboration of devices to support people. As a result of the devices' size-decreasing and their broader integration into the environment, the technology disappears into the human's surroundings until only the user interface remains perceivable by users. AmI is highly related to a blend of meanings such as, pervasive computing, ubiquitous computing, profiling practices, context awareness, and human-centric computer interaction. Features like: Embedded computing (i.e., unseen computing devices integrated with everyday objects and environments); ease of interaction (i.e., allowing users a range of natural ways to interact with information without display screens and keyboards); and context-awareness (i.e., automatically sensing the immediate environment, adapting to changes in that environment and to habits of users, and anticipating future user requirements) are the cornerstones of succesfull Aml.

*«**Am**bient **S**patial **I**ntelligence* (***AmSI***)» could be defined as, embedding in built and natural environments the intelligence to respond to spatio-temporal queries and monitor geographical events. The vision of AmSi resulted from a combination of ubiquitous computing and more recently ambient intelligence (AmI) (Duckham and Bennett, 2009). GSN could be highlighted as a key technology for integrating spatial computing capabilities in geographical environments, mainly

because of its ability to provide spatial information capture and processing services to assist in a wide range of applications (from assisted living to traffic management and environmental monitoring to emergency response, respectively). As a result, there is both distributed generation and process of information, which is increasingly integral to the use of that information in diverse human activities. Therefore, coexistence of both the technology (embedded geosensor networks) and the need (generating and processing real-time spatiotemporal information about dynamic environments, integrated with wider spatial information systems and applications) makes GSN a central technology for AmSI.

## 3. APPLICATIONS - GENERAL AND DISASTER-SPECIFIC

The WSN/GSN applications have their true roots in military interests (Xu, 2002; Khemapech et al., 2005). The civil applications came later, with the dramatic cost (and dimension) reduction of MEMS, the spread of technology, computers etc. Two main categorization trends are met, mostly a ‘traditional’ one (related with WSN/GSN use for dedicated purposes) and an object-oriented one (related with WSN/GSN use in groups of applications) (see e.g. Khemapech et al., 2005).

Generally, there could be three main categories, satisfactory enough to illustrate and clarify such almost illimitable space of applications (e.g. Reis, 2005). These three categories are: ***Monitoring/Sensing, Tracking, Retrospective*** (i.e., posterior analysis of stored data).

Obviously, a number of applications belong into more than one category and, most possibly, each one of them can also be sub-categorized into Terrestrial, Underground, Underwater, Mobile and Multimedia, by taking into account the aforementioned five types of WSN/GSN (see paragraph 2.1 above). Trying here to simplify such complexities, below follows a representative sample of some application fields/topics with no classification criteria at all (just in alphabetical order). After all, many of these fields/topics are full WSN/GSN-application categories themselves (selected comprehensive references: Karl and Willig, 2003; Arampatzis et al., 2005; Heidemann et al., 2005; Avdan et al., 2010; Yoneki and Bacon, 2005; Reis, 2005; Villa et al., 2007; Stasch et al., 2008; Eugster and Nebiker, 2008; Ogawa and Sato, 2008; Garcia et al., 2009; Nittel et al., 2008; Yick et al., 2008; Sester, 2009):

- Ambient intelligence, pervasive (ubiquitous) computing, ambient (and spatial) intelligence;
- Agriculture (farm machinery, precision agriculture and precision irrigation, viticulture, greenhouses, etc.);
- Constructions - Structural (buildings, towers, bridges, dams, plants, ports, tunnels, airports…) - SHM (Structural Health Monitoring);
- Context awareness, human-centric applications and computer interaction;
- Crime Prevention-Forensics;
- Domotics (**DOM**us inf**O**rma**TICS**) Information technology in the home (comfort, convenience, security etc.);
- Environment (Indoor/Outdoor) - Ecology - Disasters, Risk management, Decision support (some (!) cases: air streams, climate, earthquakes, fires, floods, glacier movement, guiding of trapped residents alerts/warnings, hazardous environment exploration, heating control, landslides, marine ground floor erosion, oil/gas escaping, pest control, pollution, smoke detection, status of frames (windows, doors), ventilation and air condition control, weather forecasting etc.);
- Equipment, machinery, robotics, maintenance;
- Fishery;
- Geodesy, Geomatics, Geoinformatics (integration with GIS, GNSS, sensor web, etc.);
- Habitat, wild life;
- Health - Human body - Biomedical - Wellness;
- Highly dynamic platforms (satellites, UAV, etc.);
- Improvement of competitiveness and Quality-of-Life (QoL);
- Industrial (power, inventory location, factory and process automation, etc.);
- Landscape management;
- Logistics;
- Military (border monitoring, intelligence, surveillance, battlefield, target tracking and classification etc.);
- Robotics;
- Sea-Ocean, coast, undersea surveillance/exploration, leak detection;
- Security (intruders detection, site, expensive materials, safety management etc.);
- Smart Spaces (home, office, classroom, museum, building, highway etc.);
- Soil, water, mineral;
- Surface exploration;
- Traffic;
- Transportation.

