Knowledge based Industrial Maintenance using portable devices and Augmented Reality

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Abstract. In this paper we present a framework and a system implementation for the exploitation of embedded knowledge in the domain of industrial maintenance in a mobile context, using Augmented Reality techniques. We base our approach in the SOUPA group of ontologies (Standard Ontology for Ubiquitous and Pervasive Applications). Our approach extends SOUPA with two new ontologies (*i*) the Set of Experience Knowledge Structure, used to model the user's experience and (*ii*) the AR ontology which models an Augmented Reality environment that is used to enhance the maintenance experience through virtual elements. As test case, we implemented our approach in different portable devices with video input capabilities such as UMPCs, PDAs and Tablet PCs.

1 Introduction

Nowadays, engineering systems are based on evolving paradigms; the knowledge and the user experience take a big role in today's applications as we have now the computational capability of modeling such paradigms. From an industrial point of view, there are several processes involved in the product life cycle, being one of extreme interest the maintenance of the product itself; a set of actions which is known as Industrial Maintenance (IM). IM can be defined as the combination of all technical and administrative actions, including supervision actions, intended to retain an entity in, or restore it to, a state in which it can perform a required function [6]. According to Honkanen [5], machines have to be maintained in order to increase reliability and thereby avoid production disturbances. It is, therefore, assumed that the purpose of a single maintenance action is to increase reliability. There are several techniques and theories that can be applied to the Industrial Maintenance field. The explanation of those techniques is outside the scope of this paper, but an interested reader is referred to the work of Honkanen [5]. From an application point of view, different research projects have been presented by the scientific community involving the implementation of Virtual and Augmented Reality (VR/AR) to extend the user's understanding and, in general, his experience during the maintenance work ([3],[7]). To our acquaintance, most of these approaches however, miss the potential of using knowledge based theories in the domain that might enhance the user's experience. This user, in our case, is the maintenance worker in a typical industrial facility whose special needs include mobility, fast response and immediate access to the relevant data, like specifications, historical records, etc. We show in this paper that the use of semantics and augmented reality techniques provide additional support to the maintenance tasks, by improving the user understanding of the elements being maintained. The enhancement comes when the knowledge and the user experience related to the maintenance system is embedded in the AR environment as an important aid for the user, giving him an additional level of immersion. This paper is organized as follows: In chapter 2, an overview of the conceptual basis is presented. In chapter 3, we introduce our knowledge based industrial maintenance system. In chapter 4, we show a case study implemented in different portable devices, explaining briefly some highlights, and in chapter 5, we present our conclusions and lines for future work.

2 Conceptual basis and background

In this chapter we introduce some concepts relevant to this paper. Our intention is not to give a wide description of the topics involved, but to give a short overview in order to have a self-contained paper.

2.1 Knowledge modeling using Ontologies

Following is Tom Gruber's widespread accepted definition of what Ontology is in the Computer Science domain: ontology is the explicit specification of a conceptualization; a description of the concepts and relationships in a domain [4]. In the context of Artificial Intelligence (AI), we can describe the ontology of a program by defining a set of representational terms. In such ontology, definitions associate names of entities in the universe of discourse with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Computer programs can use ontologies for a variety of purposes including inductive reasoning, classification, and problem solving techniques, as well as communication and sharing of information among different systems. In addition, emerging semantic web systems use Ontologies for a better interaction and understanding between different agent web-based systems. Ontologies can be modelled using several languages, being the most widely used RDF and recently OWL (Ontology Web Language) [11]. Ontology modelling can deliver interesting benefits as it allows inferring semantically new derived queries. These queries relate concepts that are not explicitly specified by the user, but nevertheless relevant to the query. Modern inference engines and reasoners like Pellet and Racer deliver a highly specialized, yet efficient way to perform such queries via a JAVA compliant API [11]. In the literature, data handling by Ontology-based technology is reported by researchers in different fields [11]. Furthermore, user modelling, task and experience are also possible scenarios for the exploitation of semantic data by Ontology based technology as it was addressed for example in the European IST-Project WIDE [10].

