SENSOR SERVICES FOR BUILDINGS: A FRAMEWORK AND OPPORTUNITIES

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ABSTRACT:

The Ubiquitous Computing and the Internet-of-Things concepts are gathering more attention day-by-day. In the near future networks of interconnected sensors that are monitoring the environment around us will start to generate enormous amounts of data. This newly emerging paradigm can be named as ‘Sensors Everywhere”. This new paradigm will lead -the focus of information management in disaster response- to shift from acquisition and storage of information to abstracting, analysing and consuming information. Furthermore, the value of semantic information will increase, as real-time information provided by sensors would become more meaningful when integrated with semantic information. Recent research have shown that semantically rich digital models of buildings can be transferred into and represented in geoinformation systems, which are used to support most analysis and monitoring activities in emergency response and disaster management. Furthermore, recent geo-visualisation tools such as virtual globes provide an environment for combing the information provided by sensors and representations of digital building models. This paper presents a framework for, acquiring information from multiple sensors located in a building, presenting this information as web services and later evaluates how this information can be consumed and used within the geospatial environment together with digital building models. The paper concludes with an opportunity analysis in the context of the framework.

1. INTRODUCTION

IBM’s Smarter Planet Video (ASmarterPlanet, 2010) starts with the following statements;

“Over the past century, but accelerating over the past couple of decades, we have seen the emergence of a kind of global data field, the planet itself. Natural systems, human systems, physical objects, have always generated an enormous amount of data, but we didn’t used to be able to hear it, to see it, to capture it. Now we can, because all of the stuff is now instrumented, and it is all interconnected, so we can actually have an access to it, so in effect, the planet has grown a central nervous system....Over the last ten years devices are being linked up together using networks, such as temperature sensors, flow rate sensors, electricity measuring devices, and it won’t be long or it may even have happened already that, there is more things on the Internet than there are people on the Internet. That is really what we mean by the Internet-of-Things”

The Ubiquitous Computing and the Internet-of-Things concepts are gathering more attention day-by-day. From the perspective of geoinformation management, realization of ubiquitous computing would lead to a focus shift (in data management) from data acquisition to abstraction of acquired data, as in the future the data will be constantly provided by networks of interconnected sensors that are monitoring the physical environment around us. This newly emerging paradigm can be referred as ‘Sensors Everywhere”.

This new paradigm will have implications on management of urban information, where the focus will shift towards the provision and management of real-time information. This new focus and opportunities provided by Internet-of-Things and real-time information that would available regarding the state-of building elements, environmental conditions and so on holds a key potential for facilitating the tasks in emergency and disaster response.

Recent research have shown that semantically rich digital models of buildings (which also provide advanced 3D representations of building elements) can be represented in form of geospatial information, and these building models form the key components of the digital city models. Unlike early CAD representations of buildings, in recent semantically rich representations of buildings the information regarding the building elements is meaningful (i.e. computers can understand a rectangular prism visualised in a model is not only a simple rectangular box, but it is representing a room that is in a building which is used for residential purposes). Although representing semantic information along with geometries is a huge step, the information is still stateless (i.e. does not provide real-time data on the state of the building elements). In fact, recent research and developments (which are elaborated in the following section) have shown that sensors and sensor networks can be used to collect and present information regarding the state of building elements and indoor environmental conditions. Once provided by the sensors, this information can be used together with geometric/semantic building information for facilitating emergency and disaster response activities. Tiny microcontroller boards (containing sensors) are now capable of acquiring, analysing, transferring and publishing sensor information. These boards can be, placed in various locations in the building and configured to communicate with each other or a central unit through wires or wirelessly. These boards are referred as nodes of the sensor network, which is capable of acquiring and presenting information from multiple sensors.

In this paper, we introduce an information acquisition framework focused on, i.) acquiring information from multiple sensors located in the building, ii.) presenting this information as sensor web services and iii.) evaluating methods on how this information can be consumed and used within the geospatial environment together with digital building models. Following this, the paper presents an overview on the opportunities that will arise in the field of disaster management in relation with the use of real-time information about the state of building elements and indoor environmental conditions. The paper commences with a background section on sensors, wireless sensor networks, geospatial sensor web, sensor service architectures and representation of 3D building models in geospatial environment. The following section elaborate on the developed framework and the paper concludes with the opportunity analysis.

2. BACKGROUND

Sensors can be defined as hardware components that are used to measure various physical quantities such as temperature, humidity, flow rate, force, pressure, gas ratios and so on. The sensors can either output a voltage value (i.e. analog sensors) or a boolean value (i.e. digital sensors). A Sensor Network is a -collection of sensors- that can communicate autonomously with each other or with a central computer in the network. In a Sensor Network, the nodes can be connected to each other by wires or wirelessly. Recent research have shown that there is a growing interest in establishing wire and wireless sensor networks indoors to monitor different characteristics of a building such as energy consumption, indoor air quality, temperature and so on (Kwon,2007; Tse and Chan,2008; Campa et al,2001). The buildings which provide such information sometimes referred to as Intelligent Buildings. The Wireless Sensor Networks (WSNs) have gathered more attention due to the portability of the network nodes. In parallel with the developments in sensor networks, the research in the field of geosensor networks and geospatial sensor web is also gaining momentum. On the other hand, recent research have demonstrated that semantically-rich building information can be transferred into geospatial environment and can be represented in form of geospatial models. As mentioned earlier integration of building information with information provided by sensors within the geospatial environment can provide various opportunities for facilitating the emergency response operations while making building information more meaningful. The following sub-sections elaborate on the concepts related to sensors networks, sensor services and representation of building information in geospatial environment.

