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Application of geographical concepts and spatial technology to the Internet of Things

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The role of location in real-time smart environments

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Abstract This chapter discusses the application of geographical concepts and technology in relation to the Internet of Things (IoT). Geography can be considered an important binding principle in the IoT, this is because all physical objects and the data streams they create have a three-dimensional position, dimension, and orientation in space and time, and spatial relationships exist between them. Applying spatial relationships, functions, and models to the spatial characteristics of (smart) objects and events, the flows and behaviour of objects and people in smart cities can be more efficiently monitored and orchestrated. As IT and Geo-IT technology is progressing fast, system integration of spatial technology in the IoT can be realized and should be considered.

Keywords Smart city, smart environment, Internet of Things (IoT), sensors, actuators, geospatial, Geographical Information Systems (GIS), positioning, geo-enabled events, context-aware, spatial relationships, spatial functions, spatial models, Location Based Services (LBS), spatial standards, Sensor Web Enablement (SWE), spatial big data, real-time analysis, Event Stream Processing (ESP), Complex Event Processing (CEP), pattern recognition, Service Oriented Architecture (SOA), Event Driven Architecture (EDA)

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1 Introduction

1.1 *Smart cities and the Internet of Things*

The world is faced with challenges in all three dimensions of sustainable development – economic, social, and environmental. The United Nations predicts that the world population will grow to 8.92 billion by 2050 and peak at 9.22 billion in 2075 (United Nations, 2004). At the same time, the population living in urban areas is projected to rise by 2.6 billion, increasing from 3.6 billion in 2011 to 6.3 billion 2050 (United Nations, 2012). Furthermore, population growth becomes largely an urban phenomenon concentrated in the developing world (Satterthwaite, 2007).

Population growth and rapid urbanization, especially in developing countries, creates many economic, environmental and social problems, and calls for major changes in the way urban development is designed and managed, as well as in substantial increases of public and private investments in urban infrastructure and services. The United Nations World Economic and Social Survey 2013 (United Nations, 2013a) aims to contribute to the deliberations on sustainable development with a focus on three important cross-sectoral issues: sustainable cities, food security and energy transformation. A four-pillar framework for developing sustainable cities is proposed, i.e. social development, economic development, environmental management, and urban governance (figure 1.1).

Figure 1.1 A framework for sustainable cities (Source: UN/DESA, Development Policy and Analysis Division, 2013a.)

Information Technology can be used to solve economic, environmental, and social problems more efficiently. The concept of smart cities (or smart environments) aims at using information technology to monitor and control the state of the environment at an ever-increasing resolution and with greater frequency. A Smart City is defined by (GSMA, 2013) as: “A city that makes extensive use of information and communications technologies, including mobile networks, to improve the quality of life of its citizens in a sustainable way. A smart city combines and shares disparate data sets captured by intelligently-connected infrastructure, people and things, to generate new insights and provide ubiquitous services that enable citizens to access information about city services, move around easily, improve the efficiency of city operations and enhance security, fuel economic activity and increase resilience to natural disasters”.

As computers become smaller, more energy efficient and lower priced, and network availability and speed are improving at a steady rate, Internet connected smart objects containing sensors and actuators can be deployed on a large scale in our environment, creating an Internet of Things that can help us to monitor, steer and optimize the processes in our environment in real-time.

Libelium (2013) has defined an overview of 57 Internet of Things use cases in twelve categories, i.e. Cities, Environment, Water, Metering, Security & Emergencies, Retail, Logistics, Industrial Control, Agriculture, Animal Farming, Home Automation and eHealth. A number of use cases are shown in Figure 1.2. An alternative research by Beecham Research (2013) has defined nine categories of use cases, which are partly overlapping with the Libelium categories.

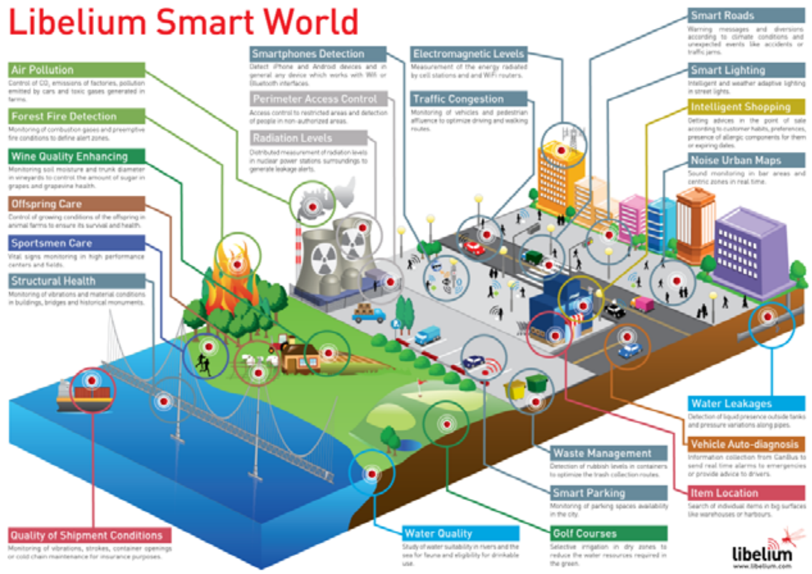


Figure 1.2 Libelium Smart World infographic – Sensors for smart cities, Internet of Things and beyond (Source: Libelium, 2013.)

A further study by Casaleggio Associati (2011) distinguish five stages in the evolution of IoT use cases; (1) Real-world objects are described on the Internet with a unique reference (e.g. the description of the Eiffel tower in Wikipedia). The objects have an information shadow online, but there is no direct interaction with the object; (2) Real-world objects are uniquely identified by a code (e.g. package with a barcode, QR, RFID, NFC). They have an information shadow online, but there is no direct interaction with the object (that is scanned and tracked); (3) Real-world objects are connected to the Internet and interact with people. They communicate, take orders and provide information about themselves, e.g. their position if they are lost or stolen; (4) Real-world objects communicate with each other and interact with each other in certain conditions, e.g. plants can water themselves when they are thirsty);

and (5) Real-world objects communicate with each other and the Internet, to which they provide information that can be elaborated and used as knowledge.

Technological developments make the realization of smart cities possible. New technological developments continue to penetrate countries in all regions of the world, as more and more people and objects are getting connected to the internet. A steady growth in ICT uptake worldwide can be observed, with an increase in all key indicators except the number of fixed telephone lines, which has been declining since 2005 (Figure 1.3). More and more countries are reaching a critical mass in terms of ICT access and use, which accelerates ICT diffusion, driven by the spread of mobile Internet (ITU, 2012).

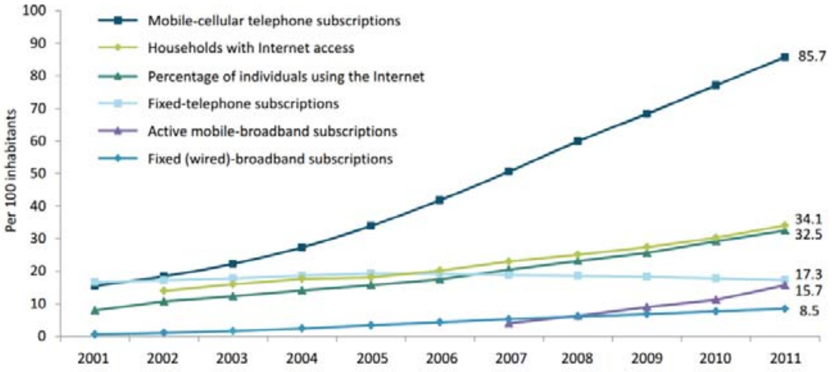


Figure 1.3 Global ICT developments, 2001-2011 (Source: ITU, 2012.)

1.2 Spatial thinking

Geography is a holistic and broad interdisciplinary research field. Scholten et.al. (2009) describe the use of geospatial concepts and technology in a variety of study areas. The research field of Geographic Information Science and Technology (GIS&T) is well described by Dibiase et al. (2006) in the GIS&T Body of Knowledge. Many problems and use cases have a spatial dimension, and to solve them, spatial algorithms and technology can be applied. For this it is crucial to know WHERE objects and subjects are, how they interrelate and react to each other in space and time, and what their spatial environmental context is.

Geography (location) can be considered an important binding principle in the IoT, as all physical objects and the data streams they may create have a three-dimensional position, dimension, and orientation in space and time, and spatial relationships exist between them. Applying spatial relationships, functions and models to the spatial characteristics of (smart) objects and events, the flows and behaviour of objects and people in smart cities can be more efficiently monitored and orchestrated. As IT and Geo-IT technology is progressing fast, the system integration of spatial technology in the IoT can become reality.

Spatial thinking is object-oriented thinking. Every object in the real world has properties, including spatial properties, such as position, dimension, and orientation at a certain moment in time. It is important to realize that these spatial characteristics of an object are integral aspects of that object. With the emergence of spatial databases it has become possible to store and query these spatial characteristics of an object in an integrated way.

Spatial properties of smart objects can be determined directly through sensors, (e.g. GPS+Gyroscope chips) or indirectly (e.g. through the known position of the RFID scanner). When the position, dimension and the orientation of an object is available (e.g. smartphone with GPS+Gyro sensors), the observations from those objects can be spatially enabled (e.g. georeferenced photos, videos, and tweets). The spatial information related to the observation can either be stored as metadata in the header of the data file or as an attribute of the data itself.

Ergo, not only real-world objects have spatial characteristics (position, dimension and orientation) but so also do the data event streams they create. Spatial characteristics of objects and observations can be used to visualize data and messages of things through the use of Augmented Reality (AR) platforms (e.g. smartphones, tablets, Google Glass devices) and AR applications (e.g. Layar). Spatial characteristics can also be used in real-time spatial (big) data analysis, providing the necessary information, knowledge and wisdom to optimize processes and to solve problems in smart cities efficiently.

