Ontology driven Augmented Exploitation of Pervasive Environments

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***Abstract*—Pervasive environments offer to software applications the possibility to interact with the reality in order to perceive the information surrounding the users and to adapt the environment and their own behavior. This problem is modeled as a set of context aware services which learn and augment the reality perceived by the user through her/his device. Application are enabled to perceive the information surrounding the users, to adapt the discovery and delivery of contents and software in order to optimize the user's satisfaction. We present a framework that implements the model to supports experts in the domain of the Cultural Heritage to augment the archaeological site with a set of multimedia contents which are delivered by innovative services to the visitors in order to guide their tour and to enhance their perception of the reality.**

***Keywords*-Augmented Reality; Ontology; Context Awareness; Mobile Devices**

I. Introduction

Pervasive environments offer to software applications the possibility to interact with the reality in order to perceive the information surrounding the users and to adapt the environment itself, or to improve the user's perception by exploiting available devices. Here we deal with the problem about how to program the user's personal device for enabling the interaction between remote services and environment by the devices themselves. Applications should be able to use pervasive sensors as their own extension in order to let the users benefit of context awareness in services exploitation. Many application contexts can benefit of a tight coupling between pervasive objects and services. Let's imagine some relevant scenarios:

- assisted exploitation of museums and archaeological parks;
- information guides in wide and crowded environments like big cities;
- discovery and recommendation of products in commercial centers;
- rescue of missing peoples in disaster situations by personal objects (smart-phones, RFIDs, Bluetooth devices);
- monitoring and safety check of activities in working areas.

For all the examples which have been cited before common issues must be addressed but it is not straightforward that the same technical and technological solution can be applied across the different scenarios and within the same class of applications. Some features to be considered in each new case study are:

1) the kind of environment: indoor, outdoor,with or without technological infrastructures;
2) dynamic changes and lack of landmarks;
3) heterogeneity of objects, entities and devices;
4) huge number of object/users and situations to be monitored and managed. In this case the complexity could increase and it could make impossible to perform the necessary checks at the required frequency, limiting the provisioning of real-time reactions.

Beyond the difficulties in dealing with the capability of getting the awareness about the environment and its perception, when this changes dynamically, services would implement adaptive and reconfigurable behaviors in order to optimize their delivery. Here we have to address many issues related to the heterogeneity of parameters and criteria to optimize the content delivery and to integrate the best suited techniques and technologies. For example, time constraints and user's positioning and interest have to be considered together but must be processed with different techniques. Furthermore additional properties to be considered in critical applications are security, traceability and certification of events, real-time reactions.

II. Related work

Many research contributions focus on the development of software/hardware architectures and frameworks for mobile context-aware tourist guides, also based on semantic techniques and technologies. In [2] authors present iJADE FreeWalker, a framework that integrates GPS, ontology and agent technologies to support location awareness for providing assisted navigation and classification of tourist information for the users. The system implements a context-aware tourist guide for the city of Hong Kong. The ontology is extracted using structural information from travel websites. CRUMPET, Creation of User Friendly Mobile Services Personalized for Tourism [3], is an agent based framework that provides a context-aware tourist guide adapting the information content and presentation according to user profile, device and connection characteristics. It is developed in microFIPA-OS, an agent platform based on the FIPA-OS that is an Open

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Source implementation of the FIPA (Foundations of Intelligent Physical Agents) standard. CRUMPET is modeled as a multi-agent system (MAS) whose agents are autonomous and share their knowledge using FIPA-ACL (Agent Communication Language). Agents use a common ontology in order to understand each other. The CHIP (Cultural Heritage Information Personalization) [4] project is a framework that uses Semantic Web technologies to provide personalized access to digital museum collections. The framework supports assisted navigation integrating heterogeneous technologies and provides semantic browsing, searching and semantic recommendations. In our approach semantic is used for knowledge representation and management, but the ontology is designed by experts of the application domain. It is used both as a common vocabulary to support interoperability aomng heterogeneous remot services, local applications and users, and for intelligent discovery of media contents. Beside pervasive technologies and augmented reality are used to enhance the visit experience and to enable visitors to explore easily pervasive areas according to their interests. Other relevant issues, like ubiquity [5], are not addressed here.

