AN ONTOLOGY BASED CONTEXT MODELLING APPROACH FOR MOBILE TOURING AND NAVIGATION SYSTEM

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ABSTRACT:

With the emergence of wireless communication, computer networks, and on-board positioning sensors, mobile computing has received vast attention lately. In this paper, a mobile tourism guiding system has been applied for a variety of tourism applications such as navigation and tour planning services. To provide intelligent personalized tourist assistant and navigation services to users anywhere and anytime, a context-aware framework convert primary context to useful knowledge by means of an ontology modelling and reasoning system. The Context-Aware Mobile Touring and Navigation (CAMTON) system proposed in this study, investigates the development of a system that is able to adapt navigation and touring services to different contexts such as location, time and user profile. This system provides relevant information in each status in a computationally efficient manner. The experiments conducted using the system show that the context model and the application adaptation strategies provide promising tourism services.

1. INTRODUCTION

The advances in mobile computing, positioning systems like Global Positioning System (GPS) and wireless communication networks are encouraging the development of Location-Based Services (LBS) for tourism applications on mobile devices such as pocket PCs, smart phones or PDAs. Mobile tourism guide systems may assist tourists both in the preparatory phase and during a trip. (Ardissono et al. 2003 and Cheverst *et al*. 2000). To personalise on-line access of users to tourism applications, context-aware services for mobile tourism systems have recently gain a lot of attention. Adding context to these systems aids them to offer more relevant information based on user's context, *e.g.* users' personal characteristics (such as education, preferences, previous knowledge, and visitor's behaviour), current location or time, mobile device capabilities, network availability. Context-aware mobile tourism systems provide both opportunities and challenges in terms of customized or intelligent services and user interface (Schmidt-Belz, 2002) (Juan Pavón, 2004) (Dejian Meng, 2009), information filtering and recommender systems (Loeb, 1992), adaptive hypertext and hypermedia (Brusilovsky, 2002) and mobile computing (J. Altmann, 2003), (Oppermann, 1999).

Several studies have investigated different aspects of presenting contextualized tourism information system. For example, The CYBERGUIDE system (Abowd *et al.*, 1997) was one of the first systems that used location aware information systems to help tourists. GUIDE system presented in (Cheverst, Davies *et al*. 2000) adapts web-like presentations by adding information about nearby attractions that might be interesting for the visitor of a city. The system provides location based information based on a radio cell infrastructure. The MOBIS (Tezuka *et. al*, 2005) system is an electronic guide based on a PDA that provides information to a visitor of a museum. The PDA receives its position from infrared signals and uses this position as a pointer to a specific content that is stored in a database on the PDA. The HIPS system deploys sub-notebooks, which supports a broader range of media content in comparison to the PDA used for MOBIS (Tezuka *et al.*, 2005). The HIPPIE system (Oppermann and Specht, 2000) proposes personalized tours in a museum by maintaining a model of user's interests and knowledge. A comprehensive and thorough review of these systems may be found in (Schwinger *et al.*, 2005) and (Chenand Kotz, 2000).

In this paper, a Context-Aware Mobile Touring and Navigation (CAMTON) system is developed that takes advantages of ontological approach to enable semantic adapted services in the field of tourism and cultural heritage. This system attempts to consolidate a repository of geographically disparate tourism databases, presents a contextualized view of the tourism and cultural heritage, senses and matches the context information and discovers appropriate geospatial services. In this system, identified outdoor services take the location, time and profile of the user into account and use this information to adequately adapt the offered service and/or information. The main features and services provided by the CAMTON system include the tourist navigation system, exploration of the cultural heritage information and recording the on-site information and updates.

This paper is organized as follows. Section 2 briefly defines the concept of context and context-awareness in mobile tourist guide systems. In section 3, the proposed context modelling is explained using the ontology modelling approach. Section four describes the service oriented architecture to provide context-aware services for users. The implanted system has been evaluated in the in section 4. The last section concludes the contents of this paper.

2. CONTEXT-AWARENESS IN MOBILE COMPUTING

Context-aware computing refers to a general class of systems that can sense their environment and adapt their decisions or behaviours accordingly. The idea of context-awareness has been introduced in ubiquitous computing research (Weiser, 1991) and has been subject to extensive research ever since. Emergence of mobile computing components in early 90's initiated the investigation of context-awareness in distributed computing.