The concept of ‘spatial relationship’ is important in spatial thinking. When the positions of objects and events are known, they can be spatially related and queried without having ‘traditional’ database relationships based on IDs. In spatial databases, spatial operators can be combined with non-spatial operators in mixed queries. The order in which the query is executed has an influence on the total calculation time. Spatial queries can be time-consuming, so a good query order is important.

2 Spatial modelling of Things

2.1 *Definition of a Thing*

The Internet of Things is about connected Things. But what do we actually consider a Thing? In a philosophical context, a Thing is an object, being, or entity (Wikipedia, 2013a). The term ‘object’ is often used in contrast to the term ‘subject’. The pragmatist Charles S. Peirce defines the broad notion of an object as anything that we can think or talk about (Wikipedia, 2013b). Smart objects (or smart things) are defined by Serbanati et al. (2011) and IoT-A (Magerkurth, 2012) as objects which are directly or indirectly connected to the Internet, that can interact with their environment, and can describe their own possible interactions. Smart objects have a physical and digital representation and have a unique identity on the web. The conceptual models of a smart thing and a proposed IoT reference are shown in Figure 2.1.

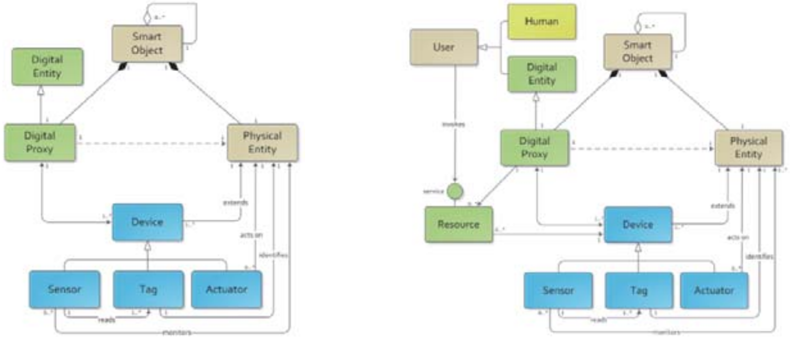


Figure 2.1 (a) Conceptual model of a Smart Object; (b) Proposed Internet of Things reference model (Source: Serbanati et al., 2011.)

2.2 *Spatial modelling*

Our environment consists of physical objects (or things), the Earth’s natural objects (trees, rocks, etcetera) and man-made artificial objects, some of which are smart objects. All these objects have spatial properties. According to Huisman and De By (2009), spatial properties of objects are: (1) location (“where”); (2) shape (“what form”); (3) size (“how big”); and (4) orientation (“facing in which direction”). The sphere of influence or effective range of an object (e.g. surveillance camera or siren) can be considered a fifth spatial property of an object. The spatial properties of an object can change in time.

Digital spatial representations (models) of real-world objects and beings have to be developed in order for computer systems to apply spatial algorithms. Use cases determine which of these spatial parameters are required to represent the object, and how the object will have to be spatially modelled. In most cases, only the location is needed, but in specific cases the other spatial properties matter.

Objects can be modelled using a vector or raster method. In the vector method, points, lines, regions, or solids can be used to represent an object. The raster method uses pixel or voxels. The vector method is often used for discrete data (i.e. with clearly defined borders), and raster representations for continuous data (e.g. distributions of height, pollution, temperature, etcetera). However, it is possible to use and mix both models.

CityGML (Gröger, et al., 2012) is an information model that can be used for the spatial representation of (sets of) 3D urban objects. CityGML provides common definitions of the basic entities, attributes, and relationships. The model contains 13 modules, i.e. Core; Appearance; Bridge; Building; CityFurniture; CityObjectGroup; Generics; LandUse; Relief; Transportation; Tunnel; Vegetation; and WaterBody. Figure 2.2 shows the top level class hierarchy of the CityGML information model.

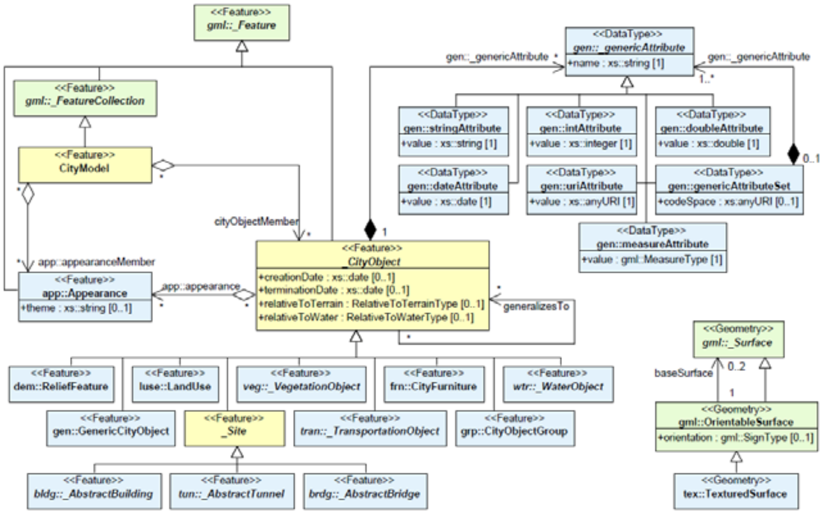


Figure 2.2 CityGML's top level class hierarchy (Source: Gröger et al., 2012.)

CityGML supports different Levels of Detail (LoD) for various application requirements, e.g. for spatial analysis and modelling, less detail is required or needed than in the case of data visualization. Therefore, the same object can be represented in different LoDs simultaneously, enabling the analysis and visualization of the same object at different degrees of resolution.

As CityGML is a generic model, in most cases this model has to be tailored for specific situations. The GenericCityObject and GenericAttribute classes (defined within the Generics module) can be used for modelling objects that are not covered by the thematic classes or which require attributes not represented in CityGML.

Objects are often derived from, or have relationships to, objects in other databases or data sets. CityGML allows for making external references links to corresponding objects in external information systems (Figure 2.3) using unique identifiers (URIs). In this way, external references can be made between the spatial representations of smart things in the CityGML model and their descriptions in external asset management systems.

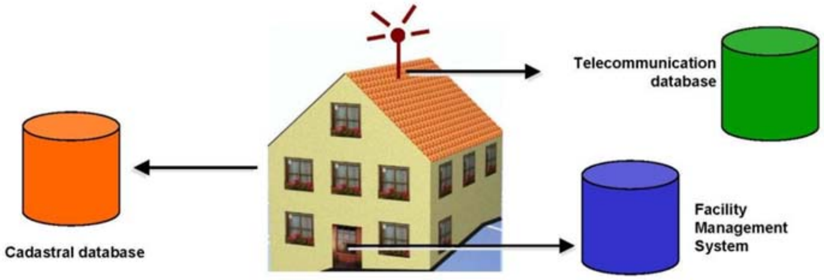


Figure 2.3 External references (Source: Gröger et al., 2012.)

Most objects in CityGML are spatially modelled in real-world coordinates (e.g. buildings, bridges). In other cases (e.g. city furniture), objects are modelled as prototypes (see Figure 2.4) of which the shape, size and orientation can be adapted using a transformation matrix that facilitates scaling, rotation, and translation of the prototype. The prototypes are spatially modelled using an internal coordinate system and positioned in real-world coordinates using a 2D or 3D base-point.

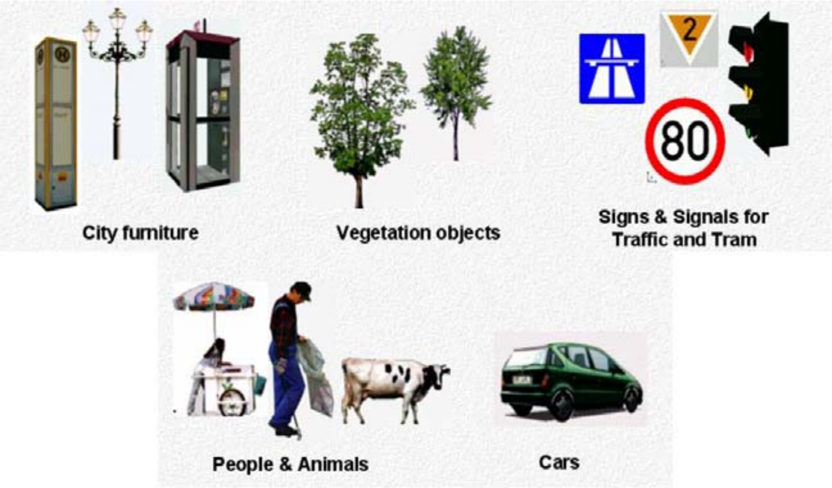


Figure 2.4 Examples of prototypic shapes (Source: Gröger et al., 2012.)

The CityObjectGroup class in CityGML can be used to group spatial objects. This is valuable, as objects often consist of a collection of smaller objects, some of which are smart objects. As the definition of a thing is quite broad, grouping gives the flexibility to spatially constitute things from other things.

3 Position, orientation, and dimension

3.1 Positioning methods

To be able to perform spatial analysis on objects in a smart city, the position of these objects needs to be known. Many methods are available to determine the position of an object. Zeimpekis et al. (2006) provide a nice description of the various methods (Figure 3.1).

