On the high-tech onrush of sensors, geosensors, sensor fusion and their networks. Their influence on geodesy and geomatics

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Abstract: Sensors and geosensors (i.e. specific "georeferenced sensors" which measure, monitor, track, record phenomena in geographic space) comprise a plethora of modern 'tools' with a vast field of applications. They are a continuous revolution on 'observation of the natural world'. In this paper, a brief introduction to them is given on the basis of their networks (Wireless Sensor Networks-WSN; GeoSensor Networks-GSN) and their combination (sensor fusion), followed by a discussion on their advantages/disadvantages and their (direct/indirect) influence on Geodesy and Geomatics. Finally, the contemporary developments and some 'visions' are discussed, based on this technology and its combination/mixture with other modern technologies/methods encountered in the field of geoinformatics (GIS), such as: sensor fusion (combination/coordination of sensors), pervasive/ubiquitous computing and ambient/spatial intelligence (ambient/spatial intelligence), Internet of Things (IoT) and finally, Web of Things (WoT).

1. Introduction to Sensors and Sensor-Networks

Sensor: It is any device that receives a signal and responds to it. Where ‘Receives’ means: ‘the measurement of a physical quantity. Consequently, ‘Responds to it’ means: ‘The conversion of the measurement into a readable (by an observer or an instrument) signal’.

Wireless Sensor Technologies (WST) is identified as one of the most important revolutions of the 21st century, worldwide. There are two (2) major categories (Garcia et al., 2009, Retscher, G. and Fu, Q., 2008, Zhu, M., et al., 2009) of these technologies:

(1). *Wireless Sensor Networks - WSN*, a very generalized category (see and Fig. 1). A WSN means autonomous and spatially distributed sensors (internationally known as *‘sensor nodes’*-for details see also §2). These nodes cooperatively are monitoring physical or environmental conditions. For better understanding and clarification, this general category needs to be decomposed into the following three (3) subcategories (Aboelaze, M. and Aloul, F., 2005, Reis, I.A., 2005, Yick, Y., et al., 2008, Garcia et al., 2009):

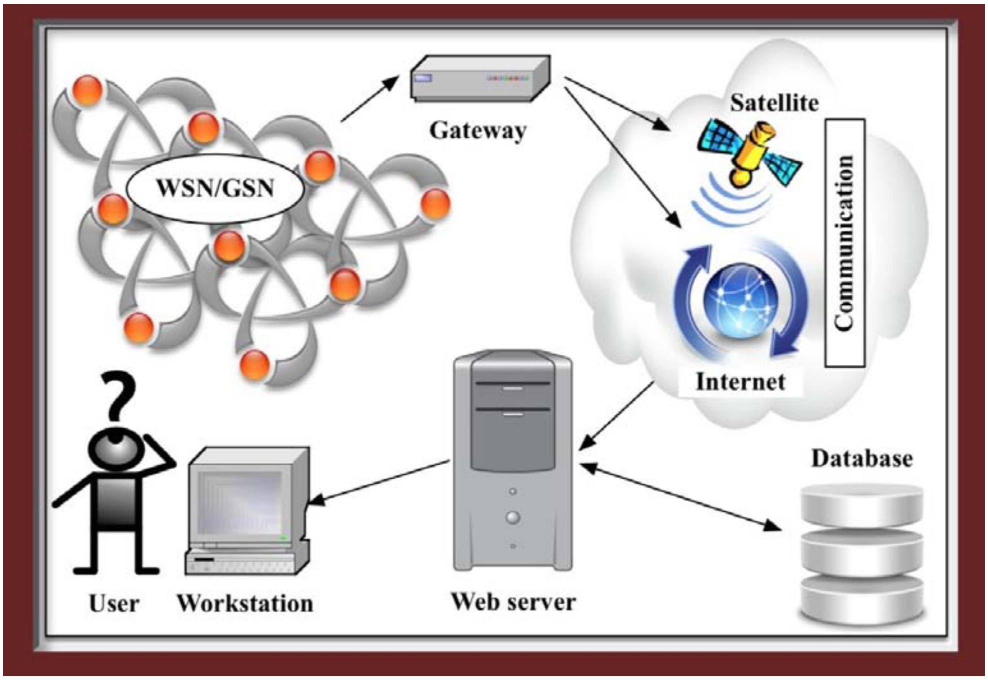

Fig. 1: *Wireless sensor/geosensors networks (WSN/GSN)-Their basic operation principle*

(1.1). *Cellular networks:* The well known 'mobile-phone networks' are a typical example here.