2.1 Wireless Sensor Networks

Wireless Sensor Networks (also known as WSNs) is a new paradigm that focuses on the use of sensor nodes (i.e. motes) which can communicate with each other wirelessly to collect information (Glaser,2004 ; Hu and Cao,2010) . Some types of these motes are capable of disseminating the information to other motes or even publishing this information to the web. As indicated in Abernathy (2011), very recent advancements in sensor miniaturization and wireless data transmission have made it possible to deploy a large number of tiny computers that collect environmental data from sensors and wirelessly transmit that data over the network to a computer base station.

A WSN is made up of individual nodes, or motes, each capable of collecting information and communicating with other motes. Sensor networks are typically self-organizing, meaning that information collected from one mote will find its way to the network's central computer by hopping from mote to mote over the most efficient path. Thus by deploying dozens, or even hundreds, of network nodes over a landscape, data can be collected over large spatial scales. The motes can then be programmed remotely to sample data at almost any temporal interval desired, providing a richness of data collection that would otherwise be unobtainable at that spatial scale. The data can be collected continuously, unobtrusively, and in harsh conditions for a long period of time (Abernathy,2011). Information coming from WSNs and Radio Frequency Identification (RFID) devices can be used for various purposes such as measuring human thermal comfort (Tsea and Chanb,2008), human movement tracking (Sakurai et al,2011), indoor asset tracking(Cho et al, 2010), improving energy efficiency (Campa et al,2011) and air pollution monitoring (Kwon et al,2007). As outlined in Abernathy (2011), a large deployment of sensors taking data measurements at frequent time intervals can quickly generate a large amount of data. For the applications that are operating in the geospatial domain sensor data will be needed in near real-time and in a spatial format for visualization and analysis. A central challenge in WSN research will be in the management, dissemination, analysis, and display of sensor data in real-time.

2.2 Geospatial Sensor Web

Traditionally, Sensor Web is defined as a web of interconnected heterogeneous sensors that are interoperable, intelligent, dynamic, flexible and scalable (Di, 2007). The Geosensor Networks (GSNs) are specific type of sensor networks that acquire, and present the information within the geospatial environment. In other words, the information that is collected from different locations and presented in GSNs has a geospatial dimension. The Geospatial Sensor Web (GSW) can be defined as an interconnected web environment composed of multiple GSNs. As mentioned in Botts et al (2007) in an Open Geospatial Consortium, Inc. (OGC) initiative called Sensor Web Enablement (SWE), members of the OGC provided a framework of open standards for exploiting web-connected sensors and sensor systems of all types: flood gauges, air pollution monitors, stress gauges on bridges, webcams, satellite-borne earth imaging devices and so on. The framework provided by OGC is a standardisation effort towards for formalization of information exchange and service interfaces of the GSW. The provided SWE framework represent OGC's standpoint for enabling data and service level interoperability in the GSW. The OGC's SWE framework consists of two groups of standards. First group involves the standards related to the formalizations in the exchange of information and includes;

- Observations & Measurements Schema (O&M)- Standard models and XML Schema for encoding observations and measurements from a sensor, both archived and real-time.
- Sensor Model Language (SensorML) - Standard models and XML Schema for describing sensors systems and processes; provides information needed for discovery of sensors, location of sensor observations, processing of low-level sensor observations, and listing of taskable properties.
- Transducer Markup Language (TransducerML or TML) - The conceptual model and XML Schema for

describing transducers and supporting real-time streaming of data to and from sensor systems.

The second group of standards is related to formalizing the web services (and facilitating the service level interoperability) in the GSW, and includes the following web service definitions;

- Sensor Observations Service (SOS) - Standard web service interface for requesting, filtering, and retrieving observations and sensor system information. This is the intermediary between a client and an observation repository or near real-time sensor channel.
- Sensor Planning Service (SPS) - Standard web service interface for requesting user-driven acquisitions and observations. This is the intermediary between a client and a sensor collection management environment.
- Sensor Alert Service (SAS) - Standard web service interface for publishing and subscribing to alerts from sensors.
- Web Notification Services (WNS) - Standard web service interface for asynchronous delivery of messages or alerts from SAS and SPS web services and other elements of service workflows. (Botts et al, 2007)

A key issue for the GSW is the requirement from sensors regarding the information about their geo-location. Multiple technologies such as GPS or Cell Phone Networks can be used to provide this information. As stated in Botts et al (2007), when the network connection is layered with Internet and Web protocols, (XML) schemas can be used to publish formal descriptions of the sensor's capabilities, location, and interfaces. In this case, web services can parse and interpret the XML data, enabling automated Web-based discovery of the existence of sensors and evaluation of their characteristics based on their published descriptions.