III. Problem modeling

In order to approach the described problem we have to model the environment where the user is moving and to reconstruct the perceptions of the user himself in order to get her/his particular vision about what is surrounding him. A real representation of the environment is necessary to identify landmarks and possibilities of intervention using pervasive actuators and sensors. On the other hand we need to get the special knowledge of the environment acquired by the user in order to support him by augmenting her/his perception of reality with something that can improve her/his satisfaction. This problem can be modeled as a set of context aware services which learn and augment the reality perceived by the user through her/his device. Reality can be augmented and adapted by interacting with neighbor objects and by delivering relevant media contents.

In Figure 1 an high level representation of this model is shown.

The environment will be modeled as a geo-referred map with itineraries, landmarks and point of interest. Of course localization of users and objects it is possible according the device technology, the available infrastructures and the kind of environment. Indoor or outdoor localization can be implemented using heterogeneous technologies, and often absolute localization could not be performed, but only nearby landmarks or object can be detected. In the following equation

$$E = \{\{POIs\}, Pos(U), \{path_i\}\} \quad (1)$$

the environment is modeled by a set of point of interest which are known a priori, or which have been detected dynamically by the user's device. $Pos(U)$ is the current

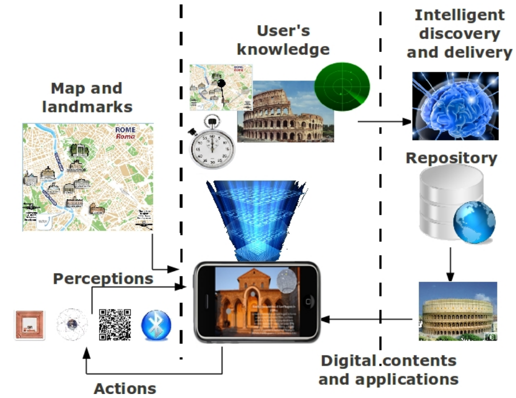

Figure 1. Problem model

position of the user. It could be an absolute position, or it could be a relative position according that has been estimated by detecting close POIs. $path_i$ represents an available itinerary for the user.

User's knowledge about the surrounding environment can be acquired by using peripherals of her/his personal mobile device, by recording and evaluating user actions or explicitly asking for user feedbacks. Some examples are user's position, interest, nearby objects, landscape, etc. Interaction with the environment and presentation of contents can be done again using user's device and her/his peripherals.

$$K(U(t)) = \{Per\{0,t\}, I\{0,T\}, D(t)\} \quad (2)$$

K(U(t)) represents the user knowledge, and eventually knowledge history, about the environment. It is reconstructed by using information coming from pervasive sensors $(Per\{0,t\})$; considering user's interests which come from what the user has done, what s/he declares, what are her/his feedbacks $(I\{0,T\})$; taking into account device capabilities $(D(t))$. Of course different components could have different weights according to their relevance or the time of perception. We could consider the knowledge at the current time, in a time widows, or the complete history. Services, in order to augment the user's knowledge and the their/user's capability to interact with the environment, have to choose, according their context awareness:

- what content and application they have to deliver;
- when it needs to execute the application or to present the content;
- how this should be done.

$$AR = \{C(K(U(t))), Mode\} \quad (3)$$

AR represents the set of contents, and the way they will be delivered, to be used for augmenting the reality perceived by the user. The optimal set, and its organization, is chosen to optimize the user's satisfaction.