(1.2). *Ad-hoc networks:* Typically installed in small-scale geographic areas for serving emergencies. They can be extended without the need of existing infrastructure.

(1.3). *Sensor networks:* Such networks are essentially systems consisting of "nodes", radio receivers (RF), micro-controllers and energy sources, and the final result is sets of multiple interconnected sensors.

The distributed in space nodes of each network, are able to:

(a). Measure various characteristics of their environment (for instance by: monitoring, detection, tracking, logging)

(b). Make calculations

(c). Communicate with each other, as members of a wireless network

This combination of recording capabilities, computation and communication is the cause these WSN named also *Wireless Smart Sensor Networks (WSSN)* (Quintero, L.F.H., et al., 2009). For all these very different sensor platforms (mainly because of their distinctive material), *«middleware[1]»* is the key to creating a common oper-

1 Middleware = special software which "bridges" the operating system with the corresponding applications running on each node of the system (Yoneki, E. and Bacon, J., 2005).

ating system. Middleware is the tool which facilitates scalability, interoperability, network expansion and development and, finally, the development of various applications (Molla, M.M. and Ahamed, S.I., 2006). In Fig. 2, a straightforward comparison between 'traditional' and wireless networks is given.

WSN Networks	Traditional Networks
Single-purpose design; serving one specific application	General -purpose design; serving many applications
Energy is the main constraint in the design of all nodes and network components	Typical primary design concerns, are network performance and latencies; energy is not a primary concern
Deployment, network structure and resources use, are often ad-hoc (without planning)	Networks are designed and engineered according to plans
Sensor networks often operate in environments with harsh conditions	Devices and networks operate in controlled and mild environments
Physical access to sensor nodes is often difficult or even impossible	Maintenance and repair are common and networks are typically easy to access
Component failure is expected and addressed in the design of the network	Component failure is addressed through maintenance and repair
Most decisions are made localised without the support of a central manager	Obtaining global network knowledge is typically feasible and centralised management is possible

Fig. 2: *Comparison between WSN and traditional networks (El-Bendary, M.A.M., 2015)*

There are five (5) types of wireless sensor networks (Akyildiz et al., 2008, Srivastava, N., 2010, Yick, Y., et al., 2008):

(i). Mobile, (ii). Multimedia (WMSN), (iii). Ground based, (iv). Underground, (v). Underwater

(2). Devices (and their systems) based on Radio Frequency Identification - RFID. Three are the basic components here: the tag (transponder), the transceiver (that reads/writes data to the tag), and finally the processor/computer (containing the database and software for information management). RFID tags can be: active, passive, semi-passive. The usual range of reading passive tags varies from 10cm to 3m (Garcia et al., 2009). The basic difference between RFID and WSN lies in the fact that RFID devices have no possibilities of cooperation between them.

2. Sensor fusion[2] and the components of sensor networks

- *Sensor node*, known also (in North America) as *mote*: It is the node in a WSN that has the ability to perform some processing to gather sensory information and of course, to communicate/interact with other nodes in the WSN. The basic components of such a node are: *The microprocessor, the receiver, the external memory, energy source and of course, one or more sensors* (Karl, H. and Willig, A., 2003). Correspondingly, a node contains the following characteristics: *sensing, processing, communication, actuation* – see also Note 5) (Arampatzis et al., 2005, Ducham, 2013). Nowadays, it is perfectly feasible structural dimensions of the order of: 1 mm^3 (nodes) and 0.001 mm (sensors), respectively. While these dimensions are impressive, however, in the very near future, they are expected to be comfortable in the order of: 1x10-6 mm!.
- *Sensor fusion:* It is the combination/mixture of data from sensors (similar/dissimilar to each other). In such a case, the ultimate aim is to obtain information, which in some respects will be *'best overall'*, compared with the information that would result from each source separately. The term *'best overall'* could for example mean: better accuracy, greater fullness (additional information), system robustness (Henderson et al., 1998, Duckham, M. and Reitsma, F., 2009).

There are three (3) different levels of fusion:

i. *Information fusion:* The highest level of fusion, often used in artificial intelligence environments, where information cannot always be represented by numbers. The participation of databases and data mining techniques is possible at this level (p.e. Kalman filtering, artificial neural networks, discrete Bayesian methods).
ii. *Sensor fusion:* In very simple words, combination/mixing of numerical data from many sources.
iii. *Data fusion:* As in §(ii) immediately above, because it is often not possible to distinguish between §(ii) and §(iii), respectively. To generalize, these two paragraphs mean: Combination of data, from different sources (i.e. measurements taken at different times, from different sensors, which are located at different locations).