2.3 Sensor Service Architectures

The server side of the Sensor Service Architectures can be investigated in two distinct levels, as the Sensor Level and the Service Level. The first level is the Sensor Level which is formed by a number of sensors connected by wires or wirelessly. The information from the sensors will be collected by microcontroller cards (i.e. tiny computers), can be analysed and transformed by them and then be published as simple XML feeds. The microcontroller cards in which the sensors are embedded (i.e. the motes) can communicate with each other with wire or wirelessly. Usländer et al. (2010) provides detailed information on typical sensor network topologies. A popular standard for enabling communication in WSNs is the ZigBee specification. ZigBee is based on IEEE 802.15.4 and can be seen as additional to Bluetooth and Wi-Fi wireless communication protocol. ZigBee has a lower transmission data rate (max 250 kb/s) than Bluetooth and Wi-Fi because it is developed for low power consumption, which is needed for networks of sensors. ZigBee operates in the industrial, scientific and medical (ISM) radio bands; 868 MHz in Europe, 915 MHz in the USA and Australia, and 2.4 GHz in most jurisdictions worldwide to transfer information wirelessly between different hardware components. The aim of ZigBee standard is to define a general-purpose, inexpensive, self-organizing, mesh network that can be used in various different areas from building automation to industrial applications. There are three different types of ZigBee devices in a ZigBee network (Figure 1):

- Coordinator (Master): Single coordinator exists in each ZigBee network. The coordinator stores information about the network and determine the optimum transmission path between each point.
- Full function device (Router, Repeater): Routers act as repeaters which passes data from other devices.
- Reduced Function Device (End Device): It is device with minimum network functionality .The End Device is usually a microcontroller board which contains sensors.

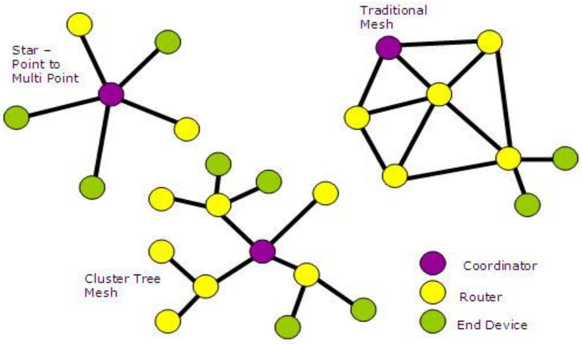


Figure 1: ZigBee Network Topologies

As shown in Figure 1, according to the ZigBee specification, ZigBee WSNs can have different topologies, such as mesh and star, in addition peer-to-peer communication is also possible in ZigBee WSNs. The second level in the Sensor Service Architectures is the service level. The service level consists of web services which provide standard interfaces to sensor data for the client applications. Two definitive characteristics of web services are Loose Coupling and Network Transparency (Pulier and Taylor, 2006). Web services are loosely coupled, i.e. when a piece of software has been exposed as a web service it is simple to move it to another computer as the service functions independent of the client application that is using the service. On the other hand, as web services' consumers and providers send messages to each other using open Internet protocols, web services offer total network transparency (i.e. the location of the web service will not have an impact on its function). Various sensor web services can be developed based on user requirements. As mentioned in the previous section OGC provided formalizations for web services in its SWE initiative. Another proposal for different interface and service formalisations for GSW can be found in Usländer et al., (2010). Virtual Sensors (i.e. soft-sensors that are used to gather and abstract data from diverse sets of sensor network nodes) can act as a middleware between the Sensor Level and the Service Level. The client side of the architecture as indicated in Usländer et al. (2010) can be composed of visualisation, reporting and other sensor applications. In terms of visualisation applications for geospatial information, recent tools offer a huge potential. As stated in Abernathy (2011), the advent of Web 2.0 tools such as asynchronous Javascript and XML (AJAX) have given online mapping tools increased versatility and visual appeal. Virtual globes such as Google Earth provide users access to geospatial information in three dimensions, allowing them to turn on and off various layers, download datasets, and create their own spatial data complete with text, photos, Web links, and even video clips.

2.4 3D Building Models in Geospatial Environment

3D geometric information regarding existing buildings can be obtained by measuring and 3D reconstruction, which has a long research history. A variety of approaches can be used for this

(Tao, 2006). 3D Laser Scanning Technology has emerged as the most innovative method and much research is devoted to developing automatic algorithms for 3D reconstruction (e.g. Arayici, 2007, Kang et al 2007, Pu 2007) and many public buildings (mostly tourist attractions) have been scanned from inside. In order to use these models in various analysis applications semantic information needs to be incorporated with these models, and this is done mostly manually. Some models generated by 3D reconstruction are new being transferred to building representations of city models (e.g.. CityGML).

Today, digital representation of buildings can be obtained from two types of source models. The first one is Building Information Models (BIMs), which contain detailed semantic and geometric information about the buildings, in fact this information is not geo-referenced. The second source is Digital City Models, which also contain semantic and geometric information about the buildings, in contrast the information is geo-referenced, but as buildings can be represented in differently levels of detail, in lower levels of detail, information regarding indoors would not be available in Digital City Models.

Since many years, digital building models have been in form of -CAD Models- (which only contain geometric information), but developments in the field have resulted with the emergence of BIMs. BIMs are capable of containing both geometric/semantic information and they are developed with the intention of covering all stage of the building/facility lifecycle (i.e. from the concept design to maintenance /demolition). Studies in the field demonstrated that it is possible to transfer (required level and amount of) 3D geometric and semantic information from an industry standard Building Information Model (Industry Foundation Classes -IFC) into Digital City Models (Isikdag 2006), such as CityGML .

