Ontological Context-awareness for Adaptive Augmented Reality

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*Abstract***— This paper presents a proposal for supporting daily user needs by simple interactions with the environment through an augmented-reality perspective and applying proactive adaptation through knowledge representation using ontologies. The proposed architecture (i-ARA) makes use of principles of Semantic Web that endow context-awareness and user personalization. In addition, this kind of services allows the supervision and management of what is happening at the environment and, in consequence, to improve information offered to users. The architecture has been used to implement applications using iPhone technology and applied to illustrative scenarios.**

Keywords- Augmented Reality, Mobile Computing, Context-Awareness, Knowledge Representation, Semantic Web

I. INTRODUCTION

Mobile devices are now able to enhance interactions between users and their surroundings by means of a combination of real world and computer generated data, called mobile augmented reality. Typically, information offered to users is static or based on particular parameters such as location or explicit user requests. An important challenge in the mobile computing area is to enable mechanisms for the management of contextual information, reasoning techniques and adaptable user interfaces to support augmented reality services, providing functionality to make decisions about what and how available information should be offered.

Bearing in mind these premises, we envision the development of context-aware augmented reality systems following the metaphor <how to>, that is, the environment establishes guidelines of how to perform a task by means of positioning significant elements whenever the user interacts with an augmented object in the environment. We consider augmented object as any thing, person or area in the environment that has associate some information and offers a mechanism to interact with it and to share the linked information. There are multiple technologies and mechanisms to achieve these requirements such as NFC, QR codes and markers. Once acquired the information from an augmented element, the user receives the guidelines to perform the desired activity. Precisely in this step appears a problem: there is not a unique relationship between an augmented element and the needed information. In order to disambiguate this relationship we propose to endow context-awareness by means of the principles and languages of the Semantic Web. The definition of a formal context model that represents the users and their surroundings can determine what information they require, specifically, applying the semantic axioms of the language associated to the context model and defining behavior rules that represent how the user's world works.

In the developed prototypes, we have used the mobile device iPhone (3GS version with iOS 4.2). This device has 320x480 pixels of screen, so its dimensions are suitable for our purpose. It has an integrated accelerometer and a digital compass that we use to locate and draw objects in the user interface regarding to vertical and horizontal axis, respectively.

This paper is organized into seven sections. Section 2 explores how to apply context-awareness through languages of the Semantic Web. Section 3 presents a general architecture for generating augmented-reality-based mobile applications, linking information to relevant elements in the environment and techniques to formalize the representation of how the user world is and infer what information users want to obtain. The architecture also includes algorithms to positioning, at run-time, the relevant elements in the user interface. Section 4 describes some prototypes and illustrates the reasoning and information retrieval mechanisms. Section 5 describes the evaluation of our system and Section 6 deals with related work. Finally, Section 7 analyzes the conclusions and contributions of this paper.

II. CONTEXT-AWARENESS THROUGH SEMANTIC WEB PRINCIPLES

Personalized and adaptive behavior is an important desirable characteristic to be incorporated in mobile computer systems, and it has been studied for many years. This kind of systems require models that describe the real world, and they abstract from the complexity of the real word in order to understand it, at least in part, thus acting more like humans. Only by understanding the world around us applications can be developed that will be capable of making daily activities easier. In this sense, context-aware applications offer opportunities for smarter services on intelligent environments and, more specifically, for offering personalized information to users depending on their current needs.

In this paper, we state the ideal scenario in which users receive exactly the information they need, at any moment and throughout their activities. This ideal is far from reality but this work offers a contribution towards that end; we present an infrastructure to support information adaptability to users by describing context situation with Semantic Web languages and offering needed information through an augmented-reality perspective.

A. Introduction to Semantic Web

Advances on Semantic Web enable people and machines to share information, describing the semantics of concepts and services on the Web (and also outside the Web). Focusing on our approach, Semantic Web helps us to reduce the human cognitive effort required to access information and facilitating the semantic description to enable machine analysis and interpretation of the particular user situation. The adaptation of Semantic Web principles to Pervasive Environments offers important benefits, mainly in context modeling. The representation of context, in particular by means of ontologies, will become a substantial part of the design and maintenance of context-aware systems. The context definition expressed in Semantic Web Languages can provide a rich and unambiguous definition of relevant concepts in the environment domain.

The architecture of the Semantic Web is built upon a set of languages and technologies. The syntax is provided by XML. The mechanism to represent information about resources is known as Resource Description Framework (RDF) [1] and the taxonomical organization is enabled using the RDF Schema. Web Ontology Language (OWL) [2] extends RDFS by including more expressive constructors to describe the semantics of the elements. Finally, SPARQL [3] is a query language to retrieve information from web data sources.