2.2 SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications)

SOUPA is a shared ontology expressed using OWL [2], designed to model and support pervasive computing applications (ambient intelligence). It consists of two distinctive but related set of ontologies, called SOUPA Core and SOUPA Extension as can be seen on figure 1.

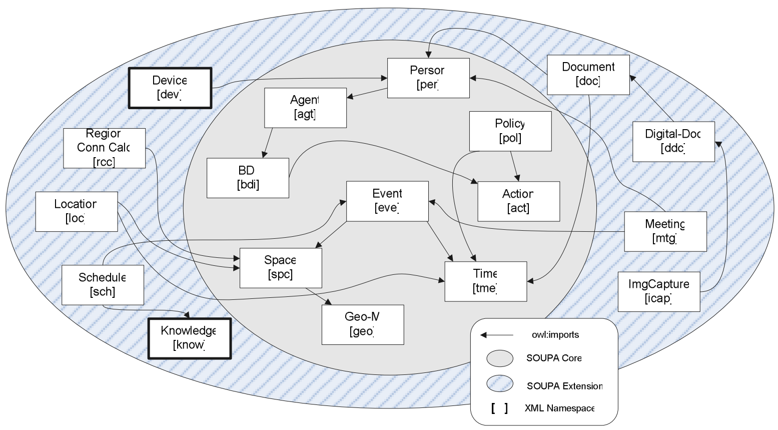

Fig. 1. The SOUPA group of ontologies (Core + Extension) [2]

The set of the SOUPA Core ontologies attempts to define generic vocabularies that are universal for different pervasive computing applications, vocabularies for expressing concepts associated with person, agent, belief-desire-intention (BDI), action, policy, time, space and event. The set of SOUPA Extension ontologies define additional vocabularies for supporting specific types of applications and provide examples for future ontology extensions. The Core and Extension of SOUPA have been applied in several research projects like the Context Broker Architecture (CoBrA) [2] which is agent based architecture for supporting context-aware systems in smart spaces. Central to this architecture is an intelligent agent called context broker (majordomo) that maintains a shared model of context on behalf of a community of agents, services, and devices in the space while providing privacy protections for the users. We intend to show in this paper that by extending SOUPA and using the CoBrA architecture is possible to implement a context aware (ubiquitous) system that helps a user in an Industrial Maintenance environment.

2.3 Virtual Reality and Augmented Reality in the Industrial Maintenance Environment

Virtual Reality (VR) is a virtual environment where the user is immersed in a virtual world in which the elements hold the physical resemblance to possible objects belonging to the real world. Milgram and Kishino created a *Virtuality Continuum* [8] to classify mixed worlds, in where we find Augmented Reality (AR) as a system that, according to Azuma [1], combines real and virtual objects in a real environment enhanced with computer generated graphics, running interactively, in real time, and aligns real and virtual objects with each other. In this work we use Augmented Reality in order to enhance the user's experience (maintenance engineer) by giving him contextualized information extracted from an ontology reasoning kernel. Augmented Reality in an industrial maintenance environment provides, for example, user experience enhancements like the viewing of information related to the object in sight that has been matched with the marker; this information can be extracted from a knowledge system or web page and is contained or handled by the ontologies. Moreover, the handling, in a graphical manner, of the contained information in manuals and operation guides.

2.4 The Set of Experience Knowledge Structure

Set of Experience Knowledge Structure (SOE) is an experience tool able to collect and manage explicit knowledge of different forms of formal decision events [9]. The SOE has been developed as part of a platform for transforming information into knowledge named Knowledge Supply Chain System. In the SOE, there are four basic components (see figure 2): variables, functions, constraints and rules associated and stored in a combined dynamic structure.