CityGML Implementation Specification (Gröger, 2008) defines CityGML as a common semantic information model for the representation of 3D urban objects that can be shared over different applications. CityGML is designed as an open data model and XML-based format for the storage and exchange of virtual 3D city models and implemented as an application schema of the Geography Markup Language 3 (GML3). CityGML defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantic and appearance properties. CityGML is applicable for large areas and small regions and can represent the terrain and 3D objects in different levels of detail simultaneously. In CityGML 5 levels of detail (LOD) were defined in order to represent city objects. 4 out of 5 LODs (1-4) are used, in terms of representing the buildings within the model.

3. THE FRAMEWORK

In this paper we introduce a conceptual framework, namely Sensor Acquisition Framework, that is defining a service architecture for information acquisition from indoor sensor networks for uniting sensor information with the 3D building model representations in the geospatial environment. Once the information from the indoor sensor networks has been acquired, this information can either i.)be visualised together with the 3D representations of BIMs, building representations in digital city models, or ii.) multi-layered indoor navigation models can be used in representing this information for facilitating the indoor navigation activities. Thus the framework concentrates on two dimensions, the first one being defining a service architecture for provision of sensor information, the second one being acquisition and visualisation of this information in the geospatial environment. There also is a third dimension as the representation of acquired sensor information with building models and indoor navigation models, which also covers the models for representation of sensor's coverage (i.e. as sensor spaces) within the building models. A recent OpenGIS discussion paper (Nagel et al, 2010) presents the Multilayer Space-Event Model, which provides detailed information regarding this dimension, in fact, our framework will not focus on this dimension in this stage. Thus, our framework consists of two layers as Information Acquisition Layer, and Representation and Visualisation Layer (Figure 2).

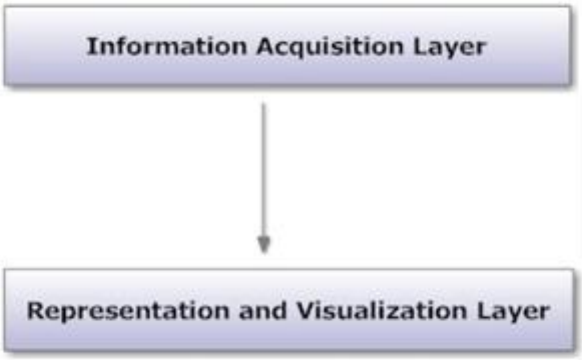


Figure 2.Layers of Sensor Acquisition Framework

The following will provide detailed information regarding each of these layers.

3.1 Information Acquisition Layer

As mentioned in the background section, the sensor networks are composed of motes (i.e. the sensor nodes.) which are able to communicate through wires and wirelessly. The motes can be composed of various hardware components including microcontroller cards, XBee transmitters (Figure 3, left), temperature and humidity sensors (Figure 3, middle) and sensors for air pollutant gases (Figure 3, right).

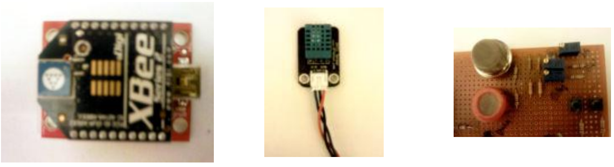


Figure 3. Hardware Components in Sensor Nodes (i.e.in motes)

In the Information Acquisition Layer, a mote is a core (cellular) level component which acquires information from the environment that it is located in, and transfer this information to another mote (i.e. the coordinator). In addition, the mote can directly publish this information as an atomic feed (i.e. in form of a simple XML that is file providing information about the sensors that is contained in that mote, this representation is very similar to Really Simple Syndication -RSS-). Motes can communicate with each other with wires, in fact a WSN architecture that is compatible with ZigBee specification is mostly preferred (in recent implementations related home automation and energy consumption monitoring).

In the Information Acquisition Layer, each mote is able to transfer and publish information obtained from sensors that are contained within that mote. In other words, one mote can provide information about a single physical value (i.e. temperature) or multiple physical values (i.e. humidity and oxygen level). For an indoor closed volume (i.e. a room) a single mote with a single sensor for measuring a physical value (i.e. temperature, oxygen level) can be used to acquire information that is valid for all that volume, a single mote with multiple sensors might be required for other physical values (i.e. sensors to detect which windows of the room are open), or multiple motes can be used to control a variety of different sensors. When a need to analyse or abstract information obtained from multiple motes arise, virtual sensors can be used in the system. A virtual sensor is a software component that is able to collect information from other sensor and motes, abstract and analyse this information and present it as if it is presented by a real sensor or mote. For example, if 5 motes are being used to collect temperature information from different parts of a warehouse, a virtual sensor can calculate the average temperature for the warehouse, and present it as if it is a value that is obtained from a single mote.