Evidently a “panspermia” of applications, which are asking for new standards, communication protocols, algorithms, designs, and services (Yick et al., 2008).

In Figure 2, the WSN/GSN application space is illustrated roughly, in relation with the scale/magnitude of the under research area and the density of the network nodes, respectively (Yoneki et al., 2005). It is easily detectable from the above list and Figure 2 that disasters (as a most significant part of the “environment monitoring”-area) have a most serious role to play in the research about applications of WSN/GSN. The terms: Disasters, Risk management and Decision support form a compelling “triptyque” for the WSN/GSN community. In a more “philosophical” approach, most of the above listed fields/topics of WSN/GSN applications are carrying, incorporated in their “genes”, a potential disaster which has just their name…., so the possibilities of new and dedicated WSN/GSN-disaster applications are unlimited……

There are five phases in every disaster´s life-cycle (i.e., response, recovery, mitigation, prevention, preparedness). This cycle, known also as **D**isaster (Crisis) **R**isk **M**anagement **C**ycle (**DRMC**), is a “clockwise perpetual” cycle and could be found (in other publications or in the Web) with some minor modifications, additions or consolidations regarding its phase-components. FEMA (2011) for example, considers the same cycle with four phases (i.e., mitigation, preparedness, response, recovery) (Doukas and Retscher, 2011).

The combination of: DRMC, WSN/GSN application categories (Monitoring, Tracking, Retrospective) and the five kinds of WSN/GSN, finds its resultant in Figure 3.

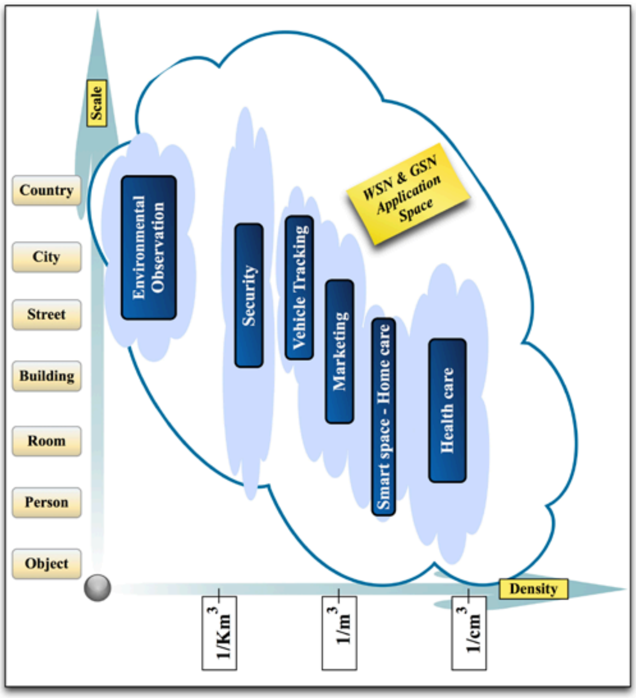

Figure 2: WSN/GSN applications space
(after Yoneki et al., 2005)