From the perspective of data processing, there is:

a) *Direct fusion:* The combination/mixture of data derived from: (a.1). A set of (homogeneous or heterogeneous) sensors, (a.2). Virtual sensors[3], (a.3). Sensor

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2 From a general encyclopedic standpoint, «fusion» is a combination of two or more different things.

3 Alternative solutions, where preferably software replaces costly or impractical physical measuring

data already found (historical data).

b) *Indirect fusion:* It uses information sources such as, the a priori knowledge about the environment and the human input.

c) Combination of the outputs, of paragraphs a) and b) above.

- *Sensor Web:* It is a "system of, autonomous and wireless sensors, with communication between them and finally, spatially distributed. This system can be prepared and used to monitor/record and explore new environments" (Delin, K.A., 2002). The principle of the Sensor Web is examined also from the perspective of cooperation/inter-operation of satellite platforms and sensors, respectively. From this point of view, it is expressed by the term *'satellite webs'* (Teillet, P.M., 2010). Satellite webs are also sensing systems, whose operation is essentially based on the Web, where a web application (software) plays the role of gateway between each WSN and Internet (see also Fig. 1).

Other researchers call the Sensor Web as *'Sensor Grid'*, others as *'Electronic skin of the Earth'* (p.e. Botts et al., 2006, Craglia et al., 2008, Karim et al., 2009). The WSNs consist of various sensors, which normally collect data.
On the other hand, the Sensor Webs collect and moreover, distribute the collected data. Based on the collected data, it is worth noting that Sensor Webs can also change their individual "behavior" (Teillet, P.M., 2010).

The nodes of WSN are *MEMS/NEMS/MOEMS* (see and Fig. 3). More specifically:

- *MEMS (Micro-Electro-Mechanical-Systems):* They are tiny, low cost devices, untethered, powered by electricity (battery). They have limited processing and data storage capabilities, limited communication range, but they also have "*sensing abilities*" (Xu, N., 2002, Garcia et al., 2009, Nittel, S., 2009). Their dimensions are in the range of 1 to 1,000 μm (i.e. 0.001mm-1mm). When their dimensions range go <100nm, then they are called *NEMS (Nano-Electro-Mechanical Systems).* The integrated circuits of MEMS, not only can "sense" the real world but they can also "react" to its stimuli. The integration of sensors and *actuators*[4] makes feasible both, the measuring of physical parameters and actuating (Arampatzis et al., 2005).
  Although MEMS have their roots in military research, it was perfectly normal and expected to expand rapidly and in applications of the everyday urban space (due to the ongoing reduction in their cost and dimensions) (Zu, 2002, Khemapech et al., 2005).

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instruments.

4 The MEMS often include moving parts, so they become actuators i.e. types of microengines to initiate and/or control a mechanism or system, and it is obvious that their operation requires energy. Actuators and sensors are bridges between digital and real worlds, respectively.

Fig. 3: *Indicative types of MEMS, NEMS, MOEMS*

- *MOEMS (Micro-Opto-Electro-Mechanical-Systems):* The advanced case where MEMS devices are combined with micro-optical elements. This provides the additional capability of sensing and handling optical signals[5].

Sensors and their categories (Exner et al., 2011):

- Sensors for measuring and control of state-variables and material properties (e.g. temperature, density, viscosity, dust content, humidity, smoke, gases, pH-value, etc.)
- Sensors for measuring and control of mechanical and geometrical parameters

5 For convenience, hereinafter the term MEMS will include MEMS, NEMS and MOEMS

(e.g. length, position, angle, speed, acceleration, pressure, vibration, sound, etc.)

- Optical and electromagnetic sensors (e.g. sensors for: for magnetic field, electricity, ionizing radiation, visible light, infrared radiation, photographing images with CCD, color sensors, optical character recognition & bar code, image processing capabilities, etc.).

3. Geosensors and their networks

Geosensor: It is any device that receives and measures environmental stimuli and moreover, can be georeferenced (Craglia et al., 2008). Typical examples of geosensors: GPS receivers, total stations, digital cameras, laser scanners, sensors on satellites, airborne sensors, LiDAR, etc.).