Although context and context-awareness has been studied in many research area's (i.e. artificial intelligent, human-computer interaction, ubiquitous computing (Dockorn Costa, 2003; Rios Mendoza, 2003; Pokraev *et al.,* 2003), a precise definition of context is still challenging. Context may refer to identity (who), activity (what), location (where), time (when), devices, network availability, status, and even the social situation (Dey, 2001). Furthermore, context-awareness is defined as (Dey, 2001): "A property of a system that uses context to provide relevant information and/or service to the user, where relevancy depends on the user's task". Context-aware services are able to understand various aspects of current situation and use them to interact with the user in a more intelligent way (Floch *et al.*, 2001). For a long time, systems like Geographic Positioning System (GPS) remained the sole source of context for the development of location-aware systems. However, location is only one aspect of a more complex physical and logical context. With the current advances in sensor technology and computer applications, context-awareness can be attained through integrated effort in the development of an open and global framework.

In this paper, context and context-awareness are employed to help a mobile tour guide system provide relevant information in each status. Using context-aware computing in CAMTON system decreases the computational cost and offers applicable information in different context of use. When the tourists move around, context information changes more frequently than if they were stationary. Movements of the mobile users change the surrounding entities and leading to entities being added or removed from the user context. Therefore, the location information is the key context of mobile tourist guide system. Moreover, different context scope could be supported by the system (such as time, device, network, user as well as location).

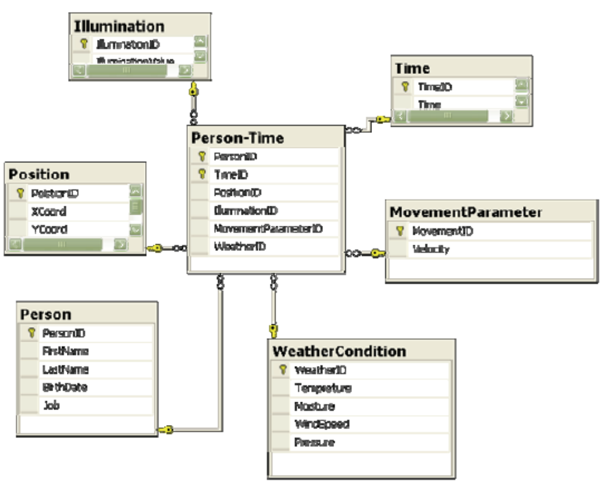

Figure 1. Physical context in the modelling design

In our modelling design, context may be classified into four main categories including computational device (such as size of display, input method, network and communication cost and quality), user (such as nearby people, user's profile, socio-cultural situation), environment (such as location, lighting, temperature, weather conditions) and time (such as time of day, week, month). The acquisition of context can be characterized by user (manual), the system (automatic) or a combination of both (semi-automatic). Based on the contexts' level of abstraction, two categories of context can be obtained: physical context that is provided by sensors or the profile data; and logical context which is derived based on the inference mechanism or data mining. Figure 1 shows the physical factors of the context adaptation in CAMTON system.

3. ONTOLOGY-BASED CONTEXT MODELLING APPROACH

CAMTON system provides tourists with context-aware recommendation and services which can be achieved using customization and adaptation towards the current context. In this section, we analyze challenges in the implementation of a fundamental characteristic of the tourism context, namely time-awareness (Kleinrock, 1996), location- awareness (Großmann, 2001), device- awareness (Rodriguez, 2001) and personalized services. From a software engineering perspective, context-awareness requires mechanisms allowing easier implementation of applications and services which use context data, as well as design of reusable sensing components. The implementation of context-awareness is made possible by a combination of different technologies. First, the system needs appropriate sensors and data collection technologies, and at a higher level technologies for fusing, analyzing and interpreting sensor data. Decoupling the sensing layer from applications is a key design principle for context-aware applications. To this end, software frameworks are needed to simplify and standardize (using appropriate patterns) the communication between applications, sensors and actuators. Moreover, to maximize the usefulness of context information for different services, designers need to create standard and widely accepted models for context information, together with standard mechanisms for accessing these models.