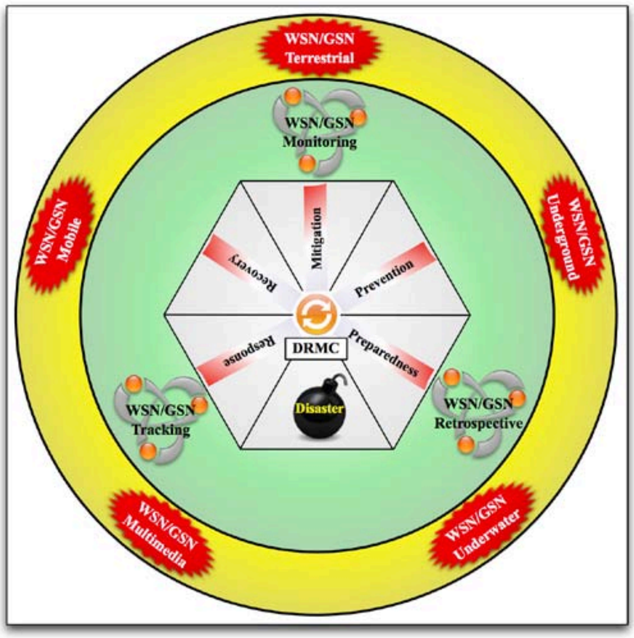

Figure 3: WSN/GSN serving DRMC

What Figure 3 tells in simple words is that every phase of the DRMC (before, during and after the event of the disaster) can be served by WSN/GSN. This can be achieved from combinations of WSN/GSN. For example, Terrestrial WSN/GSN (yellow circle area) with Monitoring features (green circle area) for Preparedness (DRMC grey hexagon), Underground WSN/GSN (yellow circle area) with Tracking features (green circle area) for Response (DRMC grey hexagon) and so on. The combinations are many and the authors of this paper believe that they are reasonable. If a number of potential such combinations happened not to find application so far into one or more of the sections/phases of the DRMC, further research and experimentation is suggested.

As it can be derived from the bibliography, there are indeed applications of WSN/GNS concerning the case of disasters. There are several projects in the research phase, there are opinions, targets and a lot of ideas (e.g. concerning the efficient search and rescue operations, known as: Search And Rescue (SAR), Urban Search And Rescue (USAR), guiding the firefighters, etc.), there is experimentation, there are real cases but so far the WSN/GSN are not the firm standard "first choice" among other available solutions. In other words, there is still a fuzzy atmosphere about the systematic application of such networks in many kinds of disasters. In general, earthquakes, floods, landslides and fires have much better share in WSN/GNS applications. Apart from this fact, most promising (as a basis for fresh new ideas and brainstorming) also appear to be technical structure-related scientific areas like Structural (civil, mechanical) Health Monitoring (SHM), structural damage detection, active and semi-active control of structures, parameter identification and modeling of structures, building automation (Balageas et al., 2006; Watters et al., 2002; Xu, 2002; Wenzel, 2009; Alahakoon et al., 2009). There are very important developments in this area, which "from its birthday" has a default evident relation with - at least one disaster - earthquakes. Finally, many ideas about future disaster-applications of WSN/GSN could be derived from other techniques and applications of WSN/GSN which do not have (at least an obvious) relation with disasters. There is a true multidisciplinary character since WSN/GSN applications attract a great variety of researchers. Scientific and technology fields like engineering, artificial intelligence, space science, geomatics, geoinformatics and remote sensing, geodesy/geography, informatics, electronics, physics (to name some), do have dominant positions into this research territory (see e.g. Alahakoon et al., 2009; Teillet, 2010). This multidisciplinary 'polyphony' could be both the "accelerator" and the "brake" to the evolution and development of dedicated to disasters WSN/GSN applications. The contemporary status of Spatial Data Infrastructures (SDI) shows bad handling WSN/GSN data (which have real-time arrival, higher frequency and smaller packages than usual geodata). Furthermore, when the plan is to integrate WSN/GSN into a DMS, top priority issues and problems that need attention and solutions belong to the following bunch: metadata registration, capability for reporting position, remotely readability, controllability (systems, observations, processes) and accessibility (parameters), support of frequent updates (warning, reacting), interface standardization, the heterogeneous nature of data. Before and above all, a "compiled" understanding of earth science (e.g. geomatics, geography), WSN/GSN, computing/informatics and of course communications is obviously necessary (Stasch et al., 2008; Jung et al., 2008; Craglia et al. 2008; Doukas and Retscher, 2011). Hopefully, in a reasonable time depth, the benefits of WSN/GSN are getting more and better, while the challenges are encountered successfully.

