Sensory Semantic User Interfaces (SenSUI)
(position paper)

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Abstract. Rapid evolution of the World Wide Web with its underlying sources of data, knowledge, services and applications continually attempts to support a variety of users, with different backgrounds, requirements and capabilities. In such an environment, it is highly unlikely that a single user interface will prevail and be able to fulfill the requirements of each user adequately. Adaptive user interfaces are able to adapt information and application functionalities to the user context. In contrast, pervasive computing and sensor networks open new opportunities for context aware platforms, one that is able to improve user interface adaptation reacting to environmental and user sensors. Semantic web technologies and ontologies are able to capture sensor data and provide contextual information about the user, their actions, required applications and environment. This paper investigates the viability of an approach where semantic web technologies are used to maximize the efficacy of interface adaptation through the use of available ontology.

Keywords: **Adaptive** User Interface, Context Awareness, Semantic Web, Ontologies

1. Introduction

In a pervasive computing environment, computer systems and devices seamlessly integrate into the life of everyday users. In such an open and dynamic environment different systems and sensors networks need to interoperate and in order to do so, knowledge sharing and common understanding of the meaning of the shared knowledge is a prerequisite. With rapid evolution of the World Wide Web and the growth of sources of data and knowledge, different services and applications are now accessible for a wide variety of users, including children, adults, elderly and disabled. These users from different backgrounds have different requirements and different capabilities and use a range of devices (traditional PC, mobile and ambient screens). In such an environment, it is highly unlikely that a single user interface will prevail and be able to fulfill the requirements of each user adequately. In dynamic and complex environments, users need a flexible user interface that is able to take into account the context and react to business knowledge and sensory input. In other word user interfaces should be able to adapt themselves based on the sensed contextual data

from user and its environment, such as location, temperature, light, movements, thoughts, physical states of users, etc.

Sensors can tightly interact with the real world and monitor physical phenomena like temperature, light, sound, movement, location and etc. Sensor networks are normally application specific with no sharing or reusability of sensor data amongst applications [18]. In order for applications and services to be able to take advantage of existing sensors and sensor networks they have be able to understand sensed data, integrate and consume such data in a beneficial way. In order to enable data integration, the meaning of sensory data needs to be understandable by different applications and services. Importantly, there is a need for sensor data to be enriched with semantic information [18]. Context awareness is an important aspect of ubiquitous computing and often facilitates the provision of appropriate services to the user. Context provide information about the present status of objects, places and devices in the environment [17]. A context aware system is a system that can use context and adapt its functionalities consequently in order to provide adequate information and services to the user [12], [17]. Sensors are able to play a major role in context awareness and system adaptation. They enable acquisition of more context information about the real world and having more context parameters the system would be able to infer more usable knowledge and information and adapt itself to those inferred knowledge. In ubiquitous computing and sensor networks, context aware applications can play a significant role in utilising received information and their context to provide services that are appropriate to a particular situation. Context awareness is closely correlated with any adaptive system. By sensing context information, context enabled applications can present context relevant information to users, or modify their behaviour according to changes in the environment.

An adaptive user interface autonomously adapts the display and available actions to support the current goals and abilities of the user by monitoring user states (behavioural, psychological, physiological, etc.), system tasks, and the current situated requirements [27]. There is an important distinction between adaptive and adaptable interfaces. In an adaptive interface, the system modifies the interface dynamically, while in contrast an adaptable system allows the user to change the presentation of the information and the interface according to their own preferences [5], [27]. There are advantages and disadvantages associated with both adaptive and adaptable user interfaces. Adaptive systems enhance user performance by reducing the workload through automation as well as providing updated context aware information, which might not be available in non-adaptive systems. A consequence of this is that adaptive user interfaces may result in the user feeling a loss of system control; in some cases reduce the visibility of the system; and may cause usability and mistrust issues [5], [27]. Adaptable user interfaces typically involve lower levels of confusion for the user and subsequently higher level of trust in the system [5]. However, they do not provide any on-the-fly adaptation and automation benefits. Depending on the planned functionality of the system and its intended use one or other of the approaches or a combination may be appropriate. Brusilovsky [10] suggests that systems can be adapted to two main categories; user characteristics and environment. Both of these categories could be sensed and transferred to systems using sensors. Semantics can also play an important role in user interface adaptation. Interestingly good deal of attention has been paid to utilising semantic web

technologies for adapting user interfaces [4], [13], [16], [24], [28]. Many of these publications focus on adaptive e-learning systems or adaptive web site navigation. However, not enough attention has been paid to sensor-based user interface adaptation, although it can provide valuable information for adapting to user characteristics and environment in order to provide more relevant services to the users. The SensUI project aims to feel this gap and provide a sensor based semantic user interface adaptation approach.