3-1- Ontology-Based Context Modelling

A context-aware system should automatically recognize the situation using various sensors. Therefore different user devices need semantically rich descriptive context models to provide shared understanding. In addition handling user query is another area where semantic knowledge is necessary. Thus, for processing context data, we need more intelligent systems that are capable of processing not only contents but also the meanings (semantics) of data. This calls for the use of a context representation model that describes concepts, concept hierarchies and their relationships. Therefore, context modelling is a key feature in context-aware systems.

Ontologies as explicit formal specifications of the terms in a domain and the relations among them (Gruber, 1993), are a widely accepted tool for modelling context information in pervasive computing domain. The reason for this acceptance is twofold. In one hand it has several advantages over other traditional modelling approaches (Strang and Linnhoff-Popien, 2004), on the other hand, the Semantic Web languages and tools have clearly gained maturity over the past years. The basic concept of our context model is ontology which provides a vocabulary for representing knowledge about tourism and cultural heritage and describes specific situations based on the user and domain context. The main advantage of this context model is sharing common understanding of the structure of context information among users, devices and services to enable

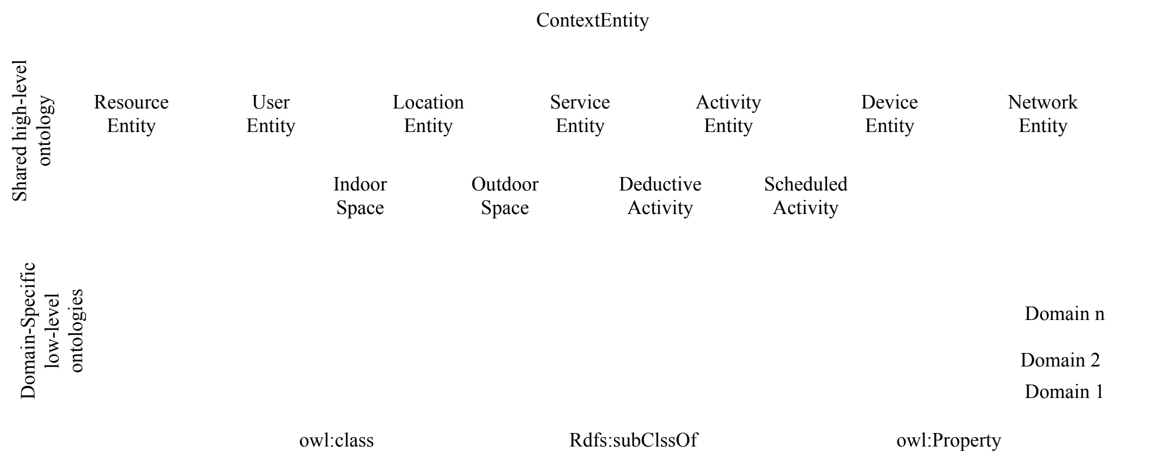

Fig.2. context ontologies which are divided into high-level and low-level

semantic interoperability between museum guide systems, the visitors and various initiatives attempting to meet the needs of the individual user. It also enables reuse of domain knowledge, i.e., building a national ontology infrastructure for cultural heritage by integrating several ontologies describing portions of the large domain. Most importantly, it enables formal analysis of domain knowledge, for example, context reasoning becomes possible by explicitly defining context ontology. The use of ontology will make our model independent of programming and application environment. In addition to the standardization of the structure of the context representation, it will help us provide semantic descriptions and relationships of entities. Using ontology, we can also perform deeper knowledge analysis by defining domain specific rules.

Our context ontologies are divided into high-level and low-level ontologies. The high-level ontology is a generic ontology which captures basic context knowledge about the physical world environments. The low-level ontologies are a collection of domain-specific ontologies which define the details of general concepts and their properties in each sub-domain. The low-level ontology in each sub-domain can be dynamically plugged into and unplugged from the upper ontology when the environment is changed, for example, when a user leaves the museum to drive a car, the museum-domain ontology can be automatically unplugged from the system; and the vehicle-domain ontology can be plugged into the system. The context ontology should be able to capture all of the characteristics of context information. First, it is responsible for captureing a great variety of context. The upper ontology defines the basic concepts of personal profile, location, computational entity and activity as shown in Figure 2.