Their most common generalized categories are two. The first one is as follows:

- 1.a. Based on satellites (for multispectral information about the Earth's surface).
- 1.b. Airborne (bound to images and LiDAR of natural and man-made structures).
- 1.c. Sensors which, in relation to the Earth's surface, are located close to it, above or below it, and they are measuring ... everything (Craglia et al., 2008).

The second general category of geosensors is as follows:

- 2.a. Ambient
- 2.b. Remote
- 2.c. Wearable

- *GeoSensor Networks - GSN:* It is a subset of WSN, "engaged" with the geographical space. This means *detection, tracking, identification, monitoring/recording of phenomena and processes in space*. It is particularly noteworthy the wide range of spaces can be covered (e.g. from the limited space of a room to a wide range of an ecosystem – see also Fig. 4) (Reis, I.A., 2005, Stefanidis, A., 2006, Nittel, S., et al., 2006, Nittel, S., 2009).

The rapid and marked expansion of geosensors already has caused the emergence of a new science called *"Geosensorics"*.

By simplifying the case of exploring options, the rule is (Sester, M., 2009): «When the infrastructure is impossible or too costly, or they do not prescribe additions or modifications, then the most appropriate solution is based on WSN/GSNs». A GSN needs at least one of its nodes to give the "position" (e.g. a GPS receiver). This implication means that, at least can be determined the relative location of the remaining nodes GSN. The nodes of a GSN can: be stationary or moving, placed on moving objects used by people (e.g. mobile 'smartphones', wearable by people sensors, cameras, etc.) (Arampatzis et al., 2005).

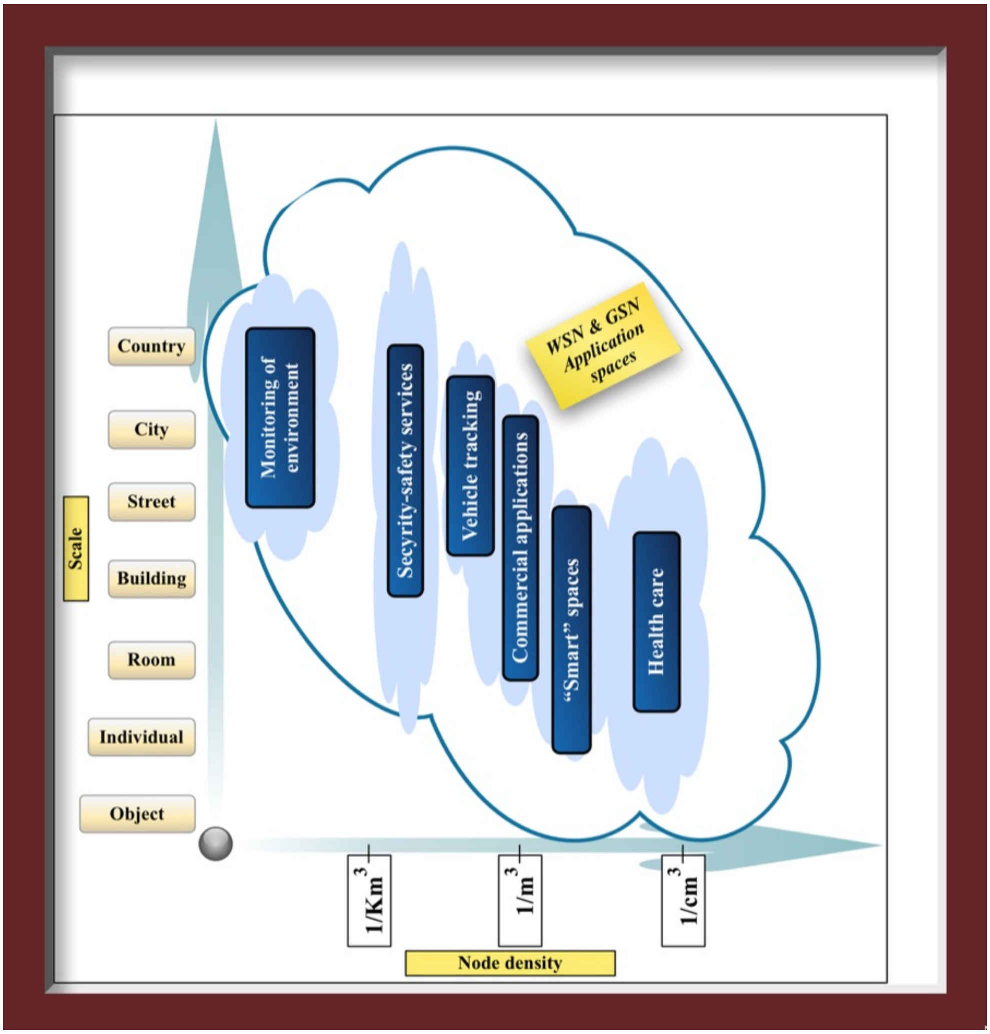

Fig. 4: *Application spaces of WSN/GSN (Axis x: Node density - Axis y: Scale of space)*