The paper proposes a novel adaptive user interface approach and is structured as follows. Section 2 presents the complexity of pervasive environments and current application of semantic web technologies in the field. Section 3 proposes a vision of adaptive user interfaces that we call sensory semantic user interfaces (SenSUI) and Section 4 describes some of the current use of ontology and sensors. The paper concludes with a research agenda derived from a comparison between the vision and current state of art.

2. Semantic Web of Things - Technologies and Sensors

The pervasive environment is a complex mix of hardware and software. Working outwards, in Figure 1, the UBIS pervasive architecture is made up of a number of devices (sensors, actuators, user interfaces etc.) that are interconnected on one or more networks. On a Web scale, the environment becomes a Web of Things [30]. These devices can interface together in order to undertake specific tasks, for example peer to peer content distribution, or with remote access to applications and services. In order for mobile devices to access remote services or applications they must first utilise pervasive middleware. Original middleware definitions describing a middleware service as general purpose services that sit between platforms and applications [8] appear too general (in light of such a UBIS environment with application components sitting on many devices and applications) and functionally specific definitions are required.
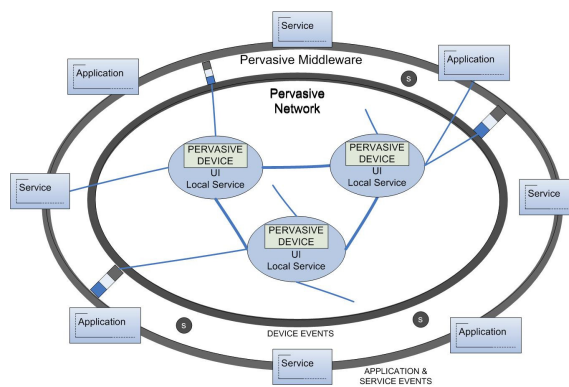

Fig. 1. UBIS Architecture [6]

In a more pragmatic vein the architecture in Figure 1 can be used to construct a high level architecture: Indentifying the applications, services and devices that are within scope of the design before mapping networks and middleware required to create connections between chosen components. Traditionally, these connections would be envisaged at design time. Connections between specific applications and devices would be designed – choosing or developing appropriate middleware and network systems. New architectural components are required if automated middleware pipelines and associated user interface are constructed on-the-fly in reaction to recognised events (e.g. simple actions such as a person passing an ambient screen) in a new and novel way. Additional relationships and dependencies between events, applications and devices are a pre-requisite for any intelligent initiation of action.

Flowing throughout the architecture are events on the middleware layers. Two event channels are described that enable: (1) Events to be consumed and generated by the Services and Applications (e.g. informing that a specific data item has changed) and (2) Events to be consumed and generated by the pervasive devices (e.g. User X is at location Y and is interested in Data Z). It is this additional stage that allows the designer to explore both the capabilities and functionality of the devices and applications (inputs, outputs, requirement – when and where etc.). Consequently, the modelling of linkages between the applications, services and devices are in response to specific events. Shared spaces (S) are also included in the middleware layer as repositories of localised information and logic – embedded within the environment. The space can viewed as a data cache with integrated logic that is able to react to the cache and external events. Event messages (typically XML documents) are read by the middleware that then identifies appropriate connections (interested parties). Understanding the connection requires that appropriate models are constructed.

The Semantic Web is an evolving extension of the current web, in which information is given well-defined meaning and is machine processable [7]: It provides a common framework that allows data to be shared and reused across applications and community boundaries [3]. Semantic Web technologies provide a powerful means of defining concepts and the relationships between Things in the real world. Ontologies are a fundamental part of semantic web technologies – providing a formal description of concepts and their relationships within a domain [32] and facilitate a shared understanding of a domain. An ontology in computer and information science is "an explicit specification of a conceptualisation" [15]. Consequently, formal logic can be used to infer new explicit knowledge from implicit knowledge that exists in the domain definition. Similar to web documents, which are defined using standards, ontologies also need a standard way of description. There are a number of languages for describing ontologies. At present the most widely used ontology languages, also W3C recommendations, are Resource Description Framework (RDF), Resource Description Framework Schema (RDFS), and Web Ontology Language (OWL); and all are based on XML.