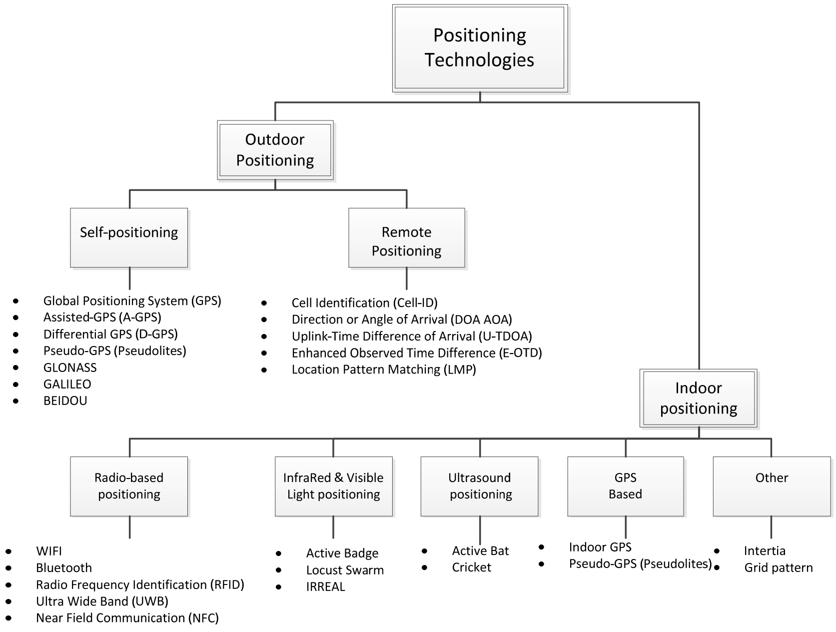


Figure 3.1 Outdoor and Indoor positioning methods (Source: Erik van der Zee, 2013. Based on Zeimpekis et al., 2006.)

The type of positioning method that can be applied depends on, for example, the size of the object (available physical space for placement of a positioning sensor in the object); the location of the object (indoor versus outdoor, above/on/in the earth's surface); the available power sources at the location of use and the type of use; and the accuracy necessary for that use.

3.2 Positioning accuracy

The accuracy of a measurement system is the degree of closeness of the measurements of a quantity to that quantity's actual (true) value. The precision of a measurement system is the degree to which repeated measurements under unchanged conditions show the same results. Dias (2007) presents an overview of common positioning technologies related to accuracy and operation scales.

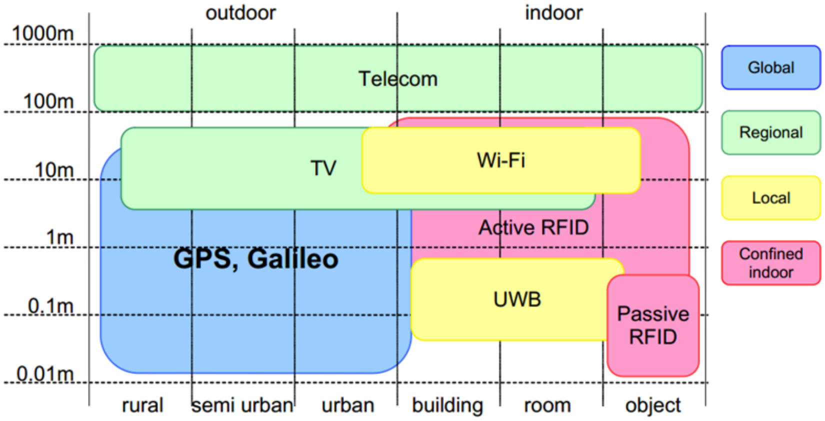


Figure 3.1 Positioning technologies: accuracy and operation scales (Source: Dias, 2007.)

3.3 Spatial orientation

In some use cases, the orientation (pitch, roll, yaw) of an object becomes important. For example, in the case of a surveillance camera, it is useful to know in which direction a camera is pointing and which area the camera is covering. Or, in the case of pictures taken with smartphones, when the orientations and positions of photos are stored, the positions of objects or people in that photo can be determined through, for example, Photosynth technology.

The spatial orientation of smart objects can be determined directly through sensors (e.g. Gyroscope and compass chip), or indirectly (e.g. determining the orientation of an object through 3D object recognition technologies). The orientation information can be stored in the header of photos or video frames.

3.4 Spatial dimension

Considering the dimension of objects, it depends what we consider to be the object. Large objects like cars, trains, planes, and ships consist of many smaller objects, some of which are smart objects, able to detect their own position or orientation. This goes down to the microscopic levels (nano robots).

Spatial dimension plays an important role in spatial context, e.g. in “Does it fit?” cases, like “Does this container fit in that ship?”, or “Can this truck pass under that bridge?”. If containers could broadcast their dimension, misfitting could be prevented. If bridges could warn approaching trucks that they are too high to pass, trucks would not get stuck under bridges.

Spatial dimension is related to spatial modelling. The way an object is modelled (0D, 1D, 2D or 3D model) determines whether this spatial property can be used or provided by smart objects.

4 Geo-enabling events

4.1 Event sources

Information events can be produced by intelligent agents or by humans. Intelligent agents autonomously observe the environment through sensors (e.g. camera, microphone, chemical). The sensor data can be processed and published as events. People can also observe the environment using their natural sensors (eyes, ears, nose, tongue, tactile nerves) and brains. They can publish their observations through applications (e.g. social media applications like Twitter, YouTube, Flickr, Blogs) that run on fixed or mobile devices, e.g. smartphones (Roche, et al., 2012). Meta-information on the status of smart objects (e.g. "battery low") can also be sent as events.

Sensors can measure in-situ (i.e. in direct contact with an object or medium, e.g. a water temperature sensor in water) or remotely (i.e. in indirect contact with an object or medium, observing or interacting with an object or medium indirectly either actively or passively, e.g. a surveillance camera detecting cars' number plates from a distance). In remote sensing, a distinction between passive and active remote sensing can be made, see Figure 4.1a.

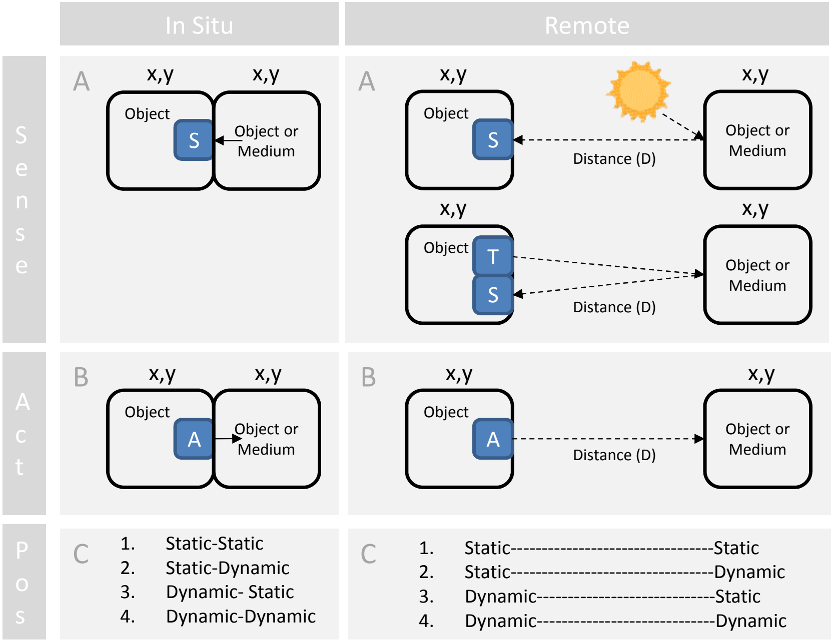


Figure 4.1 In-situ versus remote sensing (a) and acting (b). (c) Indicates that while sensing or acting, the position of objects can be static or dynamic (Source: Erik van der Zee, 2013.)

During sensing, the position of objects can be static or dynamic. Figure 4.2 shows examples of sensors mounted on static or dynamic objects.

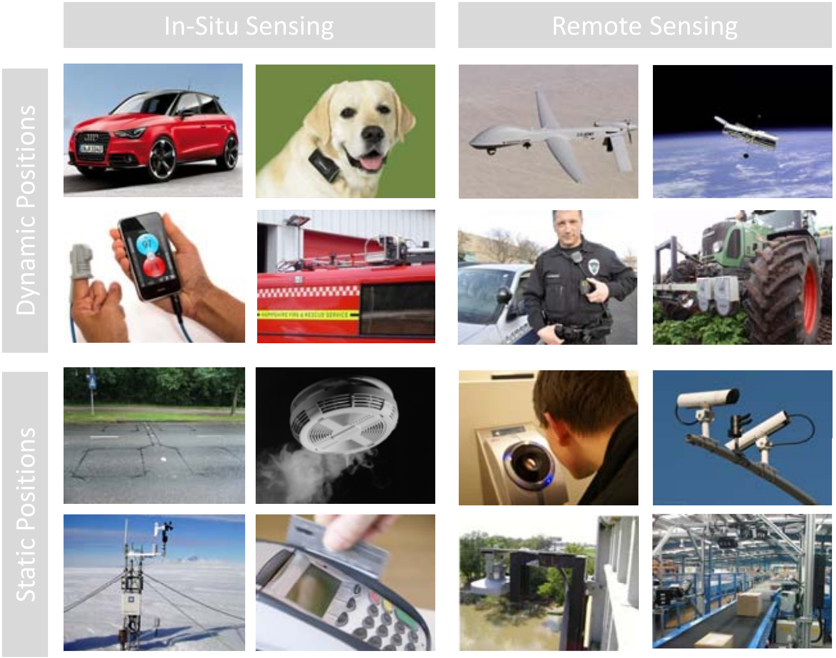


Figure 4.2 Examples of in-situ and remote sensing objects (Source: Erik van der Zee, 2013.)

4.2 Geo-enabling events

To be able to perform spatial analysis on events, the events have to be geo-enabled. Figure 4.3 depicts five methods for geo-enabling events, depending on the capabilities of the object. In cases (a) and (b), the object has a positioning chip on board, the events can be spatialized by the object itself. In cases (c)(d)(e), and (f), the object does not have a positioning chip on board. In such cases, spatializing events can take place client- or server-side (depending on the capabilities of the object), using external geocoding or geotagging services. In the examples of Figure 4.3, only server-side geo-enabling is elaborated. The spatial information can be stored either in the metadata (e.g. header) of a file (e.g. GeoTIFF), or in the event message itself (e.g. GeoJSON, GeoRSS, GeoSMS, KML, GML).

In case (a), the internal positioning chip (e.g. GPS) can be used to spatialize the events from sensors or apps installed on the object. The resulting GeoEvents can be sent to an event stream for further real-time spatial analysis. Also the position(s) of the object itself (with ID0) can be sent to the event stream. An example is a smartphone with a health app connected to external sensors (e.g. blood pressure, heart rate).