B. Ontological Context Model

Based on these premises, the information associated to augmented elements has been described through the OWL language and it is part of a general context-model. The proposed model defines four taxonomical elements (see Figure 1):

- User ontology: It describes the user profile, their situation, and their social relationships. The user model has been designed to represent the characteristics of the user, what the user want to do, and what the user is doing. This model lean on the Friend of a Friend (FOAF) specification [4]
- Device ontology: It is the formal description of the relevant devices and their characteristics, associations, and dependencies. Mobile-based applications must support the spontaneous inclusion and evolution of new devices, acquiring their characteristics and upgrading the application behavior. This ontology is compatible with well-known device specifications such as the UAProf [5] specification, concerned with capturing information for wireless devices and the FIPA Device Ontology [6] that aims to be general but offers low-expressiveness in peripheral device description.

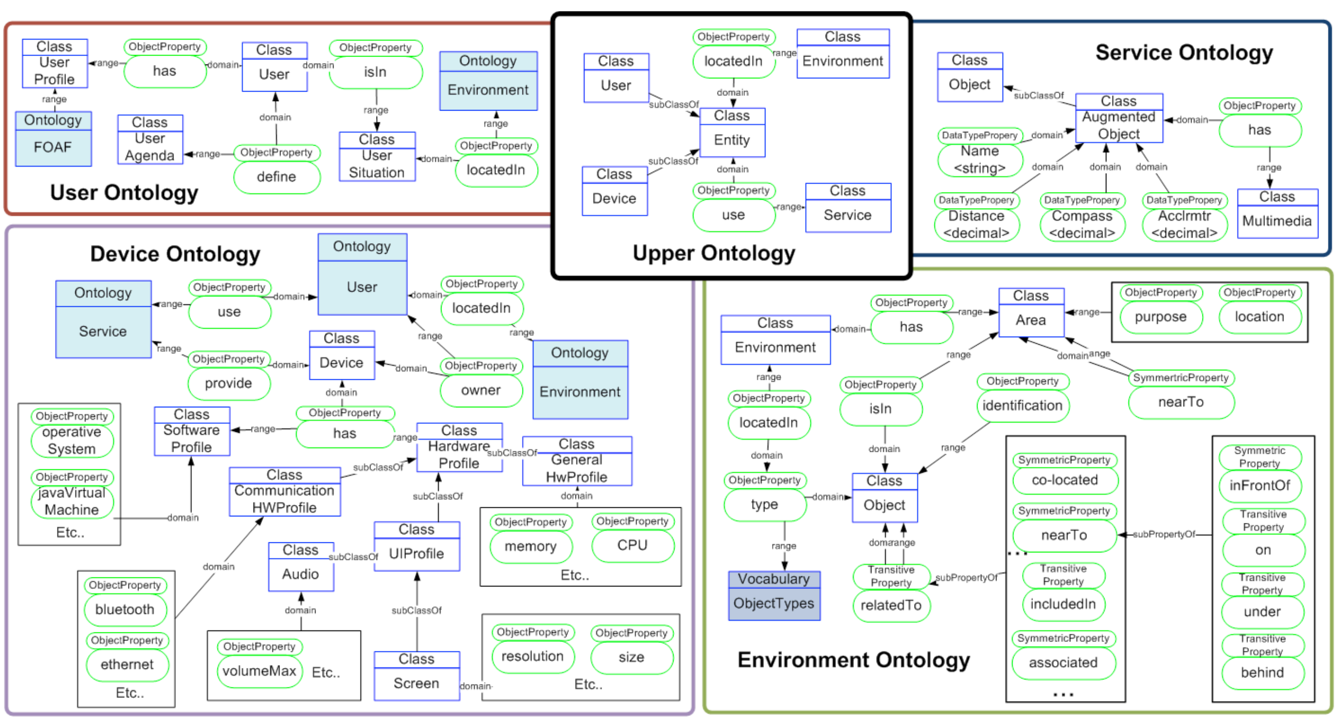


Figure 1. Context Model Ontology Overview.

- Physical environment ontology: It defines the space distribution and, besides, models objects and their physical relationships. The ontology has been designed based on a taxonomical organization and following a premise of generality to be applicable to multiple domains. Consequently, the level of detail is low, and it is necessary to adapt the model to the peculiarities of each environment.
- Service ontology: It is an ontology that specifies the context model to the particular applications and services to be offered to users.