Information received from different sensors used as contextual information, with examples such as light, speed, user thoughts, RFID input, etc. However, with information coming from various sensors in varying data formats – semantic differences result. Ontologies are an appropriate means for representing and capturing context and sensor data, with associated knowledge acquisition and reasoning. Semantic web technologies could enable semantic integration of received sensory

data and as a result context awareness and system adaptability based on the harmonised context data. Ontologies are able to capture the definitions and interrelationships of concepts in a variety of domains and enable presentation based on reasoning and knowledge deduction. This also facilitates transparent flow of semantically enriched information and knowledge and would enable sensor data and contextual information integration as it flows through the overall system. There are a considerable number of publications and projects that combine semantic web technology and sensors [18], [22], [29], [1], [20], [19], [11], [21], [23]. Section 4 will review literature on this and existing ontologies. The complex architecture already described warrants a more detailed exploration of a central part of the overall architecture – the user interface. Therefore, a vision of how the user interface is able to benefit from semantic web and sensor technologies is now presented.

3. Sensory Semantic User Interface vision

A sensory semantic user interface (SenSUI) is adaptive to user activities through the use of sensor and semantic web technologies. A SenSUI vision is an architecture that is able to provide an adaptive user interface made available through explicit and inferred knowledge – with the integration and utilization of existing and evolving ontologies. Figure 2 depicts such architecture.
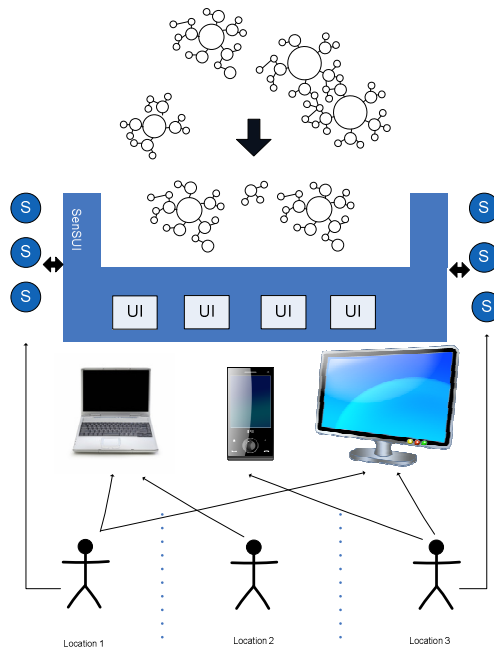

Fig. 2. SenSUI architecture

The high level SenSUI architecture is based around a software container (typically placed in or associated with a physical location or person). There are various sensors connected to the SensUI container (middleware is not considered at this point as it is assumed in place from earlier UBIS architectural work) and it provides real-world sensory data (e.g. contextual information). On the other side of the system there are different users with different interest and capabilities who are interacting with the system, using specialised user interfaces. For example, the user may interact with the same application using a laptop, mobile phone or ambient screen as they move between locations. Importantly, in order to (1) understand the sensors (2) automatically adapt the rendered user interfaces and its links to existing application systems, ontology must first be loaded into the container. These ontologies could be device ontologies supporting device recognition and classification; environment ontologies that provide information about the environment and context of the system and user; ontologies that represent data formats and thus enable integration of the different sets of data sensed by different sensors; and finally domain ontologies that could enable understanding of the meaning of concepts in a particular domain. Hence, the adaptive nature of the user interface is premised on the availability and integration of suitable ontology. In order to explore that viability of such a vision, current ontology use in this area is now reviewed.

4. Ontology and Sensors

Huang and Javed [18] introduce data integration of sensor information as the most challenging task due to the heterogeneous data sources present in Wireless Sensor Networks (WSNs) for example. They propose a Semantic Web Architecture for Sensor Networks which allows the sensor data to be understood and processed in a meaningful way by a variety of applications with different purposes. They have developed ontologies for sensor data and used the Jena API for querying and inference over sensor data. Lionel et al. [22] have identified the same problems for heterogeneous sensory data and have proposed a concept of Semantic Sensor Net (SSN). A SSN is a heterogeneous sensor network enabling dynamic tagging of semantic information to sensory data so that it can be integrated and reused across various applications. Sheth et al. [29] also point out the problems associated with the lack of integration and communication between sensor networks and refer to this situation as having too much data and not enough knowledge. They propose Semantic Sensor Web (SSW) framework, which provides enhanced meaning for sensor data by annotating the sensory data with semantic metadata. This approach leverage standardisation efforts of the OGC (Open Geospatial Consortium) [1] and Semantic Web Activity of the W3C to provide enhanced description and meaning to sensor data. Lewis et al. [20] present a data management tool called ES3N which addresses the issues of efficient sensor data storage and query processing using semantic web techniques. Krco et al. [19] point out that currently sensor solutions are used for a particular purpose and deploying new service or changing service provider requires considerable work - making re-use of sensors difficult.