In Case (b), RFID tags on object ID1 are read by a mobile (GPS-enabled) mobile RFID reader ID2. The resulting RFID reading events can be spatialized using the location chip, thus creating GeoEvents that can be sent to an event stream for subsequent real-time spatial analysis. Also the position(s) of the object itself can be sent to the event stream.

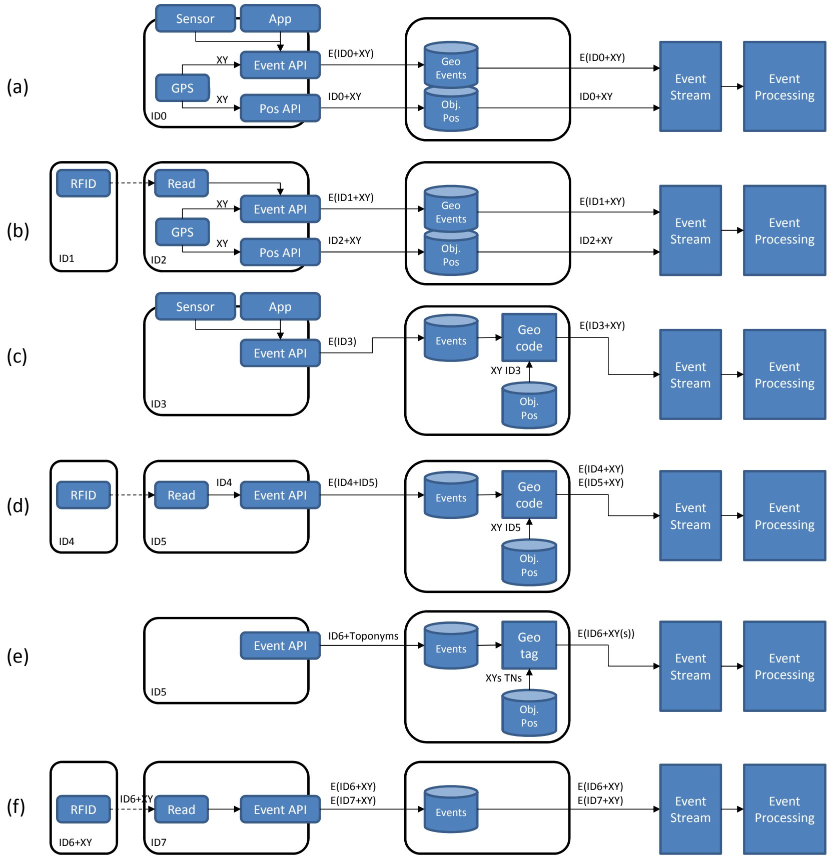


Figure 4.3 Methods to geo-enable events (Source: Erik van der Zee, 2013.) Note: For RFID also Bluetooth, NFC, or similar methods can be read.

In case (c), the object does not have an internal positioning chip, but the spatial position of the object and ID (ID3) are known (stored in a spatial object database). Using a geocoding service (which returns an XY position based on an ID), events can be spatialized based on ID. Examples of this are smart assets with a fixed position e.g. surveillance cameras, environmental sensor devices, and mobile network antennas.

In case (d), an RFID chip (ID4) is read by an RFID reader (ID5) without a positioning chip. An event containing the IDs (ID4 and ID5) is created (e.g. a bankcard with ID4 was scanned by ATM with ID5, time=yyyy:mm:dd hh:mm:ss). When the position of the RFID reader with ID5 is known (stored in a spatial object database), the position of the RFID reader can be assigned to ID4. In this way, two GeoEvents can be created. With a different technology (e.g. Bluetooth) the distance between objects ID4 and ID5 can become greater creating a positioning error. Examples illustrating this case are RFID readers with a fixed position and without a positioning chip, such as ATM machines, public transport gates, and readers in logistic centers.

In case (e), the event does not have a GPS chip, nor a known position related to an ID. In this case, if the event message contains one or more toponyms, the event can be geotagged using the known positions of the toponyms. Examples are RSS feeds that contain toponyms such as the name of an address or a Point Of Interest (POI), or other references that are stored with a location in the spatial database. For example, the toponym “O’Leary's Irish Pub” + “Utrecht” returns lat 52.099124 long 5.115681. Other examples include a RSS feed from a blog page or a QR tag message containing toponyms. As the data is unstructured, it can contain spelling errors, so in some cases no match will be found. In other cases, more than one location will be assigned to the event, if the unstructured text contains multiple toponyms.

In case (f), location information (spatial coordinates) is encrypted in a Bar code or QR code, or is stored on board in an RFID or NFC chip. When scanned, the position of the object is revealed, and can be attached to the event. In cases where it is certain that an object will stay in the same location (e.g. a chip in a concrete wall or buried into the soil of a dike), the location may be stored on the chip itself.

A special way of positioning is by using object and subject (face, gesture) recognition algorithms. Footage of surveillance cameras (with known positions) or geotagged crowdsourced photos and videos are the basis for this type of analysis. Using the algorithms, number plates, faces and voices can be detected. Since the video or photo material is geotagged and timestamped, the location and time where and when the object or subject was seen can be deduced. For example, when a new geotagged photo is posted on the web (e.g. Picasa, Flickr), a photo recognition scan action can be triggered. When a person is recognized, an alert can be initiated subsequently. In the case the video or photo material is not geotagged, sometimes the location can still be deduced, e.g. when a photo contains a face and a well-known object (landmark). When the landmark is recognized by object recognition and the position is stored in a spatial database (e.g. Eiffel tower), then the position of the face (person) can be deduced.

Last but not least, through direct Machine-to-Machine (M2M) communication, smart objects without positioning capabilities can also retrieve a position from another nearby smart object that has a positioning chip, inferring thus its own position from the other object.

5 Spatial context

5.1 Spatial context of Things

Spatial context is an important aspect in the Internet of Things, as all physical and virtual objects have spatial relationships with other objects. This characteristic can be used for the effective deployment of smart objects. Spatial algorithms (relationships, functions and models) can be applied to geo-enabled objects, events, and their effect areas, in order to determine and analyse the spatial context. The definitions of spatial relationships and functions are standardized by ISO (2011).

The spatial context of smart objects and events relates to: (1) the effective area and range of sensors and actuators of these objects or events; and (2) the spatial relationships between smart objects and events and other (smart) objects or events. Spatial context is applicable to both physical and virtual objects. Physical objects are objects tangible and visible in reality. Virtual spatial objects with real-world positions are objects that do not exist in reality, but which do have an influence in the environment, e.g. virtual zones (permit areas, administrative areas, danger zones). Alternatively, they can be virtual 3D objects (virtual sculptures), which can be made visible through, for example, augmented reality techniques. Smart virtual objects (with virtual sensors and actuators) can even create virtual events.

5.2 Effective area

The first aspect of spatial context is the effective area. The sensors and actuators of smart objects have an effective area or sphere of influence. This can be a sensing range (e.g. the view area of a surveillance camera, the measuring range of a smoke detector), or an actuating range (e.g. the audible range of an air alarm, wifi transmitter range, light beam of a lighthouse). These ranges can be modelled as 2D or 3D spatial objects and can then be used in spatial context algorithms.

As spatial properties (location, shape, size, orientation) and non-spatial properties of smart objects and events can change over time, the spatial properties of effect areas can be static or dynamic in time as well. For example, when the focal length or tilt angle of a surveillance camera lens changes, the shape and size of the view area of the camera changes, and when the bearing of the camera is changed, the orientation of the view area changes as well.

5.3 Spatial relationships

The second aspect of spatial context is spatial relationships. A spatial relationship can be used to geographically select (smart) objects that match a certain spatial relationship condition. Figure 5.1 presents an overview of seven commonly-used spatial relationships between (smart) objects that are spatially modelled as points, lines, or regions (polygons).

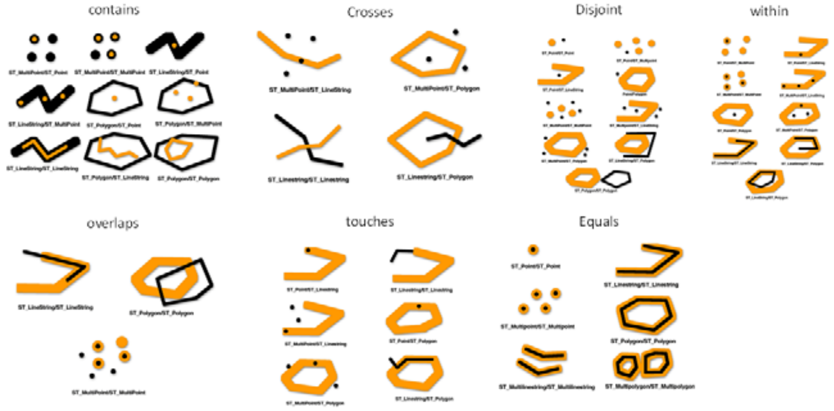


Figure 5.1 Overview of common spatial relationships. Source: Esri Inc. (2013a)

A commonly used spatial relationship in Location Based Services is the “within” relationship. For example, when an tourist with a smartphone is entering a virtual zone (e.g. a municipality area), the “within” spatial relation is true, and based on this, some action can be taken, e.g. sending a message with touristic information to that phone. Or, when a criminal with an electronic bracelet is entering a no-go zone, an alarm can be sent. Or when a smartphone or car is within 500m from home, the carport opens and the coffee machine switches itself on. The possibilities of using spatial relationships in real-world use cases are virtually endless.

5.4 Spatial functions

A spatial function creates one or more new spatial features based on the spatial properties of the input objects. The newly created spatial features can be associated or assigned to objects. Figure 5.2 shows some commonly used spatial functions. Other spatial functions include spatial joins, routing, and geocoding. A geocoder/reversed geocoder returns x,y coordinates based on address information, and vice versa. A routing function calculates a route based on ‘from’, ‘to’, and ‘via’ locations. A spatial join makes it possible to transfer attributes from one object to another based on spatial relationships.