The "weaponry" against disasters has some most promising new additions. The Ambient Intelligence (AmI) and the Ambient Spatial Intelligence (AmSI) (Zelkha et al. 1998; Aarts, 2001) have a true potential in this territory. AmI brings systems and technologies that are embedded (many networked devices are integrated into the environment), context aware (these devices can recognize individuals and their situational context), personalized (they can be tailored to people needs), adaptive (they can change in response to individual), anticipatory (they can anticipate people desires without conscious mediation). It is the perfect combination of technology (WSN/GSN) and the need (i.e., generating and processing real-time spatiotemporal information about dynamic environments, integrated with wider spatial information systems and applications). Undoubtedly, the prevalence of mobile and pervasive computing expands the horizons when the issue is to carry out in situ measurements and to gather directly WSN/GSN data (Sääskilahti et al., 2010). Another attractive path is the fact that the sensors could be in private space (indoors, outdoors) or on a user (i.e., wearable). Consequently, last but not least addition to the above mentioned promising "weaponry" is the «human-sensor» or «human-indicator» (i.e., a human with a smartphone or wearable sensor(s), a vehicle carrying a sensor) (Craglia et al. 2008; Nittel et al., 2008; Kanjo et al., 2008; Exner et al., 2011). A human-sensor carries in everyday life the proper tools which are capable to collect, exchange, and analyze local information, in simple words the user participates and collaborates, a potential that could offer powerful contribution to DMS.

Sensor Web(s) and SensorMap-like websites (i.e., visualization on the map of sensor data, as results of definite GIS-queries) (Karim et al., 2009) show that the main path (could or must) pass through the GIS "environment". At least for the present, systems like GIS offer guarantees that they can be the foundation of such a huge upper-class system (i.e., combination of GIS with WSN/GSN). The challenges are for companies and the researchers of Geomatics/GIS to conform with the specific requirements and to orientate their systems to this new hi-tech and demanding territory.

## 4. CASE STUDY: GEOSENSORS IN SMARTPHONES AND THEIR USE IN DISASTERS

Dealing with mobile devices capable to offer data access (anytime and/or anywhere) a dynamic increase in production (and interest, as well) can be seen. Benefits of their use are especially related with the fact that such devices go beyond the usual voice connections (mainly the cellular phones) or working locally (e.g., laptops, palmtops, etc.) since they also can receive/transmit data. Furthermore, the number of users worldwide has significantly increased, data collection is more energy efficient, cellular phones are adequate to sense, process, store and transfer contextual data (i.e., photos, SMS/MMS), and they have various communication channels capable of transferring the data remotely to other devices (Kanjo et al., 2008). In addition, geosensors can nowadays be found in mobile devices such as smartphones **(**Robin, 2010; Robin and Baron, 2010; Johnson, 2010).