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IV. Ontology based knowledge representation and reasoning

Semantic techniques can be used both to model the knowledge of applications and to reason about the decision to be taken about how to adapt the service delivery. An ontology implements the representation of the global knowledge. It is necessary to share a common dictionary and to describe the relationships among the entities/objects which are part of the model. In our model a common ontology include all the general concepts which are useful to describe a pervasive environment where mobile users are moving, using their devices and interacting with available facilities and other users. The general ontology is complemented with a domain ontology that is designed by an expert of the specific field. Concepts of the ontology are used on client side to describe a representation of the reality as it is perceived by the user. On the back-end the ontology is used to annotate digital resources like points of interest, contents, applications. It is also used to support reasoning. Users' behaviors, information from pervasive devices or from other users, device properties, external events are heterogeneous data that are perceived by the device and that are used to build a dynamic changing representation of the user knowledge about the reality within which s/he is moving. The applications are knowledge driven. The user's knowledge can be used by the application that is running on the device to adapt its logic locally, and it is updated remotely to improve the awareness of services at server side.

Application are events based. Events can notify an update of the user's knowledge or can be explicit service requests raised by the user. At each invocations a semantic queries, that depend on the user's knowledge, is built and processed to get the action to be performed and to content to be delivered. Results of the query are individuals of the ontology that are described by semantic annotations.

The user's knowledge is composed of many semantic concepts with *static*, *dynamic* or *locked* properties.

Components of the knowledge are:

- *Device technology and capability*. Among the static properties here we means hardware resources, on board peripherals, display size, total memory and storage. Dynamic ones can be power level, available memory and storage and bandwidth ;
- *User's position*. It is a dynamic property that can change over the time and can be evaluated using different techniques and technologies, depending on the devices, on the available infrastructures and the kind of environment (indoor or outdoor);
- *Pervasive objects*. They are dynamically discovered by the device. They can be sensors which provide information about the environment or can be used by the services themselves through the device or eventually directly if they are connected in some way to the network;
- *Time information*. We intend the current time at user side and the time that the user is spending, or has spent within the environment.
- *User's interests*. This part of the knowledge could be dynamically changed by the application according to the user's behaviors and to her/his feedbacks. The user could choose to start from an empty or a standard profile, to change it or to lock some properties interactively.

Semantic techniques are used for intelligent content and application discovery and delivery. Knowledge representation, ontology and annotations of digital resources are used to filter, organize and deliver contents and software to the device. Different techniques for reasoning can be experimented such as graph matching, description logics, neural networks or more simple ones like SPARQL (SPARQL Protocol and RDF Query Language) queries. Furthermore semantic can be integrated with other kinds of techniques to take into account constraints such as user's position and available time for exploitation.

V. Requirements and design

In Figure 2 the architectural solution of a framework that allows to apply the described approach is shown. Users,

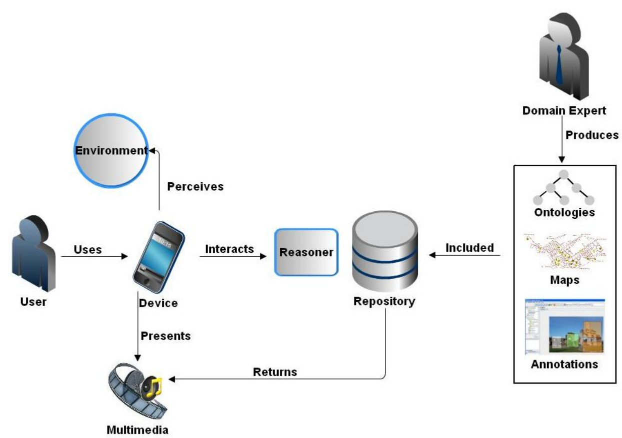

Figure 2. Architecture and roles

devices, services and producers are actors in this scenario.

On the left side the user is using her/his device that hosts a client application that is able to perceive information from the field by pervasive sensors.