Chen et al. [11] believe that a shared ontology is required in pervasive computing systems for supporting knowledge sharing, context reasoning and interoperability. They have developed SOUPA, a Standards Ontology for Ubiquitous and Pervasive Applications to address this requirement. Bornhovd et al. [9] take a business oriented look at the sensor data and point out that smart item technology can provide companies with more accurate data about their business operations and also help them to streamline and automate those operations. They believe this would result in cost reduction as well as greater business effectiveness. They discuss how SAP's Auto-ID infrastructure enables the integration of RFID and sensor technologies with existing business processes with the aforementioned view. [31] stress the importance of Ubicomp technology in the future and its impact on business processes. They provide a Ubicomp process model based on a collection of application cases and identify four basic functions to be most affected - identification, monitoring, tracking and notification. However, they do not provide any general framework that supports process aware organisation. Liu and Zhao [21] presented the idea of open sensor-rich information system. Their motivation for using common ontologies is to capture the sensor data in hierarchal form so that reasoning can be done on sensor data. Noguchi et al. [23] proposed automatic generation and connection of program components for sensor data processing in network middleware. The raw sensor data is described in RDF and they implement behaviour detection services to validate automatic generation and connection.

It can be seen that sensors can play a major role in context awareness and adaptive system. Acquiring more context information from real world would improve the effectiveness of adaptive user interfaces. However, none of the work to date provides a solution using different ontologies in conjunction with sensory data to achieve context awareness and adaptive user interfaces.

4.1. Current Ontology in the area

Considering the benefits that can be achieved by understanding and sharing sensory data, current ontology are presented as a likely means to achieving this. Table 1 provides an overview of existing ontologies that are used in ubiquitous computing and sensor related projects.

Table 1. Categorisation of existing ontologies in ubiquitous computing

Ontology	Description	Devices	Context	Data	Domain
OntoSensor	A prototype sensor knowledge repository compatible with evolving Semantic Web infrastructure. It defines classes and relationships for different sort of sensor types and sensor models.	✓			

Ontology	Description	Devices	Context	Data	Domain
COBRA-ONT	Provides a set of ontologies for modeling context in the smart meeting applications. It provides ontologies for place, meeting, agent, place, context, time, etc.		✓	✓	
SOUPA	Designed to model and support pervasive computing applications. It has references to other ontologies such as FOAF, OpenCyc Spatial Ontologies, COBRA-ONT, Rei Policy Ontology, etc.		✓	✓	
GLOSS	Describe a small set of concepts for a universe of discourse for understanding global smart spaces. Gloss ontology and associated class model are organised into four packages, namely Universe, Interaction, Space, Time.		✓		✓
CoOL	Derived from ASC (Aspect-Scale-Context) to facilitate ontology-based contextual interoperability. The ASC model has been designed to allow the representation of different aspects of context, such as temperature, distance, speed, etc.		✓		
CONON	An ontology-based context model, in which a hierarchical approach is adopted for designing context ontologies. CONON's main focus is on location, user, activity and computational entity.		✓		✓
GAS	Provides a common language for communication and collaboration amongst the heterogeneous devices that constitute a ubiquitous computing environment.	✓	✓		✓
CoDAMoS	Provides an adaptable and extensible ontology for creating context-aware computing infrastructures, ranging from small embedded devices to high-end service platforms.		✓		
CSIRO/SSN Ontology	Designed for describing and reasoning about sensors, observations and scientific models. It provides classes for concepts such as sensors, observation, location, identification, etc.		✓		
Ontonym	A set of upper ontologies that represent core concepts in pervasive computing such as time, location, people, sensing, provenance, events, device and resource.		✓		
A3ME	Provides a basic classification for self description and discovery of devices and their capabilities in heterogeneous networks including resource constrained sensor nodes.	✓			
SensorData Ontology	Describes a sensor data ontology and is created based on Sensor Web Enablement specifications.			✓	

Ontology	Description	Devices	Context	Data	Domain
MMI Device Ontology	An ontology of oceanographic devices, including both sensors and samplers.	✓			✓
CESN Ontology	An ontology for coastal environment domain.	✓			✓
NASA SWEET	A set of ontologies for earth and environmental domain.		✓		✓

The ontologies have been categorised as Devices, Context, Data and Domain ontology.