Specifically, service ontology for this proposal includes data needed to transform physical position of elements into elements of the augmented-reality user interface. These data are instances of the following classes:

- oName: representative name of the element.
- oDistance: distance between object and user.
- acclrmtr: height of element in reference to the user
- cmpass: degrees of the element around the user
- AugmentedObject: OWL URI of this element.
- Multimedia: related multimedia content.

Figure 1 shows and overview of the context model, including the main elements of the model, and the service ontology adaptation to augmented-reality-based services.

C. Personalization through reasoning techniques

Languages based on the description logics foundations (e.g. OWL-DL) allow us to apply the language semantics in order to obtain new information from previous information. Additionally, it is possible to combine description logics with rule-based systems to improve their reasoning capabilities. In general, reasoning techniques enable the definition of consistency rules, reducing the ambiguity in the context information, and thus maintaining and improving the information quality. Apart from these benefits, reasoning techniques allows us to determine what information should be shown to the user, not only based on the explicit data about user situation or users preferences, but also proactively inferred information through reasoning techniques.

OWL defines an inherent semantics that enhance the inference capabilities of our system, at the level of classes as well as individuals. The semantics is defined through formal classes axioms, descriptions (e.g. UnionOf, intersectionOf, complementOf, etc.), restrictions (e.g. Cardinality), and property axioms (e.g. InverseOf, subproperty, etc.).

Moreover, the context-aware augmented-reality-based applications developed under our proposal define their dynamic behavior using SWRL [7]. This language extends the semantics of the OWL axioms and follows the antecedent-consequent schema. Both the antecedent and consequent may be formed by a set of atoms that can be class descriptions, data ranges, and model properties. Finally, SWRL define several built-in operators (comparisons, math, Booleans, string, and time operations).

Next sections deepen these concepts and include illustrative and practical examples.

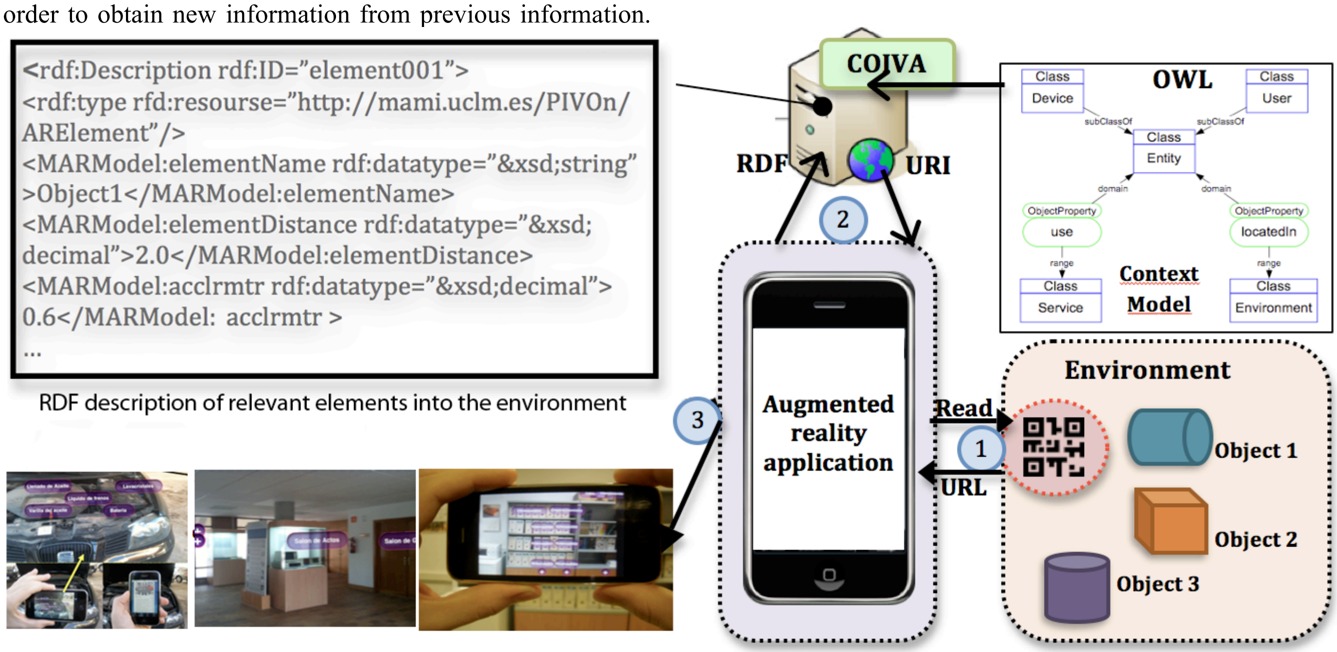


Figure 2. i-ARA arquitecture overview.