In this layer, the sensor services are web services which will provide standard web interfaces to sensor information (Figure 4). These services will provide methods for exchanging information with remote (or web) clients in compliance with an agreed service protocol. These sensor services can be state-full or state-less. In state-less web services, the service does not store information regarding the client that makes the request. Thus, state-less services can operate with minimum hardware requirements, and for this reason they would be preferred in most sensor service architectures. The Sensor Service Façade (illustrated in Figure 4) is an high-level sensor web service that will act as a gateway for multiple sensor services. The Service Façade will provide simplified and formalized methods to interact with the sensor services and will help in reducing the number of sensor services that the applications on the client side have to deal with in their interactions.

3.2 Representation and Visualisation Layer

The second layer of the framework deals with the representation of the information acquired from the sensor services and its visualisation.

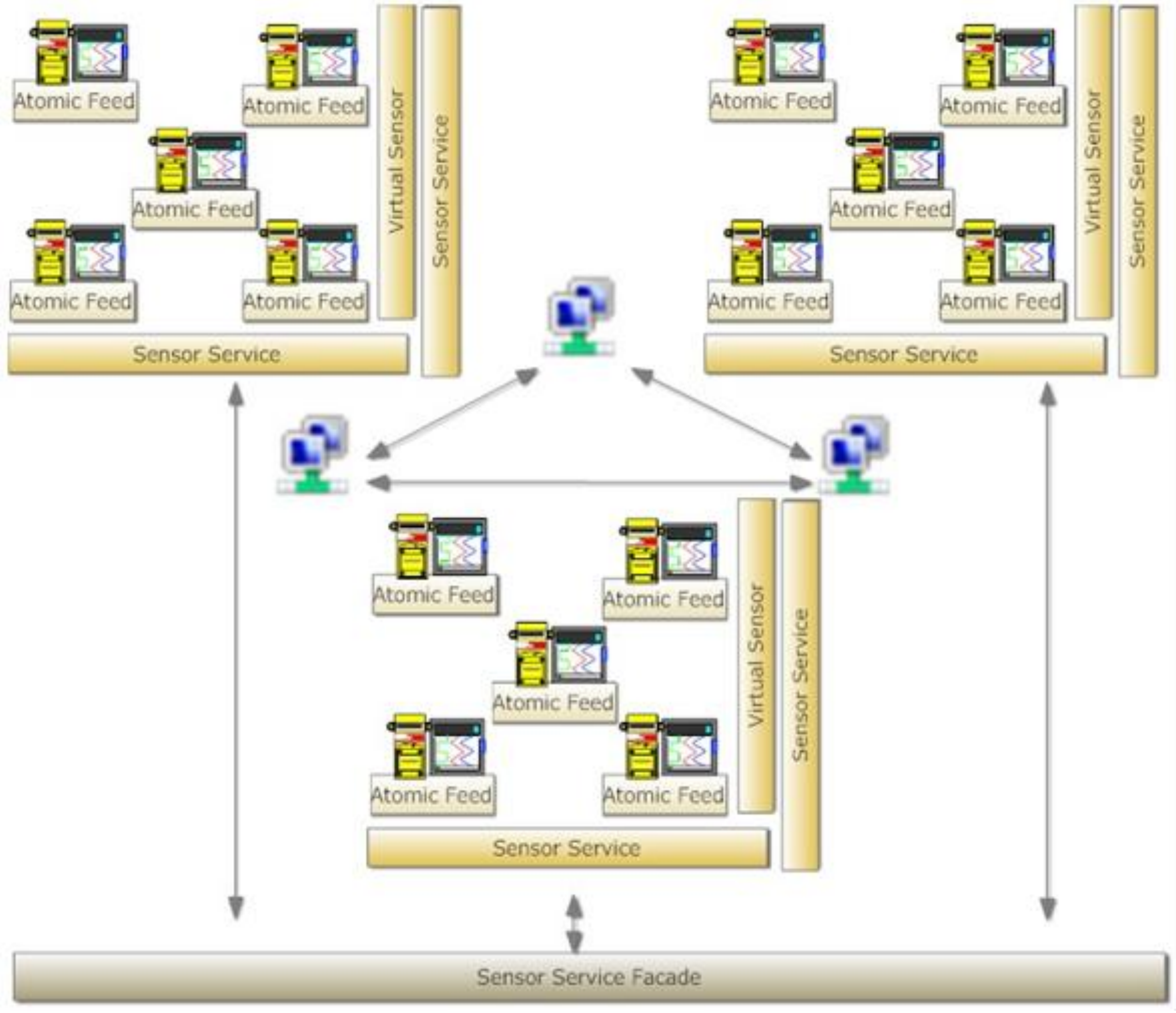


Figure 4.Information Acquisition Layer

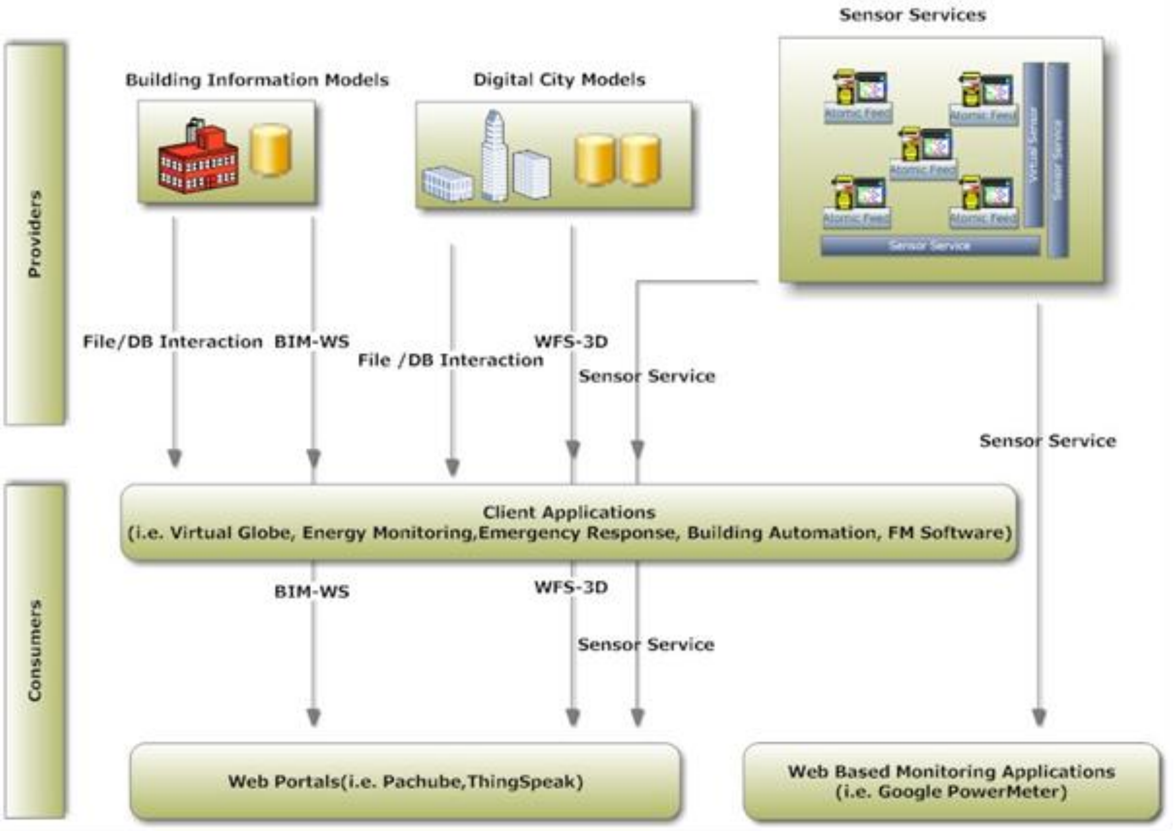


Figure 5. Information Providers and Consumers in Framework

The representation and visualisation layer contains information consumers that will be used for visualising the information coming from sensor services along with building information obtained regarding building representations (Figure 5).

The framework focuses on three types of information consumers, the first set of consumers are Client Applications including Virtual Globes, Energy Monitoring Applications, software used in emergency response including GIS, Building Automation software, FM Software and so on. Information regarding buildings can be transferred to these applications by importing physical files of the Building Information Models(BIMs), or building representations in digital city models(i.e. CityGML), in addition some of these