Devices Ontology focus on classifying and recognising different devices in the environment. These devices can be different types of sensors and actuators such as motion sensors, microphone, etc or different user interfaces such as mobile phones, laptops, etc. Ontosensor is a prototype sensor knowledge repository compatible with evolving Semantic Web infrastructure. It references and extends SUMO and is partially based on SensorML [14]. This ontology defines different classes for different sort of sensor types and sensor models. Sensors and devices included in this ontology range from acoustic sensors, e.g. microphone to chemical and motion sensor. For example GPS is a type of sensor, XBow_GPS is a type of GPS and MTS310_GPS is a model of XBow_GPS. Figure 3 depicts a part of OntoSensor ontology related to Microphone as a sensor. It can be seen in this ontology, and other device ontologies, that it is not only devices and sensors that are included, but also in some cases different models for a specific senor type. Typically, this is why ontology is categorised under Devices. A3ME provides simple classification for self description and discovery of devices and their capabilities in heterogeneous networks that includes resource constrained sensor nodes. This ontology is categorised under Devices as it provides an extensive taxonomy for devices and their capabilities. MMI (Marine Metadata Interoperability) Device ontology is another example of a device ontology covering oceanographic devices, including both sensors and samplers. This ontology can easily be categorised under Devices category as its main priority is to broadly characterise devices in the domain. In addition, it is produced specifically for the Marine industry and therefore categorised under Domain ontology as well.

Context Ontology focus on environmental and contextual information, e.g. Location, temperature, etc. This information can be transferred to application systems by sensors. Three examples of Context ontology are reviewed. The CoDAMoS context ontology [25] provides an adaptable and extensible ontology for creating context-aware computing infrastructures, ranging from small embedded devices to high-end service platforms. This ontology is classified under four basic concepts: User, Environment, Platform, and Service [26]. CoDAMoS is categorised under Context category as its focus is on context-aware infrastructure. CoOL, the Context Ontology Language, is derived from ASC (Aspect-Scale-Context) to facilitate ontology-based contextual interoperability. Ontologies implemented in ASC facilitate service discovery and service interoperability at a context level. CoOL is used to enable

context interoperability and context-awareness during service discovery and execution [33]. Ontonym is a set of upper ontologies that represent core concepts in pervasive computing such as time, location, people, sensing, provenance, events, device and resource. Thus, the ontology is categorised under Context. Ontonym is not categorised under Device as its device coverage is limited.

Data Ontology are concerned about the data received from different sensors and integration of such sensory data. The data can range from Sensor name/type, location, identifier, temperature, etc. The difference between Data and Devices ontologies is that Data ontologies focus on received data and its meaning, while Devices ontologies are mainly concerned about devices categorisation and having a complete ontology that covers the expected devices and sensors in a device/sensor network. These two types of ontologies might be used in conjunction. Context category may be considered as a type of Data ontology with focus on contextual data received from the environment. SensorData Ontology is an example of Data ontology. It is developed based on Sensor Web Enablement (SWE) [2] specifications. SensorData Ontology provides ontologies for SensorML, Sensor Observation and measurement specifications defined in SWE. This ontology is categorised under Devices as well as Data as it is mainly based on SWE's SensorML and O&M specifications, which are concerned with sensors, their characteristics, capabilities and observed sensory data. Another example for Data ontology is CSIRO Semantic Sensor Network (SSN) ontology, which is used in the description and reasoning about sensors, observations and scientific models. SSN also provides information about sensors and their characteristics and functionalities. For example, it defines classes for identification such as Manufacturer ID, Model Name, Model Number and Version. However, this ontology does not provide any specific categorisation for a specific sensor, but for a group of sensors. For example it defines classes for Nuclear, Thermal, Acoustic and Chemical sensors, but does not define any specific sensor model as in OntoSensor. SSN is also categorised as a context ontology as it provides contextual information. Figure 4 depicts a part of Semantic Sensor Network ontology.
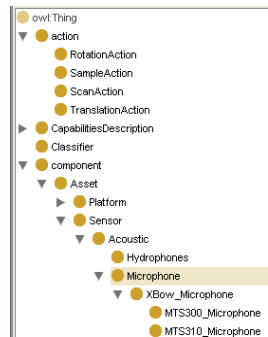
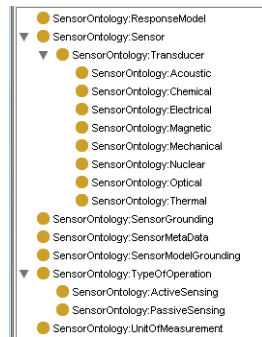**Fig. 3.** A part of OntoSensor ontology
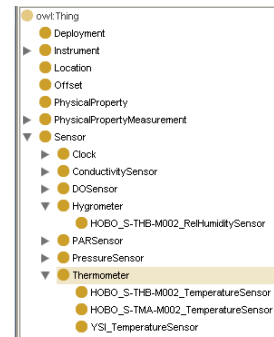
Fig. 4. A part of SSN Ontology