Starting with the integration of GPS into the cellular phone several years ago, sensors such as MEMS-based accelerometers as well as digital compasses and/or gyros may be found in a smartphone. If a tri-axis accelerometer combined with a digital compass and/or gyro is present in the phone then **D**ead **R**eckoning (**DR**) can be performed. In this case, the current and future positions of a pedestrian user can be estimated and predicted starting from a given initial position. This approximate position in the beginning can be estimated with GPS and cellular phone positioning or other absolute positioning method (e.g. in indoor environment using WiFi or RFID) (see Retscher, 2007). Then it is possible to locate a person carrying a smartphone if a disaster has happened. Through the mobile phone communication network an alarm can be sent to the emergency centre. The phone can then be located using either network-based or handset-based or hybrid location methods (see e.g. Drane et al., 1998; Dulya, 2009). In the first case, signals of the mobile phone network are used to locate the phone. The most straightforward method thereby is cellular positioning (so-called **C**ell-**o**f-**O**rigin, **CoO** short). The location of the phone is then defined by the cell surrounding the base station to which the phone is currently communicating. The positioning accuracy for CoO, however, could be quite coarse as it depends on the size of the cells. In urban environments the cell size could be as small as 500 to 50 m in radius, but in rural areas up to several kilometers. In buildings the cell size can be smaller (e.g. 10 m in radius) if so-called pico cells exist. Therefore the achievable positioning accuracy using CoO will be the highest in dense urban environments or inside buildings. Smarter solutions perform measurements of the distance travelled of the mobile phone signals between the phone and the base stations. Using **ToA** (**T**ime **o**f **A**rrival) or **TDoA** (**T**ime **D**ifference **o**f **A**rrival) measurements positioning accuracies on the 50 m level can be achieved also in suburban and rural areas if at least 3 base stations can be seen. The highest positioning accuracies, however, can be achieved with handset-based and hybrid methods. For handset-based location determination usually the location determination relies on GPS. Therefore the positioning accuracy is on the few meter level. If the mobile phone network provides some assistance to the GPS positioning then the location method is referred to as **A**ssisted-**GPS** (**A-GPS**). Then the time-to-fix to achieve the position solution is reduced and the performance is increased. With A-GPS the mobile device does not need to decode the GPS messages for each satellite or perform an extensive search for visible satellites when the system is turned on. This fact results in reduced power consumption and a significantly reduced time required for the satellite acquisition and determination of the position fix (Zandbergen, 2009). A-GPS has still the same disadvantages as conventional standalone GPS, however, as satellite signals can be blocked in urban canyons and indoors. To increase signal reception so-called **H**igh **S**ensitivity **GPS** (**HSGPS**) receivers have been developed (Lachapelle, 2004). These receivers can use very weak satellite signals to perform the location determination. Therefore an increase of the areas where GPS positioning is possible might be achieved (Wieser, 2006). In indoor and urban environments, however, the positioning accuracy of A-GPS with HSGPS receivers might be worse than in open areas, i.e., usually on tens of meter level (Zandbergen and Barbeau, 2011). If GPS positioning fails completely than the location determination can fall back to cellular positioning (i.e., CoO) in the mobile phone network.

For indoor environments MEMS-based sensors in the smartphone (see Robin, 2010; Robin and Baron, 2010; Johnson, 2010) can help to be able to locate the pedestrian user. If the user enters a building, DR can bridge the loss of lock of the GPS signals for a certain time. This time depends on the performance of the MEMS sensors. Their disadvantage is that their positions drift quite significantly in short periods of time as the sensor errors accumulate very quickly. This drift can achieve several tens or hundreds of meters after several minutes. Therefore it is necessary to perform an update of the DR positions using an indoor localization system from time to time. Suitable positioning methods include WiFi, RFID, UWB, Zigbee, Bluetooth and so on (see e.g. Hightower and Borriello, 2001; Retscher, 2007). The optimum solution would be to use the system which is currently available in the building. The accelerometers can also be used to determine if a person is currently in motion, e.g. standing or walking. If the user walks the accelerometers can detect the steps and determine the distance travelled. Using the digital compass and/or gyro the heading of the user can be estimated. Tri-axis accelerometers and gyros can be combined to form an **I**nertial **M**easurement **u**nit (**IMU**). Using an IMU inertial navigation can be performed. The next generation of smartphones will have also integrated a barometric pressure sensor for attitude determination in addition. Then it is also possible to determine the correct floor of a user in a multi-storey building environment.

If a building has collapsed due to a manmade or natural disaster (e.g. an earthquake) then this technologies can help to locate a person affected. At least cell-based positioning and the use of the internal sensors in the smartphone can provide the current location of the user. Barometric pressure sensors then might help to find out how deep a person is located under a collapsed structure. The current state and location of the person can then be reported to the emergency centre and rescue personal can be guided to find that person. Therefore the geosensors in smartphones can be very useful in disaster situations as many persons nowadays carry such a device at all times.

The advantages using mobile devices such as smartphones, however, in present are less in comparison with their limitations. The disadvantage such as frequent disconnections, varying resources dependent on location, short battery life-time, and other constraints (e.g. communication, memory, processing, storage, size of display), for the time being suggests to prefer wired computers and fixed networks when the issue is about processing (Ilarri and Mena, 2010).

## 5. CONCLUDING REMARKS AND OUTLOOK

The ‘traditional’ DMS-research is getting wider horizons and is ‘diving’ deeper into computer science and its many sub-fields quite easily and dynamically. This fact is coping with a good number of crucial issues like adaptable middleware (i.e., computer software that connects software components or some people and their applications), automated updating of geospatial databases, computer vision, data streaming and processing, location-based services, mobile computing, integration and mining of sensor data, temporal-spatial queries over WSN/GSN, virtual reality.