Many ontology languages exist including Resource Description Framework Schema (RDFS) (W3C, RDFS 2004), DAML+OIL (DAML website), and OWL (W3C, OWL 2005). OWL is a key to the Semantic Web and was proposed by the Web Ontology Working Group of W3C. OWL is a language for defining the web and is more expressive than other ontology languages such as RDFS. Comparing XML, RDF, and RDF Schema (RDF-S), OWL facilitates greater machine interpretability of Web content by providing additional vocabulary along with a formal semantics (W3C, RDF 2005). OWL is based on DAML+OIL. Generally, it uses the same language structure plus extensions. It is now being proposed as W3C standard for ontology and metadata representation. Just like DAML+OIL, OWL is based on XML and RDF/RDF-S. Therefore, it uses XML namespaces and URI's. We conducted context ontology modelling using axiom such as owl:subclass, owl:inverseOf, owl:unionOf, owl:disjointWith and owl:sameAs which are provided in OWL as shown in the following example:

```
<owl: Class rdf:ID='Visitor'>
  <rdfs:subClassof>
           <owl:Restriction>
               <owl:onProperty rdf:resource='Graduat'/>
               <owl:toClass rdf:resource ='#Person'/>
               <owl:classifiedAs rdfs:resource
  ='ftp://305678/classification#Reference'/>
           </owl:Restriction>
  </rdfs:subClassof>
</owl:Class>
```

We generated ontology-based context metadata which is stored in the repository and is retrievable by the inference engine. The data which is generated by sensors provides the information used for service inference engine. In this system, we used Protégé-OWL editor (Knublauch *et al*., 2004) which supports the OWL descriptions of classes, properties and their instances (refer to the figure 3). Given such an ontology, the OWL formal semantics specifies how to derive its logical consequences, i.e. facts that are not literally present in the ontology, but are entailed by the semantics.

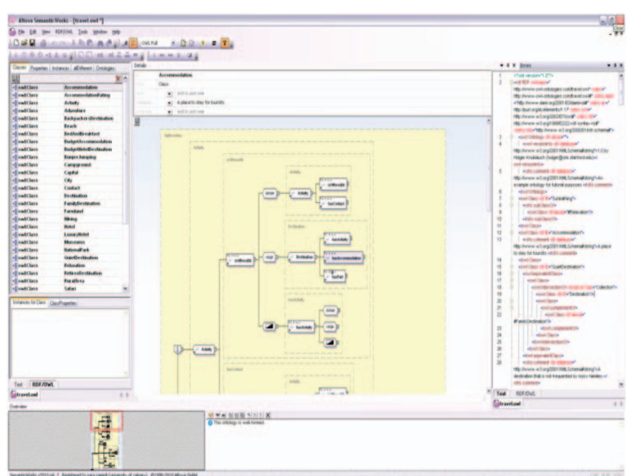

Figure 3. Protégé-OWL editor for descriptions of classes, properties and their instances

3-2- Context Reasoning

In CAMTON system, the context reasoning techniques attempt to integrate the personal data of the user, the environmental sensor, defined and sensed context according to logical operation. The important feature of our context model is the ability to support automated context reasoning which is the process of reasoning about various types of contexts and their properties. Context reasoning broadens context information implicitly by introducing deduced context derived from other types of context. It also provides a solution to resolve context inconsistency and conflict caused by imperfect sensing. Using the reasoning engine, deduced context can be inferred from sensed, defined or aggregated context based on our classification scheme. Reasoning can be used to detect an abnormal physiological condition in the user over time and track the historical changes. on the other hand, as the system needs the knowledge of experts to provide appropriate guides, we generated the rules based on user critics in our scenarios and proposed the knowledge inference technique to place reasoning in context using the rules based on the knowledge of an expert. The two semantic inference methods are executed simultaneously in one inference engine utilizing the same knowledge base.