client applications(i.e. GIS, FM applications) can interact with the shared (BIM or Spatial) databases (DBs) where building representations are stored. When the representation environment (i.e. the client) needs the model as geospatial information, transforming information from BIMs into the geospatial models might be required. Several applications such as SAFE Software FME Suite (Safe Software, 2011), Autodesk Land Explorer (Autodesk, 2011) can be used for this purpose.

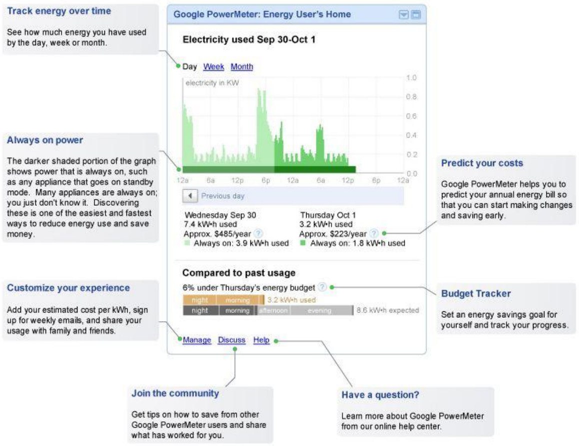
Furthermore, it is possible to use geospatial web services and BIM web services for information acquisition from digital building models (or building representations). The OGC Web Services-4 (OWS-4) project demonstrated 3 proof-of-concept case studies on how to make use of building information provided by geospatial web services (OWS-4 Summary Document, 2007 ; Lapierre and Cote 2008);

– In the Building Selection Case Study, a 3D CityGML viewer is used to consume information coming from;
    - WMS Service for Imaginary and 2D Maps
    - WFS-3D Service for City Models (providing information in CityGML format)
    - WFS-3D Service for BIM (providing information converted from IFC BIMs in CityGML format)
– In the Building Analysis Case Study, a Transactional BIM Authoring Client interacted with a WFS Service for BIM (providing information in IFC format).
– In the Building Design Case Study, a CAD/GIS/BIM editor is used to access information from
    - WMS Service for Imaginary and 2D Maps
    - WFS Service for City Models (providing information in CityGML format)
    - WFS Service for BIM (providing information in IFC BIM format)

The client applications can consume the information provided by the sensor services and visualise this information together with building information acquired from the digital building models. In the case where building information contains detailed semantics, combining semantic information with sensor information provides great opportunities for emergency response activities (which will be overviewed in the conclusion section).