III. Intelligent Augmented Reality Architecure (I-Ara)

This section is focused on describing the generic architecture that we have designed to generate context-aware augmented reality mobile applications in a general, reusable and applicable way. This architecture is the evolution of our Mobile Augmented-reality Model (MARM) that let transform situation of objects in real environments into an understandable language for mobile device and also, defines the correlation between the device movements and the automatic adaptation of the elements in the user interface. This model is independent from the specific features of mobile device; it only needs to obtain accelerometer and digital compass data from the mobile device. For this formal description, the model includes a language based on RDF to define data from the real situation of the relevant objects.

A. *Architecture Overview*

The i-ARA architecture (Figure 2) implements the principles defined on MARM and includes mechanisms to provide context-awareness. RDF-based information is transform into OWL instances. Additionally, the architecture maintains a representation of users situation and their surroundings (context model). Based on this data and the knowledge base for each scenario, it is possible to determine which elements will be shown depending on the user needs.

Figure 2 shows the whole process where the information is obtained from a server and is represented into the screen of the device. First, the mobile device has to read the augmented object URI reference. This reference corresponds to the server storing information that will be downloaded (1). In the second step, the mobile device requests the information to the server, which will respond with the file that contains the RDF description (2) obtaining the parameters that describe where every relevant element is. Finally, the user receives the generated interfaces of relevant objects in the augmented reality view (3) based on the user situation and the defined SWRL rules. Concretely, the COIVA architecture (described in previous work [8, 16]) manages the context information. This architecture, in addition to providing a specialization mechanism, supports the dynamic maintenance of context information. The reasoning engine hastens the start-up process, enabling the automatic generation ontological individuals. Moreover, context-aware architectures tend to generate excessive contextual information at run-time. The reasoning engine can support the definition of updating or deleting policies, keeping the context model accurate and manageable.

B. *Interaction techniques and data acquisition*

The proposed model tries to be general and technology independent; however, it is necessary to know the area or object user is interacting with, thus this entails three particular requirements:

- Mechanisms for linking information to relevant elements in the environment, at least, an URI reference.
- To enable interaction between users and augmented elements. At a minimum, this interaction has to allow the reading of the URI reference. This interaction should also be natural and easy to users following the ambient intelligence principles. It is also desirable but not indispensable to enable writing capabilities to leave information whenever a user interacts with an augmented object. In this way, we can personalize future interactions based on previous ones, similar to web browser cookies [9].
- To support communication between the mobile device and the COIVA server.

In our prototypes (Figure 3), we have tested QR codes and NFC technology obtaining similar results and concluding with the validity of both technologies for applications based on i-ARA but highlighting the writing capabilities of NFC.

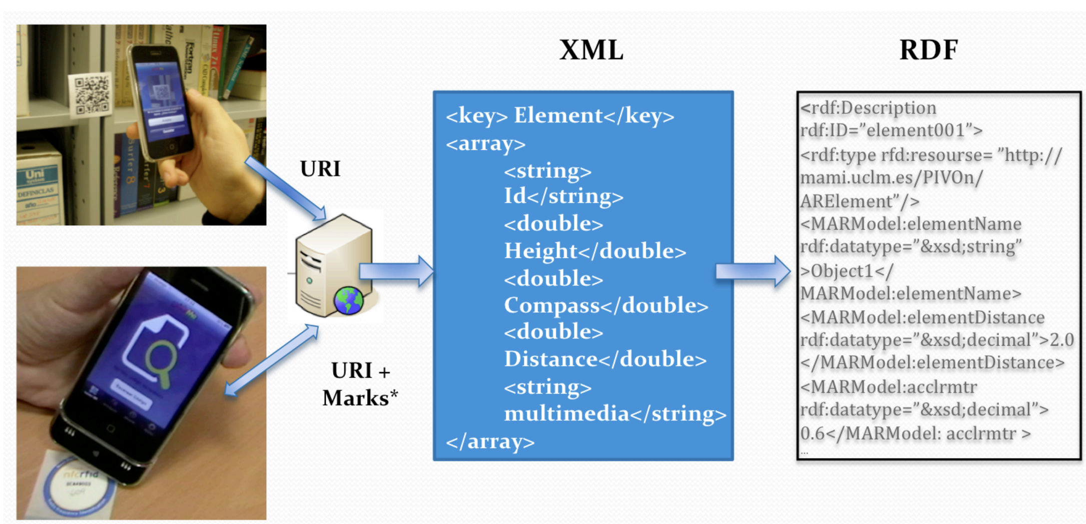


Figure 3. General XML and RDF representation of information associated to an augmented element. Acquisition through NFC and QR codes.