Sensed and inferred context data can be converted to useful information according to the context model and inference rules. Therefore, the aim of context reasoning is matching and deducing useful context using an ontology model and the axiomatic semantics-based inference and domain specific rules. Moreover, by reasoning context classification, system is able to detect and resolve context conflict. The rule repository is composed of first-order logic predicates which are generated by the OWL axiom. The OWL axiom provides the expressions defining the inheritance relationship between an entity, an equality relation and an inverse relation. The OWL axiom is also used to infer the uncertainly-defined features or meanings by chaining process. Defined rules can be dynamically created, deleted and modified when the status of the user or service provider changes. An example below shows deduced context (National park is not feasible) which can be inferred from sensed context (rainy, coordinate, time) and defined context (user preference):

WeatherCond(Weather, Rainy) ^ *Location(Coordinate, value)* ^ *Transportation(Device, Onwalk)* ^ *VisitePreference(Members,Items)* ^ *Valid(Time, OpenItems)* → *FeasibleItem (NationalPark, NO)*

In the rule based engine, different types of contexts have different levels of confidence and reliability. For example, deductive user context calculated based on the data mining of previous user selections has less confidence factor than the observed context which are provided by the user directly. On the other hand, the accuracy of observed context is also contributed in the level of confidence for that context. For example, in the location context, an RFID-based location sensor may have 80% accuracy rate whereas a Bluetooth-based location sensor may only have a 60% accuracy rate.

4. SYSTEM ARCHITECTURE

In this section, we describe the service-oriented architecture (SOA) of context aware middleware as a loose coupling between software components. Service-oriented context-aware middleware architecture has been used to help application programmers to build context-aware services more efficiently (Erl, 2005). A service consists of an interface describing operations accessible by message exchange. Services are autonomous, platform-independent and can be described, published, dynamically located, combined and programmed using standard protocols (H. Gümüşkaya, 2010). SOA is an extension of the new techniques, like XML, and Web Services to realize platform independent distributed systems (Gümüşkaya, 2010).

Principles and guidelines for designing middleware for mobile computing have been studied in different researches (Boari, 2008; M. Roman, 2001; C. Mascolo, 2004; Coulson, 2008). However, there are few examples of research deploying SOA context-aware technologies (Wenwei Xue, 2008). In this research, the context-aware system publishes the customized services based on the three modules: Context Provider, Context Interpreter and Context-aware Mobile Services. As illustrated in figure 4, the context data are collected by Context Providers. Context Providers abstract contexts from different sources: external context providers or internal context providers; and convert them to OWL representation so that contexts can be shared and reused by other components. An internal context provider may change a context by adding and removing physical sensors or by reconfiguring a set of contexts supported. This system supports wide-area discovery as a context provider, *e.g.* a weather service provider may be physically located in external networks

The low-level ontology which is defined by instances of contexts about a subject and its environment are mapped to high-level context ontology structure by the Context Interpreter. This mapping helps make the context ready for reasoning and decisions using available relations, concept ontology and rules. Context Interpreter consists of context reasoning engines and context KB (Knowledge Base). The context reasoning engines provide the context reasoning services by inferring deduced contexts, deriving secondary data (*e.g.* derivation of velocity from position and time data), checking the collected data (*e.g.* consistency and correctness), monitoring the context information and maintaining the consistency of context KB. The context KB provides the ability that other components can query, add, delete or modify the context knowledge stored in the database. The three sources of context KB, ontology and context reasoning engines are used to perform reasoning and decisions by context interpreter. The context broker is able to track and adapt context-aware mobile services to the dynamic changes of context providers.