Defining and analyzing phenomena in a GSN can be performed either in real time (from its nodes) or when the GSN is off. Then, these activities can be carried out e.g. in various distributed base stations, either in the area where is the GSN or in another remote location (Nittel, S., et al., 2006).

The most important common element of all kinds of WSN/GSN lies in the fact that they can be "integrated" in the real world.

The sensors "sense" and detect/identify the reality of the world, and the actuators can act onto the real world (e.g. by turning switches on/off, by generating sounds, by applying forces, etc.).

4. General GSN applications - Geodesy, Geomatics

Civilian applications of WSN/GSN appeared (obviously) after the military ones, been developed into the particularly fertile area of information technology and boosted by the dramatic reduction, cost and dimensions of MEMS.

Representative categorization of such applications (Reis, I.A., 2005), resulting in three major categories of them:
[1]. Monitoring/Remote sensing
[2]. Tracking
[3]. Retrospective (e.g. analysis of already existing/stored data)

Of course, the whole case is not so simple as there are applications that overlap categories.

By taking into account the already mentioned (see §1) five (5) types of networks (Akyildiz et al., 2008, Srivastava, N., 2010, Yick, Y., et al., 2008), each one of these above mentioned three (3) categories of applications can have as sub-categories the following:

(a). Ground based, (b). Underground, (c). Underwater, (d). Mobile (e). Multimedia (WMSN-Wireless Multimedia Sensor Networks).

In Figure 4, the 'applications-space' of WSN/GSN is approximated, in relation to the magnitude (scale) of the area and the density of network nodes, as well (after Yoneki, E. and Bacon, J., 2005).

In Fig. 5, a broad sample of diverse applications is given in alphabetical order.
The selected bibliography is representative (Karl, H. and Willig, A., 2003, Arampatzis et al., 2005, Heidemann et al., 2005, Yoneki, E. and Bacon, J., 2005, Reis, I.A., 2005, Eugster, H. and Nebiker, S. 2008, Ogawa, S. and Sato, T., 2008, Garcia et al., 2009, Nittel, S., et al., 2006, Yick, Y., et al., 2008, Sester, M., 2009, I.D. and Retscher, G., 2011a, 2011b, Doukas, I.D., 2013).

Although Geodesy, Geomatics and HD-Surveying (High Definition Surveying) cover just one cell in the table of Fig. 5, it is more than clear that all of the rest cells of this table, more or less, do contain "geodetic influence". After all, wherever the terms "location/position" are getting involved, this means …Geodesy/Geomatics.

The large bloom and spread of WSN/GSN had a catalytic effect, both on the very nature of the data collected and the wider area of planning future applications (Stefanidis, A., 2006, Yick, Y., et al., 2008). Thus, the new developments are:

1. Concerning data, homogeneity is being threatened (even defeated) by heterogeneity. The usual (.... preferable) single format concerning images, GIS data, etc. is loosing ground from the many different formats of data (derived from different sensors in a network).
2. There is a transition, from single-precision data to data that differ in content, resolution, precision.

Geosensors - Wide fields of applications	
Ambient intelligence	Health care, biomedicine, e-Health
Animal tracking	Industry
Competitiveness-Quality of life	Landscape management
Constructions-Infrastructure, SHM	Logistics, transportation, traffic
Crime prevention-Forensics	Machine guidance & automation
Cultural heritage	Military
Disasters (natural, anthropogenic)	Precision (farming, irrigation)
Domotics	Robotics (everywhere…..)
Ecosystems, flora, fauna	Safety, security, surveillance
Entertainment	Satellites, unmanned vehicles
Environment (interior, exterior)	Sea (surface, underwater, mines…)
Environmental awareness	"Smart" places, Urban tracking
Fischery	Smart grids-energy control
Geodesy, Geomatics, HD-Surveying	Soil, minerals, water

Fig. 5: *Indicative application fields of WSN/GSN (in alphabetic order)*

3. The character of information constantly tends to be more spatiotemporal, in contrast to the hitherto 'usual' spatial one.
4. There is a complete revision of the system of geospatial and spatiotemporal data and information, in relation to various interdisciplinary (and other) issues, like: storage (methods, tools, etc.), communications, modeling, new specifications and standards, communication protocols, algorithms, services etc.