A commonly used spatial function is the “buffer” function. For example, based on the range property of an air alarm (e.g. 500m) and the position of that object (x,y), a geographic buffer function can be applied, creating a new spatial object (region) that spatially represents the effective range of that air alarm. It can be associated with the air alarm object and subsequently be used in other spatial algorithms.

Spatial interpolation functions can be used to predict sensor values at locations where no physical sensors are present. For this, input from nearby sensors is used. There are many spatial interpolation methods, e.g. splines, IDW, and Kriging.

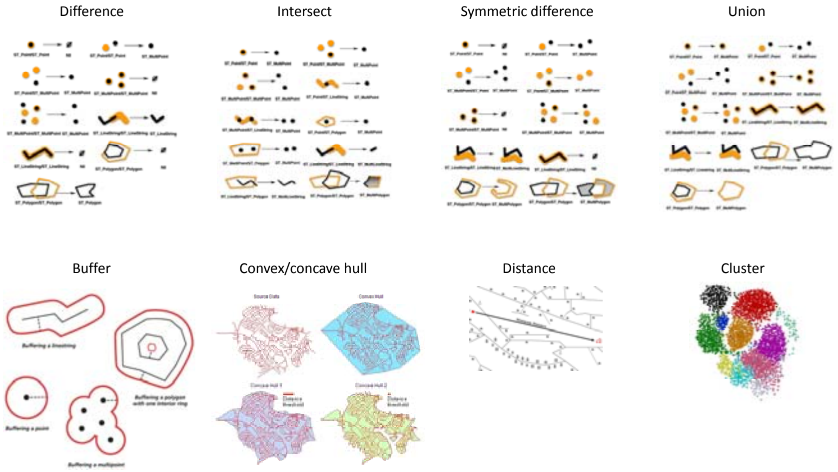


Figure 5.2 Overview of common spatial operations. Source: Esri Inc. (2013b)

5.5 Spatial models

On the basis of historical and current data, a spatial model can predict future situations. Model output (predictions) can be used to initiate precautionary actions on things. For example, when a weather model predicts severe rainfall for a certain area, a flood model can calculate the expected excess rainwater. Subsequently, water drainage can be preventively intensified by stepping up the pumping activity (actuators) at certain locations in the effect area. An example of a flood forcasting model based on real-time sensor data is described by Berger (1991). Things can also activate themselves for self-protection, e.g. a windscreen that is subscribed to a weather alert service, will automatically wind up when a storm is predicted for its location.

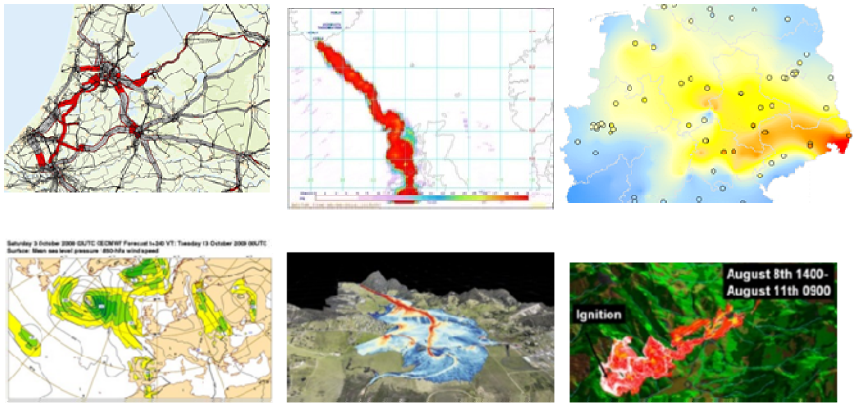


Figure 5.3 Examples of spatial model output First row (a) traffic jams (b) smoke plume (c) air quality. Second row (d) weather (e) flood (f) wildfire (Source: Internet.)

6 Spatial integration

6.1 *The OODA loop*

In a smart city, large numbers of smart objects are connected to the Internet. These smart objects can be used either to monitor their environment (i.e. other objects, events or subjects) through their sensors or to act on the environment by using their actuators. To use the capabilities of smart objects efficiently, a continuous process of orchestration and choreography of smart objects is needed. This process is described by Boyd (1987). The Observe-Orient-Decide_Act (OODA) model captures what happens between the onset of a stimulus and the onset of a reaction to that stimulus (Figure 6.1).

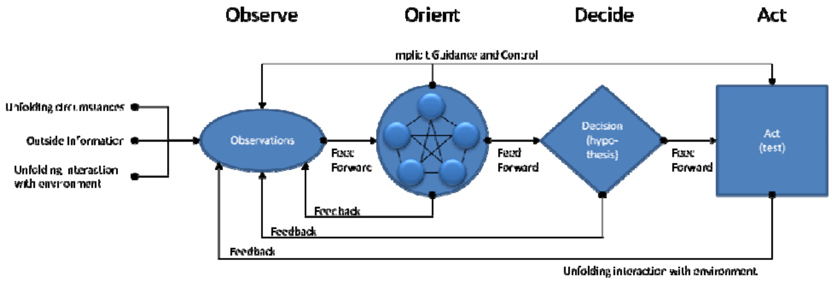


Figure 6.1 Boyd’s OODA loop (source: Boyd, 1987.)

In all the phases of the OODA loop, spatial concepts and technology can be integrated and used to improve the efficiency of processes in a smart city (Figure 6.2).

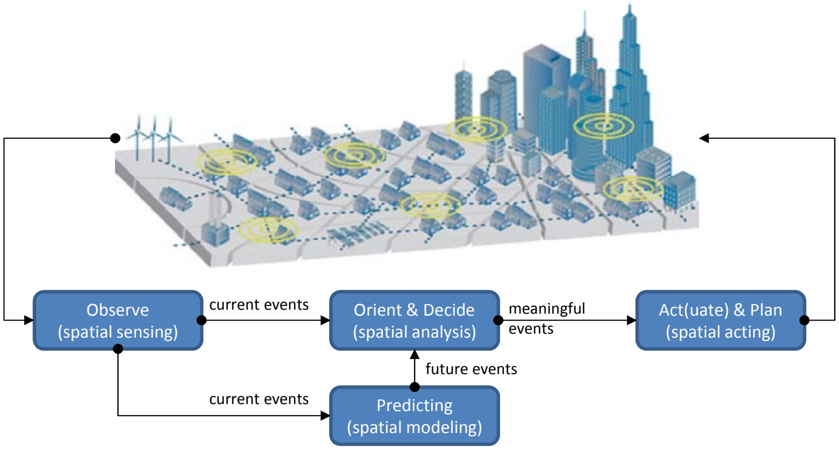


Figure 6.2 Continuous loop of sensing, analysing, predicting, and act(uat)ing in a smart city (Source: Erik van der Zee, 2013.)

Based on location, appropriate sensors and sensing ranges can be selected or activated. Spatial decisions can be made in real-time based on spatial characteristics of observations, and by applying spatial algorithms (relationships, functions, models) to positions of object and events. Furthermore, based on detected spatial patterns or exceeded spatial thresholds, appropriate actuators and actuating ranges can be selected or activated spatially.

6.2 Central versus decentral spatial processing

The process of spatial orchestration and choreography of smart objects has to be managed either centrally or decentrally depending on the “smartness” of the object. In this respect, the different levels of complexity of the use case and the actors (related to the five phases of evolution of the IoT, as mentioned by Casaleggio Associati (2011)) have to be considered.

When smart objects become autonomous intelligent agents, they can operate independently and make certain (spatial) decisions autonomously (client-side), based on their spatial capabilities (e.g. calculating the shortest route). Additionaly, agents can acquire (pull) additional contextual spatial information (e.g. “Which smart objects with certain capabilities are closeby?”) or receive (push) instructions (“Go to location x,y using route r and look there for a person with a red coat and blue pants.”) from central systems. Intelligent systems can also retrieve contextual spatial information directly from other smart objects nearby (e.g. asking information from nearby sensors using M2M communication).

Depending on the intelligence of a smart object, their events are either simple measurement values or the outcome of a complex internal analysis, performed client-side by the smart object, signalling a problem or an impending problem, an opportunity, a threshold, or a deviation. For example, when a surveillance camera has built-in face and number plate recognition capabilities, it could act as an intelligent agent, looking out for a wanted person or car by comparing a photo of that person or car number plate with its own direct observations. It will only send a georeferenced event (alert) when that person or car is detected, instead of sending unnecessary continuous streams of raw camera data to a central server for processing.

Especially for moving autonomous agents like drones and robots, real-time spatial situational awareness (Where am I? Where am I going? Where are other (smart) objects and subjects? And, where are they going?) will be vital for efficient operation in the Internet of Things.

6.3 Real-time spatial processing

Since many things and their events continuously change their spatial characteristics (e.g. smart phones), real-time spatial processing in the IoT is needed. By integrating spatial algorithms in a SOA-EDA architecture as shown in Figure 6.3, spatial event stream processing can be realized. Through an enterprise integration backbone, spatial services can be combined with other non-spatial business services.

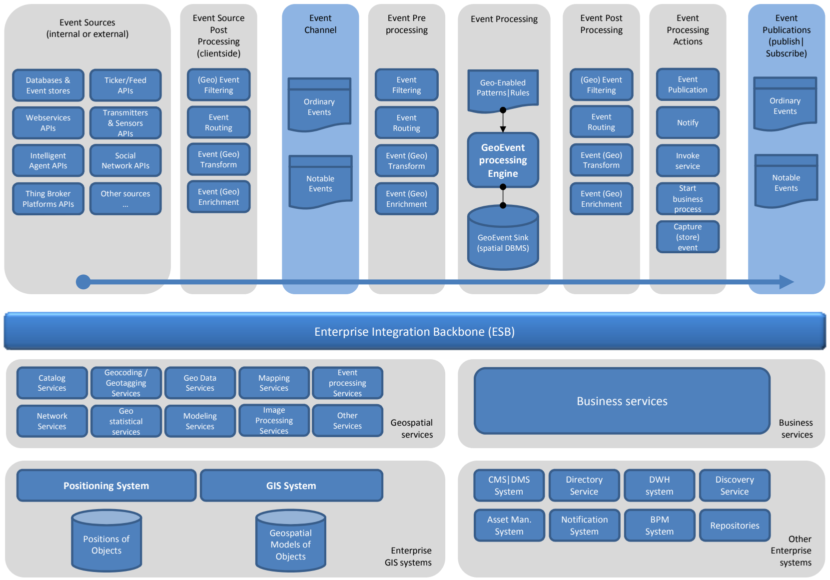


Figure 6.3 Integration of enterprise GIS in a SOA-EDA architecture. Note: Bottom layer: systems and services. Middle layer: Enterprise Integration Backbone. Top layer: the spatially enabled EDA process running in the EDA extension of the ESB (Source: Erik van der Zee, 2013.)