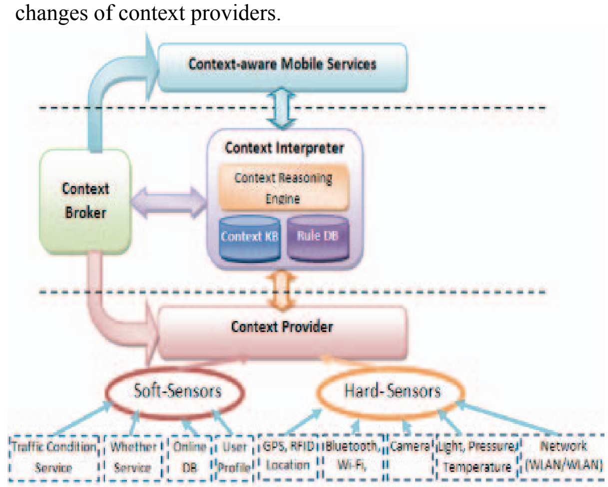

Figure 4: CAMTON context- aware system architecture

User employs a wireless handheld device (*e.g*. PDA, smart cell phone, *etc*.) to connect the system. When the tourist wishes to request a service using the predefined spatial analysis, *e.g*. the nearest restaurant in his path, the related functions are called and requests are sent to the context-aware service catalogue by the Context Broker. The catalogue has on-line and real time connections with context providers through Context Broker component. The user will send the query "socam:locatedIn(Nearest resturan ?x)" to the context broker. Context broker will load the context ontologies stored in the database and context instances advertised by different context providers, and apply semantic matching to find out which context provider provides the required context. If a match is found, the reference to the context provider will be returned to the application.

5. SYSTEM IMPLEMENTATION

New mobile communication devices combine several heterogeneous wireless access technologies such as cellular (*e.g.* UMTS/GSM, and GPRS/EGDE), GPS as well as wireless data communication LAN technologies (*e.g*. IEEE 802.11) and Bluetooth. The implemented platform operates on the top of the 3G networks and requires a permanent network connection (*e.g*. GPRS). In this system, different sensors (*e.g*. camera, compass, GPS and *etc*.) have been deployed to observe context data. GPS collects spatial locations with the accuracy of better than five meters. Such accuracy is beneficial when considering the boundaries of an archaeological site each time a site is visited. In addition to the GPS coordinates, the location can be derived from the user's speed and movement direction on the map as a logical location context (Malek M. R. and Frank, 2006). To obtain speed and movement direction the context history of the GPS signals observed over a longer period is considered.

External context information (*e.g*. weather condition, temperature, traffic flow, and *etc*.) are automatically extracted through the Web. On the other hand, users log the profile information and their preferences directly when they are using the system. There are also some mechanisms for mining historical user data and provide logical context to generate user context indirectly.

The implementation of a context-aware mobile tour system based on ontological approach depends on different criteria considered in modelling the system. Our system has been designed as a digital tour guide and pedestrian way-finder to reach destination point and other cultural heritage services. This system supports the tourists by means of location-based services in the following ways:

- It assists the tourists in organizing an individual tour navigation, route planning such as finding the nearest point of interest (POI), and wayfinding support, based on landmarks and way finding techniques (Malek M. R. and Frank, 2006 and Samany *et al*., 2007)
- It provides the tourist with personalized on-suit tourism information about POIs such as the audio/video files about historical buildings.
- It records the field data in a format that can be easily transferred into the existing geo-database quickly and accurately. User can simply manipulate and manage the existing data in a geospatial information system (GIS). Data acquisition can be supported by camera and GPS sensors for data collecting process.

There are different operating systems for mobile applications: Symbian, Palm OS, and Windows CE. These frameworks have different versions and equipments. The variations are in the velocity of processors, the amount of memory, the existence of peripheral programs such as sound and image, and the tools for communicating with the network. Windows CE which is a version of Windows used in mobile applications is now replaced by Windows Mobile. Nowadays, Windows Mobile is the operating system of most pocket PCs and smart phones. In this operating system Embedded Visual languages such as Embedded Visual C, Power builder .NET and *etc* can be utilized. CAMTON system has been implemented using .NET on Windows mobile.

The system proposed in this paper provides information and services for the user based on the updates in the context information. The system provides maps at three different levels of detail based on the display size and relevancy of the visualized information with the context of use. The maps are both north up and track up. This matter results that the unfamiliar user adapt to the environment with the least complexity. Information about the historical buildings is presented in multimedia form including text, sound and images, which enables the comparison between the historical and current view. The geodatabase (*e.g*. maps and orthophotos) and information about historical places and POIs can be stored on the mobile device or alternatively it can be dynamically loaded via a wireless network connection from a GIS server through an OGC Web Map Service3.

The application can query the SOA context-aware system to provide appropriate services for the users. The visualization of the own position as well as that of the locations of the POIs enable the user to get a quick overview of the existing monuments or search for relevant information. CAMTON is implemented based on -historical city-Bishapour. Figure 5 shows map view and the wayfinding module of this system.