By taking into account the 6 "**P**"s of Crisis Management: **P**roper **P**rior **P**lanning **P**revents **P**oor **P**erformance, all the components (phases) of disaster´s DRMC seem to be ‘fertile’ for taking full advantage of these new exciting technologies. This expectation is strongly supported by the following undisputed facts and trends concerning the status of WSN/GSN:

1. There is a stable decreasing trend of cost and sensor dimensions, as a stable increasing trend of dedicated software availability and application production. This kind of blend simply means that WSN/GSN are popular with growing public/scientific acceptance and dissemination. Popularity and dissemination are expressed through a multidisciplinary wide spectrum of “customers” (researchers/scientists).
2. A global “view” has been initiated, either with the name of SISE or, even better, GEOSS. Into this “view”, the disasters (natural and manmade) have their very important role. By considering WSN/GSN as ‘instruments’ that are sampling space-temporal processes, the risk-associated domain (and of course disaster management, decision support and their related systems), where up-to-date information is crucial, is highly favored by the advantages of these networks (to name few, e.g., ad-hoc nature, large spatial coverage - densely deployment in space, close range and high resolution, real-time observations/data/analysis, no human intervention, dense sensing of the environment). WSN/GSN are capable to effectively serve the DRMC. Arguably there is a long way for the improvement and standardization of methods, techniques, specifications/standards, policies, cooperation and integration of different systems into a consistent form of infrastructure. But the future looks bright and successful.
3. The pervasive computing/sensing character, in combination with the ambient intelligence (both AmI and AmSI), form a powerful combination that brings a revolution to “the action of observation” and to the better “understanding” of nature/Earth. The appearance of “human-sensor/indicator” makes the whole situation “unbearably” attractive and promising. Now it is attainable to reveal/observe phenomena that were in the realm of the impossible/improbable, under the support of a wider range of scales (either for time or space). Furthermore, this technology is strengthening and extending rapidly the interaction among users, the environment and the WSN/GSN.
4. WSN/GSN have a leading role into the high concentration of revolutionary technology which is prevailing geoinformatics, geomatics and GIS. There is a huge volume of work related to many sub-topics of the field of risk/disaster management. In order that an optimum exploitation of these resources is achieved, some good planning, strategy and study have to be applied. The scientific results obtained through appropriate experimentations and actual (or simulated) case-studies, will be beneficial for the adoption of newer (or the upgrading of older) specific standards and rules concerning the use of WSN/GSN dedicated to disasters and their management. Towards this Geo-informatics/WSN/GSN “El Dorado”, the Geomatics/GIS industry and research should be adjusted accordingly as the new parameters and the new scientific status rule.
5. Beyond the wide field of disasters, the blending of WSN/GSN with Geomatics opens new educational, scientific and professional horizons. The emergence of “geosensorics” is pleasantly complicating the status.

As people carry their cellular phones mostly all the time and new smartphones have geosensors integrated they may be used for localization determination of persons and objects. These modern phones include apart from GPS also MEMS-based sensors such as accelerometers, digital compasses and/or gyros as well as barometric pressure sensors. Especially their use in smartphones for localization determination of persons in an emergency situation will lead to improved performance in guidance of rescue personnel to the location of the incident.

The growing importance of WSN/GSN and new technologies concerning disaster monitoring and management is reflected by the International Association of Geodesy (IAG) to establish a new Study Group SG 4.1 on “New Technologies for Disaster Monitoring and Management” under Commission 4 “Positioning and Applications” for the next four years period chaired by the authors. The objectives of this study group include:

- To explore and test any available (or emerging) contemporary technologies that could relate with Disaster Monitoring and Management;

- To create an up-to-date disaster-catalogue (typical characteristics, major impacts and other related information, etc.) in relation with an up-to-date technologies-catalogue (e.g. benchmark datasets, hardware, software, methods, algorithms and applications, etc.).

These objectives will form the foundation of the coordination of research and other activities and tasks, as well. Furthermore, the topic is expected to attract a number of interdisciplinary aspects, a fact that will result into most interesting cooperation with a variety of other scientific and/or professional institutes, organizations, groups (including other IAG entities). Due to this international cooperation further progress is expected to be achieved in the field of contemporary sensor technologies for disaster monitoring and management.

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