GeoEvent streams can be analysed in real-time by a GeoEvent Processing Engine using predefined spatial conditions (patterns). Simultaneously, the same sensor data can be used for making predictions (e.g. weather, flood, fire propagation prediction). Once a pattern is found (e.g. threshold exceeded), appropriate automated or semi-automated actions or scenarios can be initiated.

6.4 *Catalogue of things*

In the Internet of Things, with its billions of sensors and actuators, it is vital to know where they are, and what they can measure or do. To effectively orchestrate and choreograph things with sensors and actuators in the IoT, a standardized catalogue services is required. This catalogue can be queried on location by objects or by operators, e.g. “Give me all air quality sensors in a range of 1.5 km from location x,y”, or “Give me all cameras with Automatic Number Plate Recognition(ANPR) capabilities in an area of 500 m around abc street”. A good “things” catalogue with spatial capabilities is vital and can be used to select the appropriate sensors or actuators in patterns or action scenarios. A catalogue service standard for geospatial data sets and webservices is available (OGC CS-W 2.0) Nebert, et al. (2007). A candidate standard for a sensor catalogue service Jirka and Nüst (2010) is proposed as part of the OGC SWE standards. The application of semantic web concepts to sensor discovery has been described by Pschorr et al. (2010).

6.5 *Acting on smart objects*

The last step in the OODA loop is acting. Based on sensor input and pattern analysis, notable events are generated by the Event Stream Processing (ESP) engine, and certain actions are initated. These actions or scenarios can be defined using business process models or business rules engines in an Enterprise Service Bus (ESB). This can include for example sending alerts, activating actuators in the right place, etc. Sensors and actuators can also react directly to each other through M2M communication, e.g. an irrigation system with smart soil moisture sensors and smart valves. When certain sensors detect drought, they can ask the valves to orientate themselves such that the water flows towards that sensor.

Physical actuators can be speakers, lights, motors, and electronic switches. Figure 6.3 shows examples of in-situ and remote acting objects. In most cases, smart objects contain both sensors and actuators (e.g. a surveillance dome camera contains an image sensor, a microphone sensor, and actuators like electro-motors to change the direction and zoom of a camera).

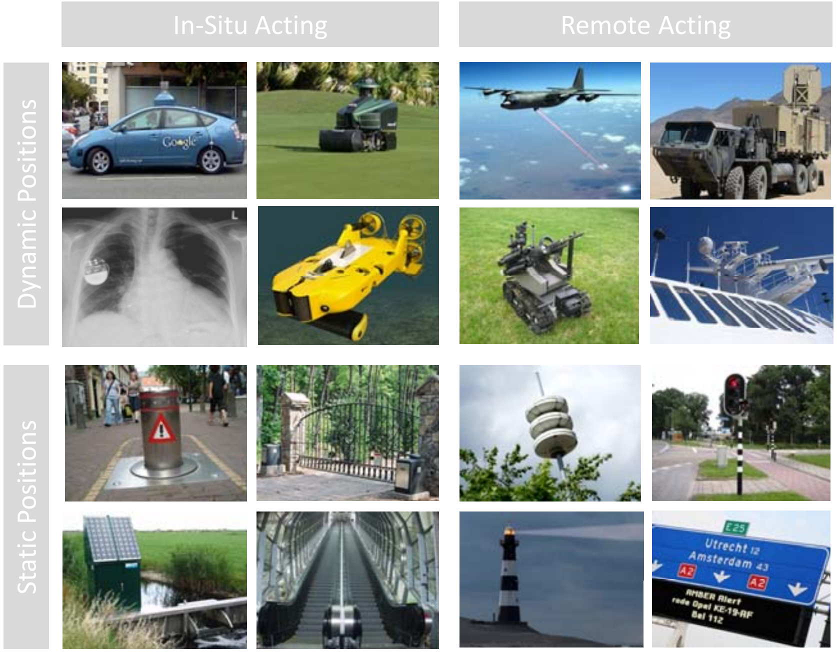


Figure 6.3 Examples of in-situ and remote acting objects (Source: Erik van der Zee, 2013.)

6.6 A sensing and acting scenario

Sensors at a large chemical complex detect smoke or high temperatures, sent as GeoEvents. ESP Engine pattern analysis reveals “fire”. As the position of the sensors is known, the fire can be pinpointed to a location. A smoke-plume model can calculate the direction of the smoke, using as input the location of the fire and using data from the closest weather sensors (using the “nearest” spatial algorithm). The model predicts a danger zone, people in the smoke-plume area are alerted by triggering the GSM towers in that area (using the “inside” spatial algorithm) to transmit a cell broadcast. The appropriate air alarms in the direction of the smoke are signalled (the properties of the air alarms are used to make the selection, range of air alarms = 900m, inside algorithm with smoke area). The right actuators (sprinklers) in the fire area are activated, and the appropriate fire doors are closed. To select the right actuators and sensors, a sensor catalogue service is used. Then the closest fire department is warned (nearest algorithm), the position of the fire is sent to the fire truck and to the control rooms, the shortest route is calculated (routing algorithm, from position = fire station, to position = location of fire). The fire truck drives off, following the route. The firetruck's position if determined by its GPS sensor, and based on this position and the predicted route, the traffic light gives green light to the fire truck, open bridges on the route are closed, and automatic bollards (in Dutch "pollers") are lowered.

7 Spatial technology

7.1 *Geospatial technology stacks*

In the past, geospatial technology used to be specialized ‘island’ technology, a niche using its own dedicated protocols and programming languages. But, recently, this situation has changed. Modern spatial technology components are based on W3C, ISO, and OGC standards, and use regular programming languages like C++, C#, Java, and Python, making it easier to integrate geographical technology in service oriented (SO) or event driven (ED) architectures (A).

A typical geospatial SOA stack consists of a spatial database, a GIS server, spatial data loading (spatial-ETL) tools, and webservice APIs integration, for example through an Enterprise Service Bus (ESB). Nowadays, geospatial technology is progressing fast. Traditional relational databases all contain spatial capabilities (e.g. Oracle, Microsoft SQL Server, Postgres, MySQL), and also non-traditional NoSQL databases are also becoming spatially enabled (e.g. Neo4J, MongoDB, CouchDB).

Recently, various vendors have extended their products with EDA real-time spatial capabilities. Ali et al. (2010) describes the spatio-temporal stream processing possibilities of Microsoft Streaminsight. Oracle provides real-time geostreaming and geofencing possibilities by combining the Oracle Spatial Database with the Oracle Complex Event Processing engine (Sharma, 2011). Esri Inc. released in 2013 their GeoEvent Processor module (Figure 7.1) as an extension of the ArcGIS Server environment. This module can perform real-time geospatial analysis on geospatial events (Mollenkopf, 2013).

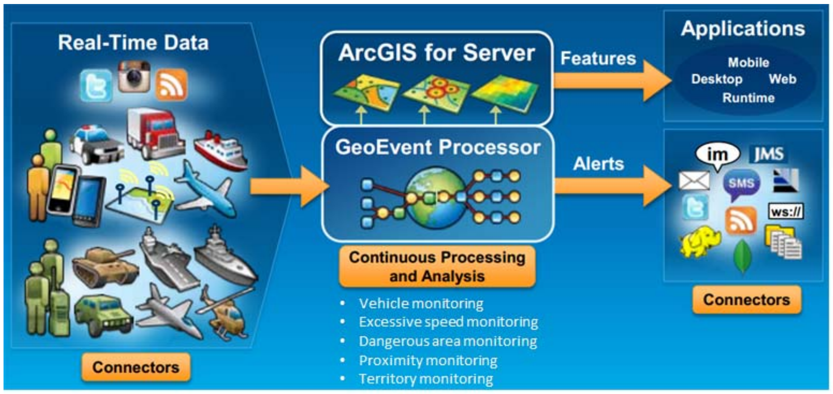


Figure 7.1 Esri GeoEvent Processor (Source: Mollenkopf, 2013.)

These developments enable the integration and leverage of spatial technology in the Internet of Things.

7.2 *Geospatial standards*

In the geospatial domain, standardization efforts are coordinated by the Open Geospatial Consortium. “The Open Geospatial Consortium (OGC) is an international industry consortium of 484 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. The OGC® Standards support interoperable solutions that ‘geo-enable’ the web, wireless and location-based services and mainstream IT. The standards empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications” (OGC, 2013). The OGC has a broad user community and alliance partnerships with more than 30 standards organizations, amongst others, ISO, W3C, and OASIS.

The consortium has currently adopted 35 standards which are implemented worldwide in a variety of Geo-IT products and solutions. The standards can be grouped in catalogue services, data services, portrayal services, processing services, encodings and others. For the sensor and actuator networks and the IoT, the OGC has developed the Sensor Web Enablement (SWE) 2.0 standard suite (Botts, et al., 2007). Klopfer et al. (2009) described real-world use cases with the OGC SWE standards. The SWE protocols have been tested in what are called OGC Web Services (OWS) Testbeds phase 4 (SOS), 5 (SPS), 6 (SES) and 7 (integration).