The application executes autonomously and proactively in order to support the users' activity within the environment s/he is moving. It discovers surrounding objects, uses them to update the representation of the user's knowledge, reacts using the local knowledge to organize and propose the available contents and facilities by an interactive interface. It could also communicate with close devices. If the connection works the device can access remote services which can exploit a wider knowledge and complex reasoning capabilities to look for additional contents and applications.

Experts of the application domain define the ontology for the specific case study. They use or design a map to represent the environment. They add POIs to the map to geo-refer multimedia contents and can link them to a concept of the ontology. Furthermore they select relevant contents and annotate them using concept and individuals from the ontology.

Remote applications implement context aware services. They use personal devices to collect perceptions and for content delivery. They use reasoning to access content repositories or Internet, and are able to discover and adapt contents which are relevant to optimize the user's satisfaction.

In order to support these activities in a real scenario we need to provide:

- ***back-end tools*** for enabling content production, their semantic annotation publishing and retrieval;
- ***services*** for content discovery, adaptation and delivery;
- ***a client application*** to support user interaction with services, with the environment and with available contents.

VI. A REAL SCENARIO

Exploitation of archaeological sites can be very difficult because of a lack of supporting infrastructures and because of the complex recognition and comprehension of the relevant ruins, artworks and artifacts. The availability of personal devices can be used to plan and support the tourist by suggesting him the visit tours, the point of interest and by providing multimedia contents in the form of digital objects which can semantically augment the perceived reality.

In this context a relevant issue is the profiling of the user, the selection and the presentation of the contents which can improve the user's satisfaction, by providing new models of interactions with reality, trough her/his device. In this context the Second University of Naples is engaged on a multidisciplinary project with both cultural and a technological aims [1].

Following the approach defined above we are implementing a technological framework that supports the experts in the domain of the Cultural Heritage to augment the archaeological site with a set of multimedia contents which are delivered by innovative services to the visitors through their mobile devices in order to guide their tour and to enhance their perception of the reality and learning.

Three case studies have been chosen to test the approach and the framework. The S. Angelo in Formis Basilica, in Campania, near S. Maria Capua Vetere - i.e. the ancient Capua, is an interesting sample because of its uncountable layers which begin with the ancient temple of the IV century B.C., going on with the late- republican temple, unto the basilica that witnesses so many previous phases. The devices and the procedures allow to perceive some elements in the landscape, such as landmarks, which otherwise could not be noticed. It is necessary to understand the history and the details of ancient sanctuary and for the exploitation of the country nearby in ancient times. From the sanctuary one sees at the bottom the pianura campana, which still witnesses the centuriazione, and on the top the Monte Tifata, rich of archaeological evidence- such as temples, dwellings, thermal structures- to be studied with regard to the project. The project is carried out also on the ancient town of Norba and on the amphitheater of Capua: the former, because of its 44 ha in width, in a huge open park, has to be described with special regard to urban plan and architectural features because it is largely saved and still buried. It was founded in the V B.C. and destroyed in 81 B.C., later it was seldom inhabited just at the beginning of the Middle Ages. Usually visitors are surprisingly impressed by the walls in opera poligonale: that is why, in this case, the aim is to draw visitors attention on other landmarks (temples, houses, the street frame) and to represent by interpretation of aerial photographs, survey on the spot, specific digging sample, by means GPS, what is still underneath the surface. The last topic is the amphitheater of Capua, the second one as for width in the ancient world: in this case visitors shall be able to realize the whole building, with the service rooms and the devices underneath, with reference especially to the set of urban layers which the building stood in and which has been radically altered.

VII. IMPLEMENTATION

To satisfy the requirements of the presented case studies we need to provide a technological solution that does not need infrastructures for letting the software know the user location and her/his feeling about the environment. It means that Bluetooth, RFID, GPS, electronic compass, camera, network connection and others are the technologies which can be used together or independently to get information about the user perceptions and to augment her/his exploitation of the archaeological site. The user will be able to download at home, before to leave, or on site, if the network will be available, the map of the area to be visited. The map will include all the points of interest that identify the relevant objects of that area and different cultural itineraries which could be exploited on site. Also contents can be discovered and downloaded in advance. On board software and remote services will assist the cultural visit by augmenting the reality by the user's personal device. In the following we detail the technological choices which have been taken to implement each component of the framework.