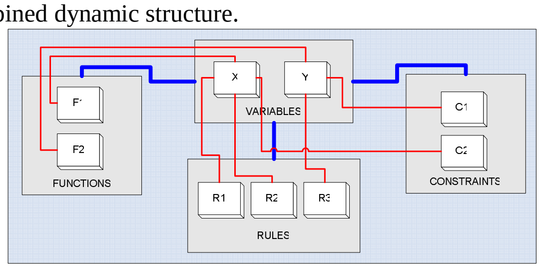

Fig. 2. The Set of Experience Knowledge Structure

The combination of the four components of the SOE offers distinctiveness due to the elements of the structure that are connected among themselves, imitating part of a long strand of DNA. A SOE produces a value of decision, called efficiency. Besides, it is possible to group sets of experience by category, that is, by objectives. These groups could store a "strategy" for such category of decisions. Furthermore, an OWL ontology modelling the SOE was presented by Sanín et al. [9], and it was added to SOUPA with the purpose of extending its functionality in a way that formal decision events can be suggested to the Maintenance User during his/her work. Those stored sets of experience are produced by past decisions made by maintainers with the same or similar elements. E.g. the user is checking during her/his duties a butterfly valve. Since it is a fluid restringing element, possible decisions taken in the past on such valve, or a similar element (ball valve), could be suggested by the system.

3 The UDKE System

In this chapter, we introduce our Knowledge based Industrial Maintenance system using portable devices and Augmented Reality. We call our architecture UDKE (User, Device, Knowledge and Experience). UDKE provides a possible conceptual model of a maintenance system that combines knowledge, user experience and AR techniques. The schema is divided in layers which are depicted in figure 3.

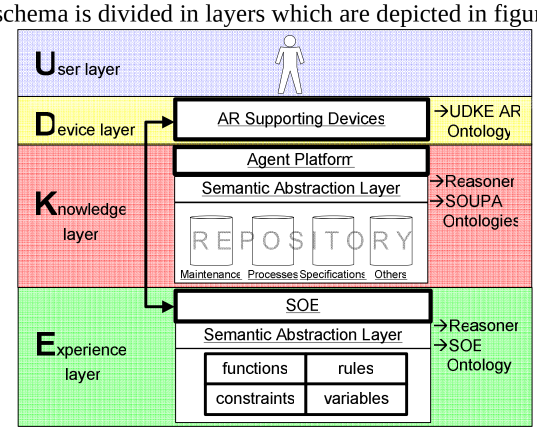

Fig. 3. The UDKE System

The *User layer* contains only the user, handling the particular profile, session, etc. The *Device layer* contains the modeling of the different devices used to capture the environment (a camera, a PDA, a pocket PC or a Tablet PC, etc) introduced as an extension to SOUPA that we call the UDKE AR ontology. In the figure 4, such extension is depicted (extending from the SOUPA class **dev:device**)

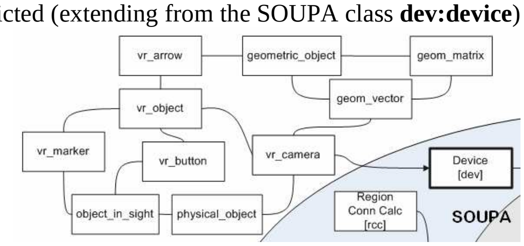

Fig. 4. The UDKE AR extension to SOUPA

The *Knowledge layer* contains the agent platform whose main objective is to interact via majordomo messages with the Semantic abstraction engine. It contains the

SOUPA Core and the SOUPA Extension ontologies as well as a reasoner system that is in charge of performing the semantic queries. The Ontologies feed their instances from different repositories relevant to the maintenance domain (historical data, programmed stops, cycles, etc). In the *Experience Layer*, the SOE is enclosed as an OWL ontology with different data bases that feed the reasoning system with functions, rules, constrains and variables used to specify new decisional events or even to contain past decisional events taken over similar elements (where similar refers to the object in sight element or in other words the element in which the maintenance engineer is considering at a given moment). In the next figure, we show the extension place of the SOUPA set of Ontologies in which we derived the Set of Experience Knowledge Structure ontology that was presented by Sanin et al. [9], the extension class is **know:Knowledge**.