The second set of consumers would be the Web Portals. Currently portals such as Pachube (Pachube,2011) and ThingSpeak (ThingSpeak,2011) are becoming popular in representing the information coming from various sensors around the world. A web portal specifically developed for monitoring buildings for disasters can make use of building information provided by geospatial or BIM web services, together with information acquired from sensor services. The web based (geo) visualisation tools such as Google Earth API or X3D viewers, in representing 3D building information together with information acquired from sensor services would very much contribute to the usability of these portals. For example, Pachube is now using Google Earth API, for visualising the information coming from multiple sensors, regarding air pollution levels, temperature, humidity and so on in 3D.

The third set of consumers of the information provided by, sensor services and digital building models would be personalized web based monitoring applications. First generation of these type of applications include web based home/office monitoring systems (i.e. CCTVs) that are used for security purposes, these systems in fact only provide visual information with no semantics. The second generation of web based monitoring applications of today is focused on providing semantic information about the environment that is monitored. One recent example of this type of applications is Google PowerMeter (Figure 6).



Track energy over time

See how much energy you have used by the day, week or month.

Always on power

The darker shaded portion of the graph shows power that is always on, such as any appliance that goes on standby mode. Many appliances are always on; you just don't know it. Discovering these is one of the easiest and fastest ways to reduce energy use and save money.

Customize your experience

Add your estimated cost per kWh, sign up for weekly emails, and share your usage with family and friends.

Google PowerMeter: Energy User's Home

Electricity used Sep 30-Oct 1

Wednesday Sep 30
7.4 kW•h used
Approx. $485/year
Always on: 3.9 kW•h used

Thursday Oct 1
3.2 kW•h used
Approx. $223/year
Always on: 1.8 kW•h used

Compared to past usage

6% under Thursday's energy budget

Predict your costs

Google PowerMeter helps you to predict your annual energy bill so that you can start making changes and saving early.

Budget Tracker

Set an energy savings goal for yourself and track your progress.

Join the community

Get tips on how to save from other Google PowerMeter users and share what has worked for you.

Have a question?

Learn more about Google PowerMeter from our online help center.

Figure 6.Google PowerMeter (Google, 2011)

By making use of the PowerMeter, a person can monitor energy usage over time from anywhere on the web based on information provided by sensors located in his/her house. The second generation of the web based monitoring applications can make use of the information provided by sensor services, to monitor conditions such as occurrence of fire or flood in the house, and automatically inform the emergency responders regarding the situation. In fact this is not the only opportunity provided by the use of sensor information along with geometric/semantic information provided by building models, various opportunities that arise for emergency response and disaster management by the use of proposed framework will be elaborated on in the following section.

4. CONCLUSIONS

There are technical advantages provided by the framework such as establishing a client-independent software architecture by making use of loosely coupled nature of web-services. The implementation of sensor services in building, consuming information acquired from them and using this information along with building information provides various opportunities for emergency response and disaster management. In this conclusions section we will provide an overview of each opportunity.

Client-Independent Architecture: The information provided by sensor services of the framework can be presented, visualised and analysed by any client application that is able consume web services. The client can either be, a GIS that is used for managing and monitoring the energy infrastructure of city or a simple personal web based monitoring application that is visualising the house energy consumption in a virtual globe, additionally the client can also be a mobile phone or an android tablet. The information gathered from sensors such as temperature, humidity, state of building elements (i.e. the window being open/closed), the occupancies in rooms, information regarding danger of fire and flood, radiation levels in the building, the state of Heating/Ventilation/Air Conditioning (HVAC) Systems, the state of elevators and escalators (i.e. in operation or not), oxygen and other gas levels will be available for the emergency responders, regardless of the hardware, operating system and software they use. This loosely coupled nature of the sensor web service architecture would act as a key technology for acquiring the conditions regarding the building, as different hardware and software platforms (ranging from mobile phones to workstations) will be used by different members of the emergency response team during the operations. In summary, the client-independent nature of the sensor web services, will make it possible for every kind of device to acquire the information from them.

Ubiquitous Monitoring: Our interpretation of ubiquitous monitoring has two dimensions. In the first one we view the building elements as “things” that are continuously providing information about their own state (i.e. when their state changes). For example, a when a window becomes closed it will provide/publish information regarding its state of being closed, or when a room is in fire, the room will provide information about its state of being -in fire-. In summary in ubiquitous monitoring the role of information providing shifts from computers to “things” (i.e. in our case to the building elements). In the second dimension of our interpretation we assume that by ubiquitous monitoring the information regarding building elements would be available 24/7 regardless of the emergency situation. In other words, by the implementation of the described architecture, the information that is provided by the building elements, will be available without interruption even when an emergency situation or disaster occurs. Although to achieve this is not a simple task, sensor service architecture provides unique opportunities for ubiquitous monitoring. For example an earthquake can damage several floors of the building and thus sensors in these floors might stop functioning, the situation would be similar in a flooding situation. In this case, other sensors in the network will continue to function and provide information about the state of the elements and the condition of the building, i.e. as the functions of these motes are independent from other that are damaged and thus the sensor network will still continue to operate and report gas levels or a fire that would occur in the building after the earthquake. In this case combining semantic information coming from building models with sensor information provides advantages in answering the questions such as “Would you provide the average CO_2 level in the rooms which are not affected by the fire?”, “Would you provide the number of doors which are open in the floors that are affected by the flood?” and so on, can be answered in real time.