Figure 5: Some pages of CAMTON system

6. CONCLUSIONS

The proposed system of this paper is a multimedia and spatial database which is integrated with different sensors such as digital camera and GPS in mobile environment. More uncertainty is involved in mobile devices in comparison with desktop and static systems. Furthermore, as mobile information systems are fairly personal, making the system aware of the context enhances its performance dramatically. To demonstrate this issue, a system called CAMTON (Context-Aware Mobile Touring and Navigation) is proposed in this study. The CAMTON framework generalizes the location-based services to context-based services with the purpose of assisting context-aware services and applications in mobile or desktop environments.

In this paper, we have presented a context modelling approach and a service oriented web services architecture that guarantees the adaptation of cultural heritage and tourist contexts. The context model uses ontology representation based on the basic context descriptors. These descriptors are considered as base classes in the ontology hierarchy to represent domain independent concepts. The domain specific subclasses are defined as sub classes of the base ontology classes. The proposed model, also benefits from the features of OWL and related ontology rule languages for managing context data.

As a future work, the semantic description of the data can be used to perform reasoning and combine the location information provided by different positioning sources. This integration can help spread the positioning coverage and achieve a higher positioning availability and precision. This can be considered as the next step in developing a system with more accurate position information.

7. REFERENCES

Abowd, G.D., Dey, A.K., Orr, R., 1997, Brotherton, J. Context-Awareness in Wearable and Ubiquitous Computing. *1st International Symposium on Wearable Computers,* pp. 179-180.

Altmann, J. L., 2003. Context-Awareness on Mobile Devices - the Hydrogen Approach. *Proc. of the 36th Hawaii International Conference on System Sciences (HICSS-36)*, Minitrack on Mobile Distributed Information Systems. January 6-9, Big Island, Hawaii.

Ardissono, L., Goy, A., Petrone, G., Segnan, M., Torasso, P., 2003, "Intrigue: Personalized Recommendation of Tourist Attractions for Desktop and Handset Devices", *in Applied Artificial Intelligence*: Special Issue on Artificial Intelligence for Cultural Heritage and Digital Libraries 17(8-9), pp. 687-714.

Boari, M. L., 2008. Middleware for automatic dynamic reconfiguration of context-driven services. *Microprocess. Microsyst.* 32, 3 , 145-158.

Brusilovsky, P. M., 2002. From adaptive hypermedia to adaptive Web. In P. Brusilovsky, & M. T. Maybury, *Communications of the ACM* (*CACM*), Vol. 45, No. 5, Special Issue on the Adaptive Web.

Chen, G. And Kotz, D., 2000, A survey of context-aware mobile computing research. technical report, Dept. Of computer Science, Dartmouth College

Cheverst, K., N. Davies, *et al*., 2000. Developing a Context-aware Electronic Tourist Guide: Some Issues and Experiences. *CHI 2000*, Netherlands.

Coulson, G. B., 2008. A generic component model for building systems software. *ACM Trans. Comput*. Syst. 26, 1 , 1-42.

DAML website: http://www.daml.org

Dejian Meng, S. P., 2009. An intelligent context-aware spatial routing system in mobile environment. *Proceedings of the 5th International Conference on Wireless communications, networking and mobile computing* (pp. 5461-5464). Piscataway, NJ, USA: IEEE Press .

Dey A.K., 2001. Understanding and Using Context. *Personal and Ubiquitous Computing*, 5(1):4– 7, Feb 2001.

Dockorn Costa P., 2003, "Towards a Service Platform for Context-Aware Applications", Master's thesis, University of Twente, August 2003

Erl, T., 2005. *Service-Oriented Architecture: Concepts, Technology, and Design*. Prentice Hall.

Floch, J., Hallsteinsen, S., Lie, A. and Myrhaug, H.I., 2001, A Reference Model for Context-Aware Mobile Services, In *proceeding of NIK*.

Großmann, M. L., 2001. A World Model for A World Model for Location-Aware Systems. Informatik, Vol. 8, No. 5 .