The main parameters that characterise 'sensor performance', are:

- *Range:* maximum and minimum values that can be measured
- *Resolution or discrimination:* smallest discernible change in the measured value
- *Linearity:* maximum deviation from a 'straight-line' response
- *Sensitivity:* a measure of the change produced at the output for a given change
- *Accuracy/Precision:* difference between measured & actual values (i.e. random/system errors)

The main sensor challenges faced today, are the following:

- Technical documentation
- Compatibility/integration issues. Environmental issues
- The selection of the proper sensor(s) for the specific task(s)
- Reliability, Durability, Maintenance
- Technical support

- Cost
- Performance
- Availability

5. Modern developments in geosensors and their networks

Apart from the term "Geosensorics", and other new key-terms already started infiltrating and enforced on the premises of Geodesy - Geomatics, as follows:

5.1 *Spatial computing:*

Originally meant *"calculations with information about the space"*. Nowadays, modern spatial computing (and geoinformatics) has begun substantially mean *"calculations ... somewhere"* (i.e. "calculations with information, within the space, but also about the space") (Bacharach, J. and Beal, J., 2007, Beal, J. and Schantz, R., 2010). More specifically:

So far, the conventional approaches were based on the assumption that the spatial information is stored, sorted and processed within large "data warehouses" (e.g. GIS, geodatabases). The location of such a repository does not have relation to the information contained into it or to the data processing occurring within it. When information about a geographical area is distributed across this geographical area, the construction and maintenance of central data-repositories soon become unmanageable (or undesirable). Apparently, when the calculations occur within the geographical area but also about this geographical area, understandably is a fact extremely challenging for the traditional computational models of spatial computing and geoinformatics.

The problem is solved with the new philosophy of "calculations ... somewhere", as based on another principle, in which the information is related to their position in space. Also, if there are difficulties in information handling, then the creation of "geospatial information neighborhoods" comes to the rescue. This makes it easier to exchange information between "data warehouses" that are spatially close together.

GSN networks are a highly representative example of this new philosophy of "calculations ... somewhere", as their nodes create and provide information on their geographical environment.

5.2 *Pervasive/Ubiquitous computing:*

According to this principle, in each (... almost) device can be integrated circuits suitable to connect this device with an infinite number of other network devices. If this objective is achieved, it is possible to combine ‘cooperations’ with a number of technologies, like: networks, wireless computing, voice recognition, Web capabilities and artificial intelligence. In simple words, the ultimate aim of this principle is to create a context where there will exist permanent connectivity (which will end up being inconspicuous, even invisible). The pervasive/ubiquitous computing is responsible for the general term *'Context-aware/awareness'* (Schilit, B.N., et al., 1994, Schilit, B.N., and Theimer, M.M., 1994), where as "context-aware-system" is defined the system which can adapt according to its context. In simple words, "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" (Dey, A.K., 2001).

The 'context' is divided into three categories:

i. *Computing context* (e.g. connectivity, bandwidth, resources/devices, etc.)
ii. *Physical context* (e.g. temperature, humidity, lighting, noise, etc.)
iii. *User context* (e.g. user profile, activity, location, nearby people, social situation, etc.)

5.3 *Ambient Intelligence - AmI:*

A term which means the sensitivity and response to people's "electronic contexts/environments" (Zelkha, E., et al., 1998, Aarts et al., 2001, Duckham, M. and Bennett, R., 2009). The world (space) characterized by ambient intelligence is the one based on cooperations among devices, which are available to serve people. As the geometrical dimensions of these devices are being reduced with the time, and as such devices diffuse in (and "merged" with) the environment, the result will be the 'gradual disappearance of technology' in the human environment. Thus, in the final stage of this process, the only thing remains perceived by users will be just the *'user interface'*.