A. Environement Map

To provide a description of the environment within which the user is moving we need a geo-referenced map that implements the model described in Equation 1 by describing

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buildings, roads, bans, itineraries and Points of Interest (POIs). We used the OpenStreetMap format to design open maps. In Figure 3 the map of the S. Angelo in Formis cathedral is shown. It has been built by exporting a model that was originally built by Autocad and has been exported into a GPX (GPS eXchange Format) format. The JSON (JavaScript Object Notation) tool allowed us to import the GPX (GPS eXchange Format) trace and to add manually details and POIs. Each point represents an artifact, a ruin or any other entities of cultural relevance and can be described using a list of key-value pairs. Some of them have been used to link the POIs to URLs of multimedia information, or to provide a semantic description of the POIs itself. The tool allow to export the map in an open format that can be read and used by the client application that is presented in this paper.

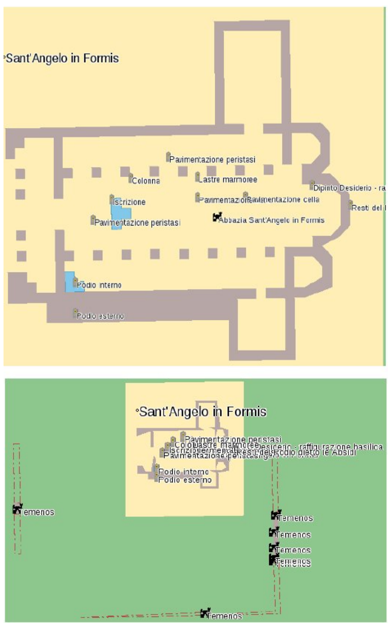

Figure 3. S. Angelo in Formis map

B. Ontology and annotation

An ontology has been designed to describe the sites of interest and to annotate the related media. It support the implementation of the model described in Equation 2. A general part includes the concepts which are common to all the class of applications that can be modeled according the proposed approach. Among the others the *Time* class and her/his properties (*CurrentTime*, *AvailableTime*, *ElapsedTime*, *ExploitationTime*) allow to organize and assist the visit taking into account time information and handling time constraints. *Position* class and its properties allow to localize the user and objects around him. An application specific part of the ontology include the concepts that belong to the domain of the cultural heritage and additional classes and individual which are proper of the case studies introduced in the previous section. In Figure 4 a snapshot of the ontology is shown. In particular we can see the *Building Element (Parte di Edifici)* class an its subclasses, *Amphitheater Element (Parte di Anfiteatro)* and *Domus Element (Parte di Domus)* which are proper of the sites of interests. The ontology is used: 1) for annotating the