C. *Adaptive information retrieval*

The information that is retrieved in order to be displayed to users is selected on the basis of two principal criteria: the matching between the user information, the interacted augmented object and the explicit search terms that the user determines (if he/she determines search terms), and the behavioral rules defined for the specific visualization service.

```
IF AbsoluteValue(ObjectDPositioningObjetoAxisX – CompassPositioning) >
                                        (ScreenAngleOfView/2) Then
    IF CompassPositioning< 180 Then
        IF(ObjectDPositioningObjetoAxisX >CompassPositioning) &
            (ObjectDPositioningObjetoAxisX < CompassPositioning+180)
                pointX = RightSideX
        IF NOT Then
                pointX =  LeftSideX
    END IF
    IF NOT Then
        IF (ObjectDPositioningObjetoAxisX <CompassPositioning)
            & (ObjectDPositioningObjetoAxisX > CompassPositioning-180)
                pointX = LeftSideX
        IF NOT Then
                pointX = RightSideX
        END IF
    END IF
IF NOT Then
    pointX = (ObjectDPositioningObjetoAxisX – CompassPositioning) *
                        (ScreenWidth/ScreenAngleOfView)+(ScreenWidth/2)
END IF
```

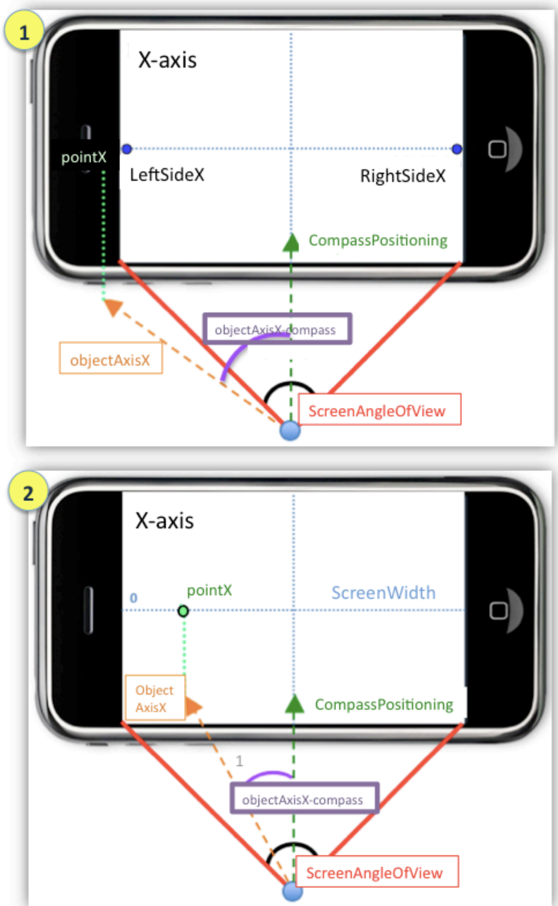


Figure 4. Algorithms to determine at run-time the vertical position of the element based on compass.

Focusing on the first criteria, we based the selection on the existence of certain individuals in the ontological context model that link the user, the augmented object and the search terms. In more detail, we obtain a quantitative measure of significance, in range [0,1], based on the existence of certain individuals in the context model; this measure is inversely proportional to the distance between each pair user-object, user-term, object-term, that is, the number of relationships between each pair of ontological classes [15]. We select most scored elements that pass a threshold (typically 1/8, e.i, less than 9 properties linking both clases), which has been obtained experimentally. Precisely, this mechanism exploits OWL semantic axioms, obtaining relevant information that is not explicitly included in the context model.

However, information personalization cannot only be based on the existence of certain individuals in the context model. It is necessary to include more complex mechanisms to select candidate contents to be offered. Concretely, mechanisms based on SWRL rules, powered by built-in constructors and XQuery operations that enable selection by the particular value of an ontological instance and applying math, Boolean, string or date operations. We show some practical examples in the Section IV.

D. *Visualization Algorithms*

We have defined mechanisms to transform the object information and the device sensor parameters into augmented information in the user interface, at run-time. Once acquired the parameters that define the spatial position of the relevant objects in the environment, a virtual representation is displayed in the screen based on current user point of view. Additionally, the mobile device analyzes values from sensors to refresh the elements in the X-axis through the compass values and the Y-axis using accelerometer values according to user movements.