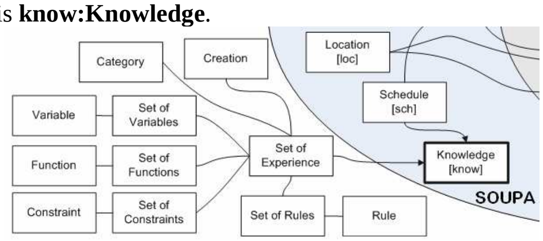

Fig. 5. Extension of the SOUPA set of Ontologies with the SOE

4 Case study

The user during his maintenance patrol takes his portable device with a camera attached to it. For every object to be maintained, a related VR marker can be found (following the sensor concept in ambient intelligence). When the system finds a marker, a matching element to be maintained is identified according to the context (user, task, priority) and a set of information is extracted from the repositories. The output video stream of the camera is mixed with 3D objects and other relevant information and is displayed to the user in his portable device screen (figure 6). The exploitation of the experience arises when for example the maintenance worker is checking a pipe and discovers a pressure drop. By using embedded knowledge, the user can relate the pressure drop in the tube to a pump, because the line pressures, due to elevation or friction which are parameters of such pump, are directly related. As one decreases any of these variables, the pressure in the line will also decrease.

4.1 Implementation issues

The system was tested using different portable devices, our implementation uses JAVA as the core language for the prototype implementation. The graphic library and the AR engine used were GL4Java and JARToolkit library respectively. All the ontology modeling was done in Protégé and the API used was the Protégé OWL API. The agent platform used in our implementation was JADE, and for reasoning purposes over the ontologies we chose RACER. When a marker is detected, the system calculates the matrices necessary to place the augmented information via JARToolkit calls. Following the application flow, the Agent platform begin its work starting a majordomo service whose main function is to serve as an intermediary between the user and the rest of the architecture. The majordomo handles the events in the knowledge layer data bases through reasoning over the SOUPA ontologies. The majordomo also handles the Experience layer through reasoning over the SOE ontology in order to obtain knowledge from past experiences or similar devices being maintained. Once that all that information is obtained/inferred and possible experience are acquired from the SOE using the reasoning system, a last step is performed by returning such information to the device (UMPC, Pocket PC, etc) and displayed(streamed) it in its graphical output.

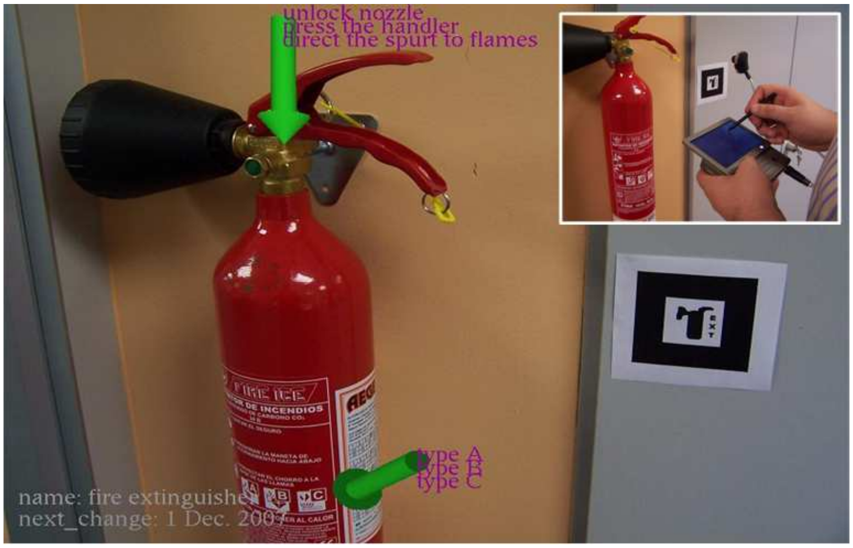

Fig. 6. AR Enhanced user view using the UDKE Platform

5 Conclusions and Acknowledgements

In this paper, we presented a framework and a system implementation for the exploitation of embedded knowledge in the domain of industrial maintenance in a mobile context, using AR techniques. An extension to SOUPA was presented with two ontologies: the Set of Experience Knowledge Structure (presented by Sanin et al. [9]) and a new ontology for handling AR objects. The framework was implemented in different portable devices as test cases. For our future work, we plan to test the system in a real facility in where a maintenance system is already implemented in order to test the system's feasibility. Also, we plan to extend the SOE ontology from a decisional point of view by including Genetic Algorithms. We want to thank the

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