The OGC has identified the need for standardized interfaces for sensors and actuators in the Internet of Things. Therfore, the OGC formed a ‘Sensor Web for IoT’ Standards Working Group (IoT SWG, 2013). The IoT REST API SWG aims to develop such a standard based on existing IoT portals with consideration of the existing OGC Sensor Web Enablement (SWE) standards. The OGC PUCK protocol (OGC, 2012) facilitates the publication of vendor-specific information of things, which makes it easier to “plug and play” things into sensor networks and the Internet of Things.

8 Case Studies and Examples

This section presents some case studies and examples of the efficient use of spatial concepts and technology related to the Internet of Things.

8.1 Smart recycling bins

Smart recycling bins with sensors can alert when the bin is reaching ‘full’ level. As the positions of the bins are known and the containers send their status to a central server, spatial route-planning capability enables waste collection companies to manage their bins in the most efficient manner, collecting on a “as-needed” basis instead of collecting on scheduled regular basis (e.g. once per week). This contributes to substantial savings in fleet management costs. For more information at http://www.smartbin.com.

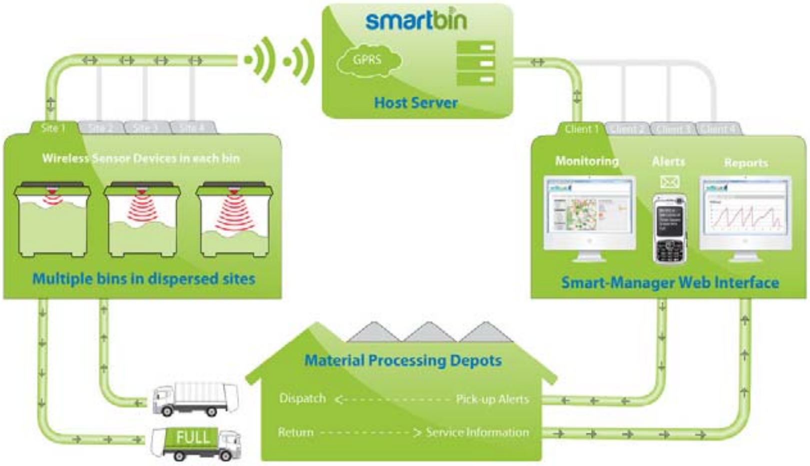
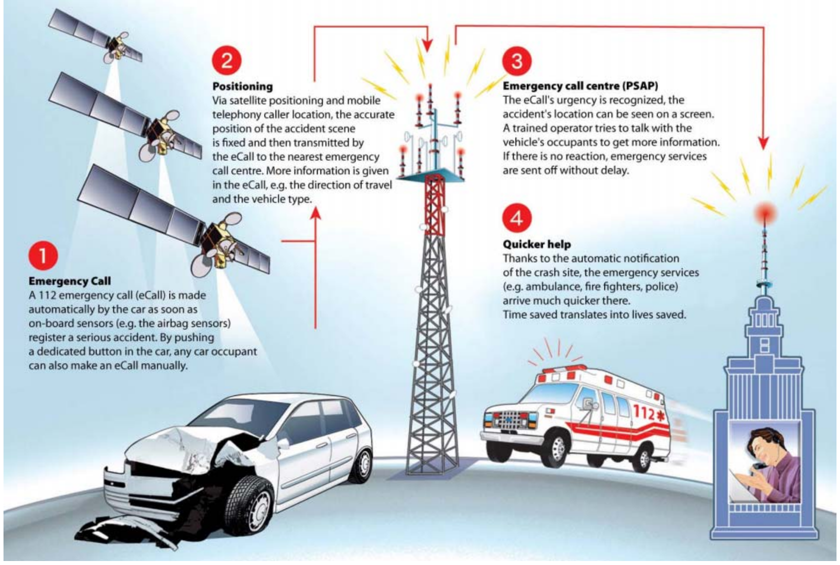


Figure 8.1 smartbin workflow. Source: Smartbin (2013).

8.2 Smart cars (eCall)

A European Parliament adopted resolution, issued in June 2012, states that new vehicles have to be equipped with the eCall system by 2015. The eCall system in a car automatically calls 112 when an accident has happened. The warning message contains impact sensor information, as well as GPS coordinates. The information is sent to the nearest emergency response authority, which can use the GPS coordinates to calculate the shortest route to the accident. For more information at https://ec.europa.eu/digital-agenda.



① **Emergency Call**
A 112 emergency call (eCall) is made automatically by the car as soon as on-board sensors (e.g. the airbag sensors) register a serious accident. By pushing a dedicated button in the car, any car occupant can also make an eCall manually.

② **Positioning**
Via satellite positioning and mobile telephony caller location, the accurate position of the accident scene is fixed and then transmitted by the eCall to the nearest emergency call centre. More information is given in the eCall, e.g. the direction of travel and the vehicle type.

③ **Emergency call centre (PSAP)**
The eCall's urgency is recognized, the accident's location can be seen on a screen. A trained operator tries to talk with the vehicle's occupants to get more information. If there is no reaction, emergency services are sent off without delay.

④ **Quicker help**
Thanks to the automatic notification of the crash site, the emergency services (e.g. ambulance, fire fighters, police) arrive much quicker there. Time saved translates into lives saved.

Figure 8.2 E-Call, how it works Source: European Commission digital agenda (2013).

8.3 Location based dating

Location based dating connects people with the same hobbies, ideas or status (e.g. single) based on (smartphone) location. When two people with a matching profile are within a certain distance, they get an alert on their phones. Examples of location based mobile dating services include Brightkite, Grindr, Meetmoi, Okcupid, Sonar, and Skout. The same principle could be applied to "dating" of IoT devices.

8.4 Location based marketing

In marketing, location is important to show exactly the right advertisements or touristic information to the right people at a certain location and time. The value of location based marketing is explained by Schmeisser (2011).

8.5 IJkdijk(smart dikes)

IJkdijk (Peters, et al., 2010) (Pals, et al., 2009) is an experimental dike which contains sensors that enable the continuous monitoring of the condition of the dike. When saturation occurs, the location of weaknesses and possible breaches can be detected at an early stage, and the necessary precautions can be initaited. For more information at http://www.ijkdijk.nl.

8.6 Meteo radar alerts

Using weather sensors and spatial prediction models, weather patterns can be predicted and weather alerts can be sent to people's smartphones or to things, e.g. smart umbrellas or other weather-dependent things. This can be combined with route planning, predicting routes that keep you dry. A good example is The Netherlands meteo radar ('Buienradar' in Dutch) alerts. Rain alerts can be set based on shower distance, and communicated via a smartphone app. For more information at www.buienradar.nl.

8.7 National Data Warehouse for Traffic Information

The Nationaal Datawarehouse Wegverkeersgegevens (Viti, et al., 2008) is a datawarehouse that receives real-time data from the highway. It is a system of sensors (ANPR cameras, inductive-loop vehicle classifier and speed sensors) and actuators (matrix signs, traffic lights) working closely together in a semi-automated or automated way to manage traffic jams, accidents. When the positions of cars are known, traffic jams can be pinpointed, and subsequently the traffic flow can be diverted or regulated by smart traffic lights. For more information at http://www.ndw.nu.

8.8 ANPR cameras

In the detection of crime or the enforcement of the law, location plays an important role. As cameras become smarter, they are able to detect number plates and faces. ANPR cameras are used in The Netherlands for the enforcement of environmental zones to improve air quality. For this reason, trucks are not allowed in the city centre at certain hours of the day. When a truck is detected by ANPR cameras in the environmental zone at the wrong time, the number plate can be checked in the central car register and, based on this information, an automated fine procedure is initiated. For more information at http://www.milieuzones.nl.

8.9 Ankle bracelets

More than 100,000 parolees and sex offenders are wearing ankle bracelets in the US. GPS ankle bracelets can be used to track and trace people geographically. When they enter a forbidden neighbourhood (geofence), an automated alarm with the position of the person can be sent to the nearest police station or officer in the field. GPS bracelets can also be attached to people, pets, or things to find them and bring them back more easily if they are missing or stolen. Micheal et al. (2006) describe intriguing emerging ethics of humancentric GPS tracking and monitoring.

9 Epilogue

As the Internet of Things is a holistic concept, collaborative, cross-sectoral, and interdisciplinary research and thinking is needed to design it and to develop it further. It is important to realize that space (location, orientation, dimension) and time play an indispensable role in the Internet of Things, as all objects and the data events they create have spatial properties and are spatially related to each other. Space and time can be the “glue” to connect smart physical devices in an efficient way. Geospatial concepts and technology should therefore be an integral part of an IoT architecture. With ever-increasing computing power and technological advancement in geospatial technology, real-time geospatial analysis can be integrated and used in the Internet of Things.

The United Nations GGIM report on future trends in geospatial information management (United Nations, 2013b) mentions the importance of geospatial technology in relation to IoT. Also, the US Department of Labor designated geotechnology as one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology (Gewin, 2004). Large enterprises like Google, Apple and Microsoft are increasingly using geospatial technology to create location based services. There is an increasing need for skilled people with knowledge on spatial concepts and technology, but unfortunately spatial concepts and technology are only briefly touched on, or even absent in the general IT curricula. A growing awareness is needed, so that general IT programmers and IT architects can become more familiar with geospatial concepts and technology. To achieve this, crossovers between geography and general IT curricula should be made.

10 References

Ali M. [et al.] Spatio-temporal stream processing in microsoft streaminsight [Journal]. - [s.l.] : IEEE, 2010. - Vol. Bulletin of the IEEE Computer Society Technical Committee on Data Engineering.

Beecham Research Sector Map showing segmentation of the M2M Market [Online] // Beecham Research. - 2013. - August 1, 2013. - http://www.beechamresearch.com/article.aspx?id=4.

Berger H.E.J. Flood forecasting for the river Meuse, Hydrology for the Water Management of Large River Boons [Conference] // Proceedings of the Vienna Symposium. - Vienna : IAHS Publication, 1991. - Vol. no. 201. - pp. 317-328.

Botts M. [et al.] OGC® Sensor Web Enablement: Overview And High Level Architecture [Book]. - [s.l.] : Open Geospatial Consortium Inc., 2007. - Version 3. - OGC 07-165.