These algorithms (see Figures 4 and 5) are device-independent and need to know the particular features of the mobile device, specifically, the screen characteristics (ScreenWidth, ScreenHeight and angleOfView) that are obtained from the device ontology. The algorithms determine if the object is in the camera's field of view. This is solved calculating the absolute value of distance (in degrees) between the object and compass positioning. In case the object has to be shown inside the screen, the algorithm (section 2 in Figure 4) returns its position in pixels (pointX). If the object is out of field of vision, we need to decide if adjust it in the left side or in the right side. This is solved with the first section of the algorithm (Figure 4).

A similar procedure is launched for determining vertical positioning of the virtual object (Figure 5). The conditions are equivalents but changing the compass values to accelerometer (acclmrt) values.

IV. APPLICATIONS

This proposal follows a generic perspective and can be applied to multiple scenarios. In this section we describe some particular prototypes to illustrate the contributions of our work.

We focus on a scenario that involves groups of users that share interests and agendas, working collaboratively and having a dynamic information flow. This specific prototype can be applied to similar scenarios that involve people working together, for example, a research lab.

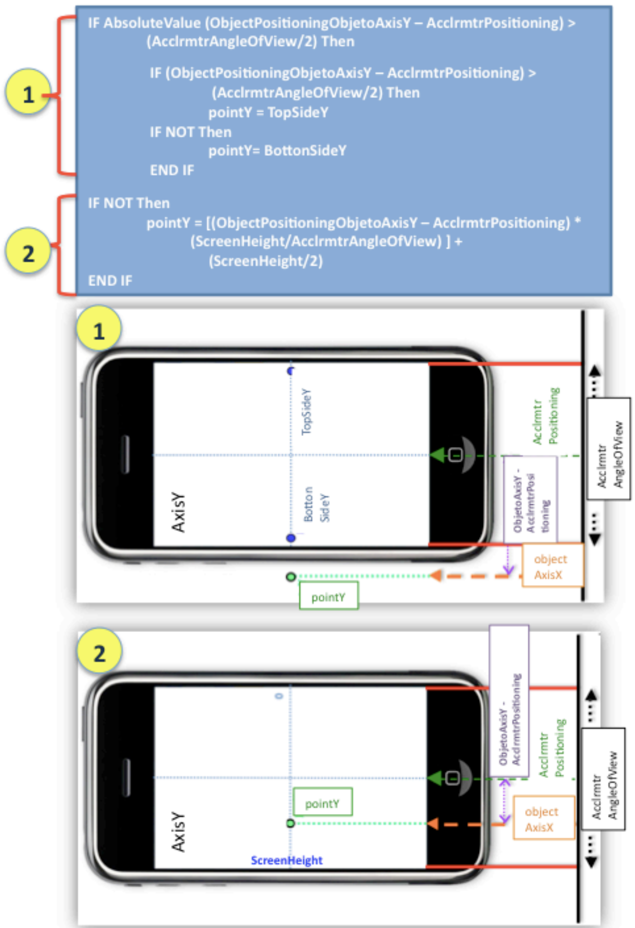
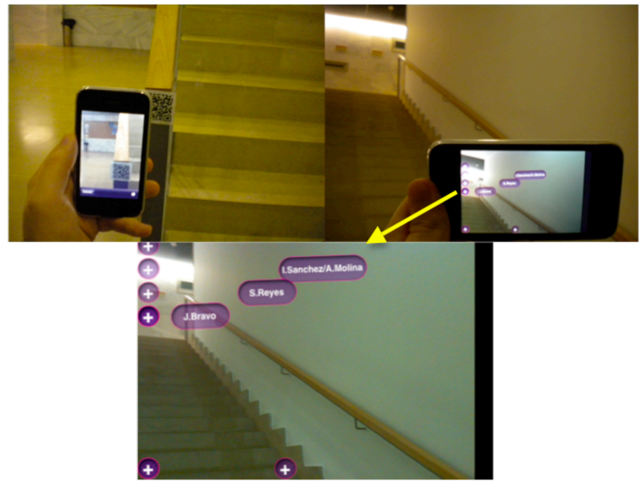


Figure 5. Algorithms to determine at run-time the horizontal position of the element based on accelerometer.

We focus on a scenario that involves groups of users that share interests and agendas, working collaboratively and having a dynamic information flow. This specific prototype can be applied to similar scenarios that involve people working together, for example, a research lab.

First example deals with finding resources in an environment, for example a printer. The user interacts with a particular area and obtains people or spaces with available printers to the user. The trivial approach could retrieve printers whose owner is the user. Our context-aware approach enables a more intelligent behavior, for example, retrieving information of printer directly or indirectly linked with the user through OWL properties.