Gruber, T.R., 1993. A Translation Approach to Portable Ontology Specification. *Knowledge Acquisition*, 5(2):199–220, Jun 1993.

Gümüşkaya, M. V., 2010. A Software Solution for Mobile Context Handoff in WLANs. In K. E. Tarek Sobh, Novel *Algorithms and Techniques in Telecommunications and Networking* (pp. 305-309). Springer Netherlands.

Juan Pavón, J. M.-S., 2004. In L. K. A. Karmouch, MATA 2004, *LNCS 3284 (pp. 322–330)*. Springer-Verlag Berlin Heidelberg.

Kleinrock, L., 1996. Mobile Nomadicity: Anytime, Anywhere In *A Disconnected World. Networks and Applications*, 1(4) .

Knublauch, H., Fergerson, R.W., Noy, N.F., *et al*., 2004. The Protégé OWL plugin: An open development environment for semantic web applications. In: *Proceedings of the 3rd International Semantic Web Conference (ISWC)*, Hiroshima, Japan, November 2004

Loeb, S. T., 1992. Information Filtering. *Communications of the ACM (CACM)*, Vol. 35, No. 12 .

Malek, M. R. and Frank, A. U., 2006. A Mobile Computing Approach for Navigation Purposes, In *Web and Wireless Geographical Information Systems*, Springer Berli / Heidelberg, pp. 123-134

Mascolo, L. C., 2004. Principles of Mobile Computing Middleware, Middleware for Communications. Wiley.

Oppermann, R. S., 1999. A Nomadic Information System for Adaptive Exhibition Guidance. *Int. Conf. on Hypermedia and Interactivity in Museums.* Washington.

Rios Mendoza D., 2003, "Using ontologies in Context-Aware Services Platforms", Master's thesis, University of Twente, November 2003

Rodriguez, J. e., 2001. Extending e-business to Pervasive Computing Devices - Using WebSphere Everplace Suite Version 1.1.2. IBM Redbooks, *International Technical Support Organisation*, SG24-5996-00.

Roman, F. K., 2001. Reflective Middleware: From your Desk to your Hand. IEEE Distributed Systems Online, vol. 2, no. 5 .

Samany, N. N., Hajibabai, L., M. R. Delavar, Malek, M. R., Frank, A. U., 2007. An Agent-based Indoor Wayfinding Based on Digital Sign System, Proceeding of Urban Data Management Symposium 2007. ftp://ftp.geoinfo.tuwien.ac.at/frank/af_udms2007-RFID-final_07.pdf

Schmidt-Belz, B. M., 2002. Intelligent brokering of tourism services for mobile users. In K. F. Wöer, Information and communication technologies in tourism 2002: Proceedings of the International Conference in Innsbruck, Austria. Springer-Verlag Wien.

Schwinger, W., Grün, Ch., Pröll, B., Retschitzegger, W., Schauerhuber, A., 2005. "Context-Awareness in Mobile Tourism Guides–A Comprehensive Survey", Technical Report, Business Informatics Group at Vienna University of Technology, July 2005.

Strang, Th. and Linnhoff-Popien, C., 2004. A Context Modeling Survey. In 1st Int'l Workshop on Advanced Context Modelling, Reasoning and Management, pp. 34–41, Sep 2004.

Tezuka, T., Yokota, Y., Iwaihara, M., Tanaka, K., 2004. Extraction of Cognitively-Significant Place Names and Regions from Web-Based Physical Proximity Co-occurrences. In: Zhou, X. *et al*. eds. Web Information Systems – WISE 2004. Lecture Notes in Computer Science, 3306. Springer, pp. 113-124.

W3C, RDFS, 2004. (RDF Vocabulary Description Language 1.0: RDF Schema), Recommendation 10, February 2004, http://www.w3.org/TR/rdf-schema/

W3C, OWL, 2005. Web Ontology Language Overview, Recommendation, 10 February 2005, http://w3.org/TR/2004/RDC-owl-features-20040210/

Weiser, M., 1991. The Computer for the 21st Century. Scientific American, vol 265, no. 3 , 66-75.

Wenwei Xue, H. P., 2008. Schema matching for context-aware computing. Proceedings of the 10th international conference on Ubiquitous computing, September 21-24. Seoul, Korea .