Crowd-Sourced Monitoring: Crowd-Sourced Monitoring refers to monitoring of events and physical conditions by a vast number of people and devices that is in/near the region where the event occurs. This approach is extremely useful to enable ubiquitous monitoring of emergency/disaster situation. When a disaster such as an earthquake occurs, huge number of people will not be in a condition to monitor the event, in addition a considerable number of devices and sensors would stop functioning. In this situation, if a crowd of people, and devices/sensors controlled or monitored by them can provide information regarding the emergency situation, this information would be highly valuable. A very recent example is the Crowd-Sourced Monitoring of radiation levels in various regions of Japan. Hundreds of real-time networked geiger counter measurements (contributed by concerned citizens in Japan) are gathered and abstracted by Pachube and visualised in a virtual globe (i.e. by using Google Earth API) (Figure 7).

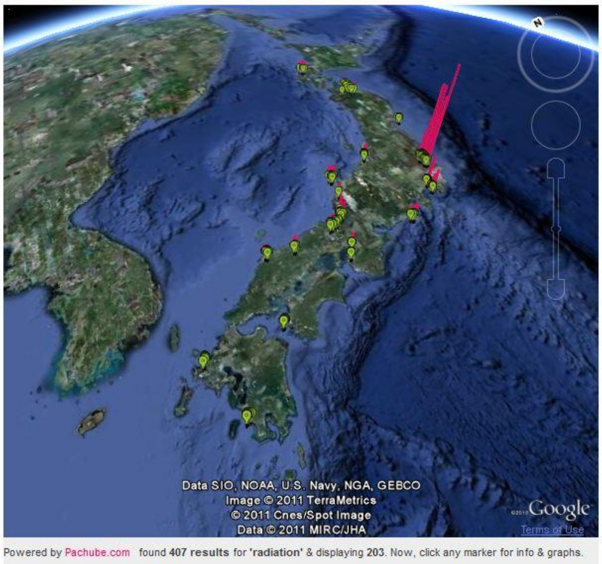


Figure 7. Real Time Visualisation of Radiation Levels in Japan (Pachube,2011)

Crowd-Sourced Monitoring can be very useful in real-time monitoring of the spreading of the fire in a forest, i.e. sensors located in the buildings in the forest area can provide information on if the fire has reached the region by providing temperature and gas level information inside and outside the building. Crowd-Sourced Monitoring can also be useful in Tsunami events, lots of houses can become flooded in a very short time period, and a crowd-of-sensors that are still in operation (in buildings that are not flooded) would provide key information regarding the invasion of flood water within the region.

Human-Building Interaction: With the integration of sensors into building elements and establishment of sensor networks to monitor the state of the elements and the conditions in the building, the building itself becomes the information provider. This information can either be provided in a continuous manner (i.e. according to publish/subscribe model) or on demand. The provision of information on demand by the building elements, when combined with motes ability of controlling the actuators (i.e. devices for moving and controlling mechanism) offers opportunities by enabling the human-building interaction. Although the current version of the provided framework concentrates on one-way communication rather that two-way interaction with the building, the two way interaction also provides unique chances. For example, in a fire response operation an emergency responder can acquire information from the sensors (motes) located in each floor regarding the spreading of the fire, in response, he can then invoke the web services to interact with motes which will then invoke the actuators to close the doors in certain floors to prevent spreading of the fire to other floors. Furthermore, sensor-to-sensor / mote-to-mote autonomous interaction is also possible and a mote can collect information regarding the emergency situation, and interact with another mote to perform an action. The concept when implemented might be regarded as a shift from automated building to an Intelligent Building. Human-Building Interaction might provide other opportunities in other emergency situations, such as floods, for example sensors in the building can interact with the actuators to close doors to prevent some parts of the building from being flooded by water, in fact if there can be people in these parts of the building and they can be trapped as they cannot get out. In this situation, the people in the rooms can interact with the motes (to control sensor and actuators) to let them out of that building part. In summary, the ability to consume information from sensors, and the ability to control the actuators provides unique opportunities by enabling human-building interaction in emergency response operations.

This paper has provided a framework of information acquisition from indoor sensor networks and presentation of this information with multiple different clients. The architecture proposed in the framework offers several opportunities arising from its client-independent nature. Regardless of the hardware and platform used on the client side, the sensor information would be available to the users in real-time. In fact the building's visual representation might require some extra hardware and software resources depending on the client. The architecture presented in the framework will contribute to the Ubiquitous Monitoring of indoor environments, while Crowd-Sourced Monitoring brings particular advantages in situations such as post-earthquake radiation level measurements (which can also be extended to cover the radiation measurements for indoors). Finally the tight-integration of the sensors with building elements makes the building -an information provider- i.e. the Intelligent Building-. This in turn would make human-building interaction possible with the help of sensors and actuators residing in the building.

Future research will focus on testing and validating the framework for different use cases, by using different types of indoor sensors, wire and wireless sensor network architectures, virtual sensors and web services.

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