All this information is modeled in the context model and, consequently, can be obtained following the information retrieval criteria. Figure 6 shows this example graphically. Focusing on some retrieved elements:



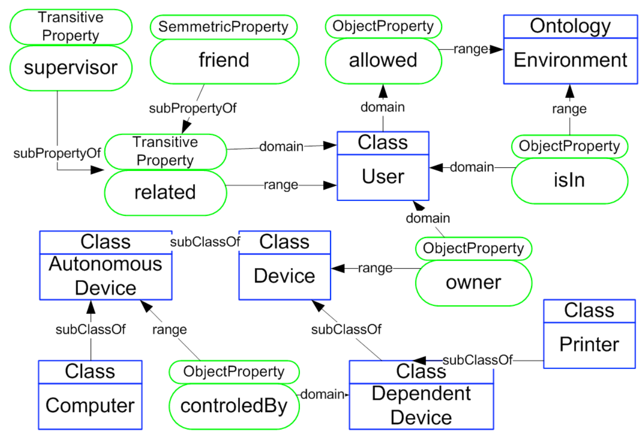
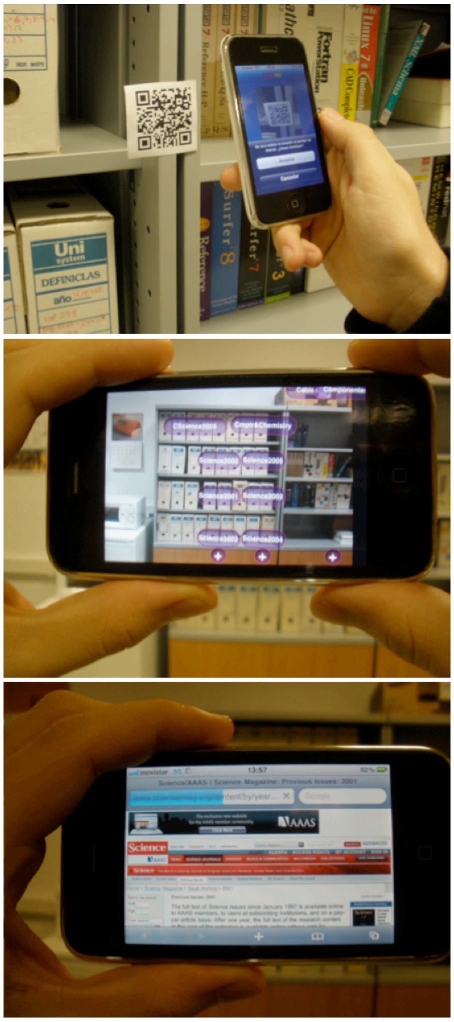


Figure 6. Involved classes and properties in the printer example.

All this information is modeled in the context model and, consequently, can be obtained following the information retrieval criteria. Figure 6 shows this example graphically. Focusing on some retrieved elements:

- J. Bravo (instance of the User class): J. Bravo supervises the current user (related classes). He is owner of a computer with printer and he is located in his office (distance criteria value: 0,33)
- S. Reyes (instance of the User class): He is a friend of J.Bravo (transitive and symmetry properties) allowed to access to a printer-room and he is located in his office, an instance of the Environment class. (Distance criteria value: 0,14)
- A. Molina (instance of the User class): She has a tablet-pc with remote access to printers. We do not know her location, but her tablet-pc is into the I.Sanchez office; maybe she is there too (distance criteria value: 0,17)

Users, devices and offices are instances of classes and the location, functionalities, permissions and relationships are properties of the context model. The criteria of distance between users and printer instances through model properties determine which elements must be shown.



document (?d) & user (?u) area (?a) & archived (?d,?a) & locatedIn (?u,?a) & topic (?t) & userTopic (?u, ?t) & docTopic (?d, ?t) => relevantElement (?d, ?u)

Figure 7. Information retrieval of relevant documents through a SWRL rule

Second example is an application to receive relevant documents in a library or archive. User context model helps to determine which document should be displayed based on the user's topics of interest. This functionality has been implemented through the SWRL rule included in Figure 7.

V. EVALUATION

We evaluated the prototypes through interviews and user studies. Twenty users (twelve men, eight women) participated in the experiment over a period of 4 days. The experiments were incorporated into their daily activities to simulate actual situations. The amount of time that each user tested our prototypes was 15 min per day on average. The population included ten engineering undergraduates, two Ph.D. candidate, two professors, and eight users that are not related to university (and particularly they were not familiar with new technologies) all between the ages of 21 and 59. In the future, we plan to elaborate others studies through a quantitative system analysis to measure the validity of retrieved information.