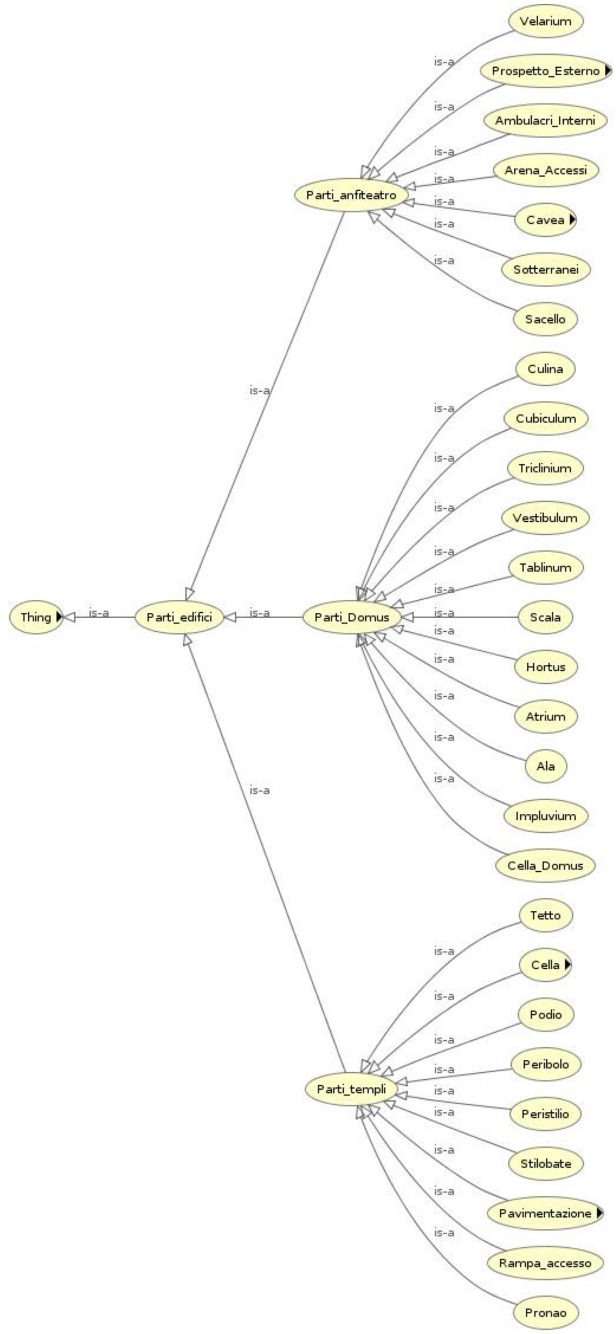

Figure 4. Ontology and annotations

multimedia contents; 2) to represent the user's knowledge;

3) to perform reasoning for intelligent discovery of those documents which are relevant to the optimize the quality of the cultural visit. To annotate texts, images and any kind of contents we chose the AktiveMedia tool (available at: http://sourceforge.net/projects/aktivemedia/). In Figure 5 a picture of the Amphitheater of S. Maria Capua Vetere is annotate with the *Column* and the *Arc* classes which are part of this kind of building.