Boyd J. A discourse on winning and losing [Journal]. - Maxwell Air Force Base : [s.n.], 1987. - Air University Library Document No. M-U 43947 (Briefing slides).

Casaleggio Associati [Online]. - February 2011. - August 1, 2013. - http://www.slideshare.net/casaleggioassociati/the-evolution-of-internet-of-things.

Dias E.S. [et al.] Adding Value and Improving Processes Using Location-Based Services in Protected Areas [Journal]. - [s.l.] : Research on Computing Science, 2004. - Vol. 11. - pp. 291-302.

Dias E.S. The Added Value Of Contextual Information In Natural Areas: Measuring impacts of mobile environmental information [Book]. - Amsterdam : Vrije Universiteit, 2007. - ISBN 978-90-8659-173-2.

Dibiase D. [et al.] Geographic Information Science & Technology Body of Knowledge [Report]. - Washington D.C. : Association of American Geographers (AAG), 2006. - ISBN- 10: 0-89291-267-7, ISBN-13: 978-0-89291-267-4.

Esri Inc. [Online]. - 2013a. - http://edndoc.esri.com/arcsde/9.1/general_topics/understand_spatial_relations.htm.

Esri Inc. [Online]. - 2013b. - http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Spatial_operations.

European Commission Digital Agenda [Online]. - 2013. - http://ec.europa.eu/digital-agenda/en/ecall-time-saved-lives-saved.

Gewin V. Mapping opportunities [Book Section]. - [s.l.] : Nature, 2004. - 427(January). - doi:10.1038/nj6972-376a.

Gröger G. [et al.] City Geography Markup Language (CityGML) Encoding Standard Version: 2.0.0 [Report] / OGC. - [s.l.] : Open Geospatial Consortium (OGC), 2012. - OGC 12-019.

GSMA Guide to smart cities - The Opportunity for Mobile Operators [Report]. - London : GSMA, 2013.

Huisman O. and De By R.A. Principles of Geographic Information Systems – An introductory textbook [Book]. - Enschede : International Institute for Geo-Information Science and Earth Observation (ITC), 2009. - Vol. Chapter 2. - Educational Textbook Series. - ISBN 978-90-6164-269-5, ISSN 1567-5777.

IoT SWG The OGC Forms "Sensor Web for IoT" Standards Working Group [Online] // Open Geospatial Consortium. - 2013. - http://www.opengeospatial.org/node/1650.

ISO Information Technology — Database languages — SQL multimedia and application packages — Part 3: Spatial [Report]. - Geneva, Switzerland : ISO, 2011. - Reference ISO/IEC FDIS 13249-3:2011(E).

ITU Measuring the Information Society [Report]. - Geneva, Switzerland : International Telecommunication Union, 2012. - ISBN 978-92-61-14071-7.

Jirka S. and Nüst D. OGC® Sensor Instance Registry Discussion Paper [Report]. - [s.l.] : Open Geospatial Consortium, Inc, 2010. - OGC 10-171.

Klopfer M. and Simonis I. SANY - an open architecture for sensor networks [Book]. - [s.l.] : SANY Consortium, 2009. - ISBN 978-3-00-028571-4.

Libelium 50 Sensor Applications for a Smarter World [Online] // Libelium. - 2013. - August 1, 2013. - http://www.libelium.com/top_50_iot_sensor_applications_ranking.

Magerkurth C. Internet of Things – Architecture IoT-A Deliverable D1.4 – Converged architectural reference model for the IoT v2.0 [Report]. - [s.l.] : European Commission, 2012. - Deliverable within the Seventh Framework Programme (2007-2013). - IoT-A (257521).

Michael K., McNamee A. and Michael M.G. The Emerging Ethics of Humancentric GPS Tracking and Monitoring [Conference]. - Copenhagen : IEEE Xplore, 2006. - ISBN 978-0-7695-2595-2, doi 10.1109/ICMB.2006.43.

Mollenkopf A. Using ArcGIS GeoEvent Processor for Server to Power real-time applications [Conference]. - Esri International Developer Summit : Esri Inc., 2013.

Nebert D., Whiteside A. and Vretanos P. OpenGIS® Catalogue Services Specification [Book]. - [s.l.] : Open Geospatial Consortium Inc, 2007. - Version 2.0.2, Corrigendum 2 Release. - OGC 07-006r1.

OGC Homepage [Online]. - 2013. - August 1, 2013. - http://www.opengeospatial.org.

OGC OGC® PUCK Protocol Standard Version 1.4 [Book] / ed. O'Reilly T.. - [s.l.] : Open Geospatial Consortium Inc, 2012. - OGC 09-127r2.

Pals N. [et al.] Remote and in situ sensing for dyke monitoring - te IJKDIJK experience [Journal] // GeoSpatial Visual Analytics. - [s.l.] : Springer, 2009. - pp. 465-475. - NATO Science for Peace and Security Series C: Environmental Security. - ISBN 978-90-481-2898-3.

Peters E. and Van der Vliet P. Digidijk & Alert Solutions: real time monitoring van civieltechnische constructies [Journal]. - Gorinchem : SJP Uitgevers, 2010. - Civiele techniek. - pp. 14-16.

Pschorr J. [et al.] Sensor Discovery on Linked Data Technical Report [Book]. - Dayton : Kno.e.sis Center, Department of Computer Science and Engineering, 2010. - http://knoesis.org/library/resource.php?id=851.

Roche S., Kloeck K. and Ratti C. Are 'Smart Cities' Smart Enough? [Book Section] / ed. Rajabifard A. and Coleman D.. - Needham : GSDI Association Press, 2012. - ISBN 978-0-9852444-0-8, D/978-0-9852444-1-5.

Satterthwaite D The transition to a predominantly urban world and its underpinnings [Journal] // Hu-man Settlements Discussion Paper Series. - [s.l.] : International Institute for Environment and Development, 2007. - September : Vol. 2007.

Schmeisser R. Location Based Marketing [Journal]. - [s.l.] : GRIN Verlag, 2011. - ISBN 978-3-640-92240-6.

Scholten H.J., Van de Velde R. and Van Manen N. Geospatial Technology and the Role of Location in Science [Book]. - [s.l.] : Springer, 2009. - Series: GeoJournal Library Vol. 96. - ISBN 978-90-481-2620-0, ISSN: 0924-5499.

Serbanati A., Medaglia C.M. and Ceipidor U.B. Building Blocks of the Internet of Things: State of the Art and Beyond [Book Section] // Deploying RFID - Challenges, Solutions, and Open Issues / book auth. Turcu C.. - [s.l.] : INTECH, 2011. - Vol. Building Blocks of the Internet of Things: State of the Art and Beyond. - DOI: 10.5772/19997. - DOI: 10.5772/963, ISBN 978-953-307-380-4.

Sharma J. Oracle Spatial and Fusion Middleware products OBIEE Suite, JDeveloper, Complex Event Processing [Conference]. - 2011.

Smartbin [Online]. - 2013. - http://www.smartbin.com.

United Nations Future trends in geospatial information management: the five to ten year vision [Report]. - [s.l.] : United Nations - Global Geospatial Information Management (GGIM), 2013b. - D10227.

United Nations Sustainable Development Challenges - World Economic and Social Survey 2013 [Report] / Department of Economic and Social Affairs. - [s.l.] : United Nations publication, 2013a. - ST/ESA/344 - E/2013/50/Rev. 1, ISBN 978-92-1-109167-0, eISBN 978-92-1-056082-5.

United Nations World Population To 2300 [Report] / Population Division ; Department of Economic and Social Affairs. - [s.l.] : United Nations publication, 2004. - ST/ESA/SER.A/236.

United Nations World Urbanization Prospects: The 2011 Revision [Report] / Population Division ; Department of Economic and Social Affairs. - [s.l.] : United Nations publication, 2012. - ESA/P/WP/224.

Viti F. [et al.] National Data Warehouse: How the Netherlands Is Creating a Reliable, Widespread, Accessible Data Bank for Traffic Information, Monitoring, and Road Network Control [Journal] // Transportation Research Record (TRR Journal). - Washington D.C. : Transportation Research Board, 2008. - Volume 2049 / 2008. - pp. 176-185. - ISSN 0361-1981.

Wikipedia Object [Online] // Wikipedia. - 2013b. - August 1, 2013. - http://en.wikipedia.org/wiki/Object_(philosophy).

Wikipedia Thing [Online] // Wikipedia. - 2013a. - August 1, 2013. - http://en.wikipedia.org/wiki/Thing.

Zeimpekis V., Kourouthanassis P. and Giaglis G.M. UNESCO – EOLSS [Book Section] // Telecommunication Systems and Technologies – Vol. I. - [s.l.] : UNESCO – EOLSS, 2006. - Vol. Mobile and Wireless Positioning Technologies.

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List of Abbreviations

The following abbreviations are used in this chapter.

- ADE Application Domain Extensions
- ANPR Automatic Number Plate Recognition
- API Application Programming Interface
- AR Augmented Reality
- CEP Complex Event Processing
- EDA Event Driven Architecture
- ESB Enterprise Service Bus
- ESP Event Stream Processing
- ETL Extract Transform Load
- GGIM Global Geospatial Information Management
- GIS Geographical Information System
- GIS&T Geographical Information Science and Technology
- GML Geography Markup Language
- GPS Global Positioning System
- IDW Inverse Distance Weighted
- IoT Internet of Things
- JSON Java Script Object Notation
- LBS Location Based Services
- LoD Level Of Detail
- NFC Near Field Communication
- OGC Open Geospatial Consortium
- QR Quick Response
- RFID Radio Frequency IDentification
- SOA Service Oriented Architecture
- SEP Simple Event Processing
- SES Sensor Event Service
- SIR Sensor Instance Registry
- SOR Sensor Observable Registry
- SOS Sensor Observation Service
- SPS Sensor Planning Service
- SQL Structured Query Language
- SWE Sensor Web Enablement
- UN United Nations
- UWB Ultra Wide Band

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