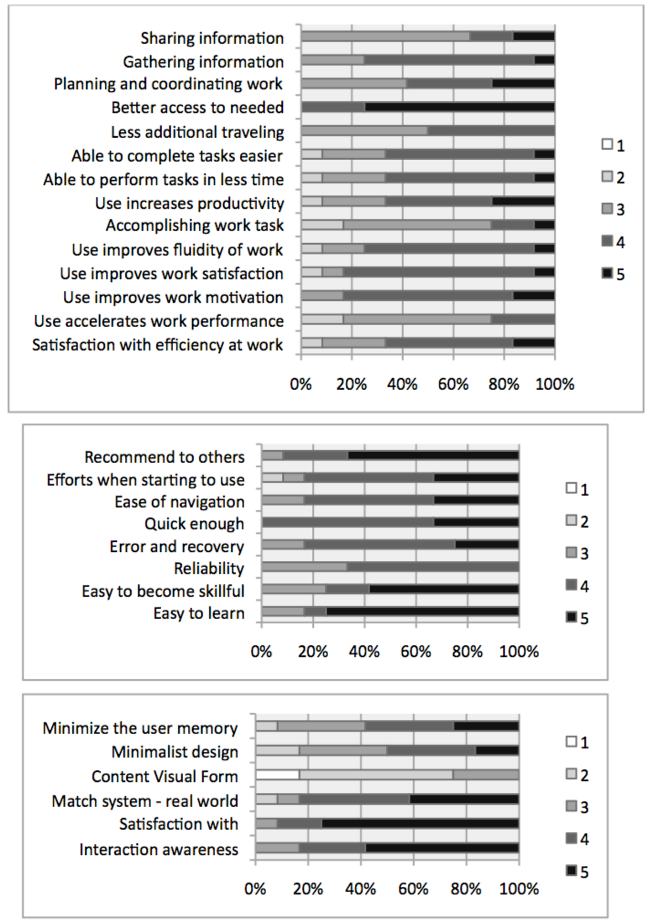


Figure 8. User experience evalaution

This evaluation (Figure 8) focused on user experience. These items are a subset of the MoBiS-Q questionnaire [10] and we have applied a Likert-type scale to evaluate the validity of each item (when 5 is the higher rating). The users evaluated the use of augmented objects to obtain augmented-reality-based information adapted to their needs. In general, the users gave high ratings to most of items. Specifically, the average agreement was 75.25% and the rating average was 4.35 out of 5. They gave lower ratings to issues related to mobile user interface, thus it could be improved. We have analyzed groups of users divided by technological familiarity and applied a one-way ANOVA. We have rejected the hypothesis that the groups were equivalent regarding technological familiarity; we have obtained significant high P-values for questions related to the minimization of user memory needs, easiness of learning, and the simplicity of navigation in the groups divided according the technological experience. In general, we learned that usability concerns have to be improved to make the use easier to every kind of users. The ANOVA results also determined the equivalence of the two groups on the functional items (first graph) in the questionnaire. For that, the main goals of this proposal have been reached.

VI. Related Work

There have been numerous proposals for augmented reality focus in several scenarios. For example, in mHealth, Breton-Lopez et al. [11] have developed a system to analyze the anxiety level by simulating a real phobia-inducing situation and generating an adapted therapy; in military environments, Feiner and Henderson [12] proposed an augmented-reality-based system to train soldiers on mechanical reparations. In these matters, there are also several applications to train physicians, for example, on surgery [13]

However, context-aware augmented reality through mobile devices is still an area to explore. Most of advances on this topic use a partial view of the context, typically, focused on location and user preferences. Few recent publications are deeper exploring this topic. For example, the CAMAR system [14] that personalizes displayed content based on a context representation. In contrast with our proposal, CAMAR does not follow a generalist and reusable perspective neither includes reasoning techniques.

VII. Conclusions

This proposal describes an infrastructure to support adaptive retrieval information following an augmented-reality perspective. Using an ontological context model by means of Semantic Web principles, information retrieved to users can be personalized to their current situation and needs. This adaptive behavior exploits the semantics axioms of OWL language and the expressiveness of a simple language as SWRL.

Apart from adaptive information, the i-ARA architecture implements general and reusable mechanism to transform the positioning of relevant information into a mobile user interface, updating it according to user movements, based on compass and accelerometer values.

In summary, the main requirements for context-aware augmented reality have been analyzed and implemented through a unified and extensible system, exploring the use of Web Semantic principles, more specifically, OWL ontologies and adaptive behavior using SWRL.

Acknowledgment

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