5.4 *Ambient Spatial Intelligence - AmSI:*

The vision of AmSi is the combination of Pervasive/Ubiquitous computing with Ambient Intelligence (AmI) (Duckham, B. and Bennett, R., 2009, Duckham B., 2013). AmSI is the integration of the 'appropriate' intelligence' in both the built and the natural environments. Its ultimate target is double, one the one hand the environment must response to spatiotemporal queries and on the other hand, the environment must monitor events occurring into the space. The aim of AmSI is to implement technologies wich will make the *"Calculations ... somewhere"* feasible. GSNs, with spatial information and computational services they offer, are obviously identified as a key technology in this case (see and §4). By summing up §5.2, §5.3 and §5.4, in the case of ubiquitous/pervasive/AmI/AmSI system, this belongs to a 'special category' of information systems. It uses sensors/geosensors to acquire information from various sources (of context/environment). Then, it processes the contextual information and as a result it takes some responses through actuators.

5.5 *Internet of Things (IoT):*

One of the two final and newest technology issues, concerning (also) sensors/geosensors (and of course their networks) variously, is IoT. There is a bunch of terminology concerning IoT (see also: European Economic and Social Committee, 2009). An appropriate 'mixture' of them, is expressed here: A network of interconnected computers to a network of interconnected objects (especially, everyday objects), from books to cars, from electrical appliances to food, and thus create an 'Internet of things'. These objects will sometimes have their own Internet Protocol addresses, be embedded in complex systems and use sensors to obtain information from their environment and/or use actuators to interact with it. Of course, these 'things' are readable, recognizable, locatable, addressable, and/or controllable via the Internet (whether via RFID, wireless LAN, wide-area network, or other means). Until the year 2020, the results of research-reports (from companies like Cisco, Morgan Stanley, etc.) forecast that about 50-75 billion devices (!!) will be connected to the IoT.

5.6 *Web of Things (WoT):*

The second final and newest technology issue, concerning (also) sensors/geosensors (and of course their networks) variously, is WoT. It is a vision inspired from the Internet of Things where everyday devices and objects, are connected by fully integrating them to the Web. Examples of smart devices and objects are: ambient devices, WSN/GSNs, household appliances, etc. The WoT is dealing with reusing the Web standards. Under this philosophy, its target is to connect the rapidly expanding ecosystem of embedded devices built into everyday smart objects. In order to access the functionality of the smart objects, it uses well-accepted and understood standards and blueprints (p.e. URL, HTTP, RSS, etc.).

The comparison between IoT and WoT, in simplified terms says that the IoT is the hardware, the physical layers, connections, etc. Mainly, it is about connecting electronic devices or 'things' to the Internet. The WoT is operating on top of IoT. Its target is the standardization of the use of web-technologies, which will lead to the ultimate materialization of applications and web-services. The devices themselves live in the IoT layers. On the other hand, WoT is 'located' on the higher levels. Thus, the levels of identity, authorization and authentication, reside in the WoT layers. Consequently, the WoT comprises p.e. authentication, data layers, HTTP protocol connections and so on.

6. Conclusions

A brief overview of the field as of the main components of the sensors/geosensors (and their wireless networks) has been carried out in this paper. The fact is undeniable. This is a revolutionary new technology that dynamically affects many sciences, including of course and Geodesy/Geomatics. The observation of the natural world was never before observed in such an innovative way. Several developments were presented, by covering both the existing categories of applications, as well as completely different 'visionary' tendencies. These different visions have begun gradually to assume shape, through the combination of: sensors/geosensors, pervasive/ubiquitous computing, and finally ambient/spatial intelligence. Although WSN/GSN offer unique sources of information, so far they complete than replace the existing spatial data collection technologies. But the scene is changing rapidly.

The "static" solutions of geoinformatics (e.g. digital terrain models, still images, flat-layers of GIS) started and show inherent weaknesses and their inefficiency in terms of the capture and communication of the information (which definitely is characterized by dynamic nature) collected from geosensors and their networks. The detailed three-dimensional virtual reality is now upon us, and to be done from the complex and dense information collected from these networks.

In summary, the situation today is concentrated on three key points:

i. The WSN/GSN networks create strong incentives to applications of the new philosophy: "calculations ... somewhere," i.e. Calculations with information within the space and about the space
ii. Decentralized spatial computing is a key tool of this philosophy
iii. Ambient Spatial Intelligence (AmSI), in 'cocktails" with IoT and WoT, is ultimately implements a set of tools and methods for the application of the new philosophy: "calculations ... somewhere", to real-world problems. Assuredly, the future is approaching fast!.

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