Fig. 5. A part of CESN Ontology

Domain ontology represent specific domains, e.g. the physical environment. Examples of Domain ontologies are MMI Device, as explained above, CESN (Coastal Environment Sensor Network ontology) and NASA SWEET (Semantic Web for Earth and Environmental Terminology) ontologies. CESN focuses mainly on the instruments in the domain including the sensors. Different types of sensors are defined in this ontology such as Pressure Sensor, Thermometer, Hygrometer, etc. Also specific sensors are defined in this ontology such as HOBO_S-THB-M002_RelHumiditySensor which is a Hygrometer or HOBO_S-TMA-M002_TemperatureSensor (a Thermometer Sensor). This ontology is categorised under Domain as it provides domain specific information as well as Devices as it clearly defines devices and sensors in the domain. Figure 5 depicts a part of CESN ontology. NASA SWEET ontology is specific to earth and environmental domain. Its focus is mainly on the environmental phenomena, such as weather, climate, flood, etc. SWEET is categorised as both a Domain ontology and a Context ontology because the phenomena that it captures can be considered contextual indicators.

It is important to note that these categories are not mutually exclusive and the purpose of the categorisation is to identify the main purpose of each ontologies. Furthermore, many of the ontologies exist in more than one category that is again because they can have more than one purpose. It should also be noted that some of the ontologies reference external ontology (e.g. Time Ontology), which can broaden their scope. Interestingly, no ontology covers all categories and this could highlight the need to bring together a number of ontology as each category is required for SenSUI.

5. Research Agenda

When considering current state of art ontology as a basis for realising the SenSUI vision a number of research question require consideration:

- How should ontology be used to model user interface components and the data contained within them (in relation to sensor related ontology)?

- How are suitable ontology discovered and selected for use within the SenSUI container?

- How can ontology be integrated pre-, during and post- use (e.g. devices described in a number of separate ontology)?

- Which of the ontology identified provides the most utility for user interface generation?

- What are the relationships between the events that trigger user interface changes and sensor data? Further, where are the relationships to the underlying application systems?

- What rules are required to process a sensor data alongside a combination of device, context, data and domain ontology?

- What are the demarcation lines separating different user interface renderings and how is this defined (rules, ontology, applications)?

- What is the temporal scope of sensor data in a user interface context (e.g. how long does the RFID sensing of you next to the ambient screen apply)?
- How domain neutral can a system become? For example, is it possible to drop a domain ontology into a SenSUI architecture for it to work in the new domain?
- How can ontology be rated (again with respect to duplicity) and how dynamic is this in a SenSUI environment?
- Undertake an in-dept study and testing of existing ontologies for "in-use" applicability within a SenSUI platform.
- Identify further ontologies and categories of ontology – including their relationships with those already discussed (e.g. Service Ontology).
- What are the additional middleware requirements in order to adapt user interfaces based on sensory data and defined ontologies?
- How can inter-related ontology be harmonised before or during use (e.g. several device ontology together – or – different categories of ontology)?
- Is it possible to add more context and domain ontologies in the future to automatically enhance the capabilities of the middleware and user interface?

6. Conclusion

This paper proposes a novel approach to adaptive user interface engineering that makes use of both sensor and semantic web technologies. Current state of art Semantic Web approaches are reviewed in relation to an architectural vision of Sensory Semantic User Interfaces (SenSUI). A SenSUI container model is presented that consumes both sensor data and ontology in order to automatically generate specialised user interfaces. Devices, Context, Data and Domain ontology have been identified as possible candidates for the SenSUI platform. The outcome of the review is a research agenda focused primarily on the selection and use of ontology to improve the adaptability of user interfaces in a pervasive environment.

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