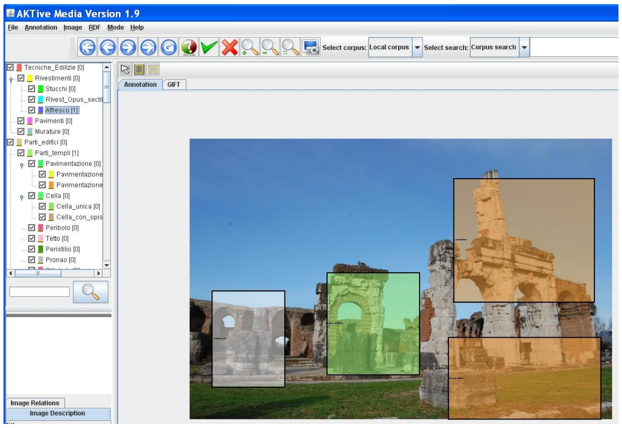

Figure 5. The annotator

The output produced by the annotator is an RDF file that use concepts and properties of the AktiveMedia ontology and of the domain ontology. An example of RDF annotation is described below. We filtered a set of properties. In particular *hasConcept* specify the ontology class or the individual by which the selected part of the image has been annotated.

```
<?xml version="1.0" encoding="windows-1252"?>
<rdf:RDF
   xmlns:j.0=""
   xmlns:rdf=""
   xmlns:dc=""
   xmlns:j.1="">
 <rdf:Description rdf:about="">
   <j.0:usesOntology></j.0:usesOntology>
   <j.0:hasAnnotation>
     <rdf:Description rdf:about="">
       <j.1:anID></j.1:anID>
       <j.1:hasContent></j.1:hasContent>
       <j.1:annotationText></j.1:annotationText>
       <j.1:botomX></j.1:botomX>
       <j.1:bottomY></j.1:bottomY>
       <j.1:hasShape></j.1:hasShape>
       <j.1:hasConcept></j.1:hasConcept>
       <j.1:topX></j.1:topX>
       <j.1:annotationHeight>
       </j.1:annotationHeight>
       <j.1:topY></j.1:topY>
       <j.1:hasComment></j.1:hasComment>
     </rdf:Description>
   </j.0:hasAnnotation>
   <j.0:width></j.0:width>
   <j.0:comment></j.0:comment>
   <j.0:hasHashCode></j.0:hasHashCode>
   <j.0:height></j.0:height>
   <dc:description></dc:description>
   <j.0:hasPath>
     image_example.jpg
    </j.0:hasPath>
   <j.0:content> </j.0:content>
   <dc:creator> </dc:creator>
 </rdf:Description>
</rdf:RDF>
```

C. Digital repository and semantic discovery

The Fedora repository (available at: http://fedora-commons.org/) is used to store digital objects, which are included in Equation 3, and supports their retrieval. Into the Fedora repository a digital object is composed of a set of files which are:

- *object metadata*: used by the client application to understand how to deliver the content;
- *binary streams*: which are images, video, text ... any kind of raw information to be delivered;
- *RDF annotation*: that describe the semantic of the object according to the ontology;
- *disseminations*: filters to be eventually used for adapting the object according to the target client.

We loaded the Aktive-Media ontology and the domain ontology into the Fedora repository in order to exploit its embedded SPARQL (SPARQL Protocol and RDF Query Language) engine that is used to select the optimal set of individuals that means contents. Multimedia contents are automatically stored into the repository after the annotation phase. The RDF output is automatically processed using an XSL (eXtensible Stylesheet Language) transformation to make it compliant with the format required by the Fedora repository.

D. Content types

Different types of content models have been defined and simple examples have been produced.

- Multiple images whose transparency can be graduate by the user to compare changes in different periods. In the same way real picture can be compare with paintings. Old picture can be compared with what is seen by the camera.
- Part of the image acquired by the camera are recognized and linked to related multimedia contents;
- Virtual reconstructions which are synchronized with the camera output or the detected RFIDs;
- Text, audio, video and composite media.

A content descriptor is attached to every digital object. It is used by the device when the content must be delivered. The descriptor defines the right player for that media, configuration parameter and necessary input.

In Figure 6 an example of delivered content is shown. The user focus the camera on a particular view of the S. Angelo in Formis Basilica and sees the original temple of

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Diana Tifatina. In particular the perspective viewed by the camera is the same shown by the video.

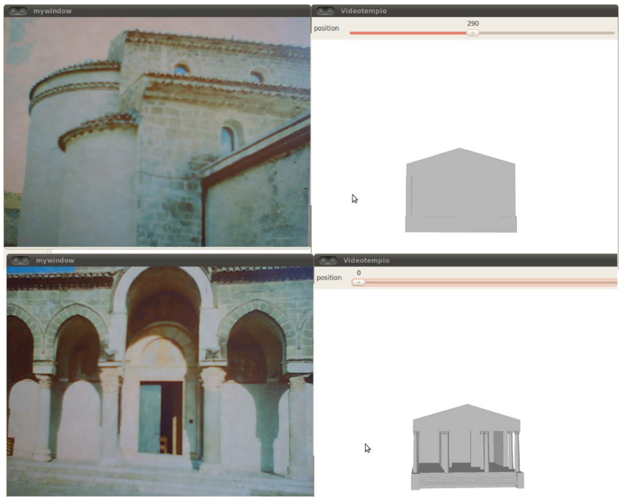

Figure 6. Synchronized video

E. Remote services

A remote service has been conceived to support content discovery and delivery.

It uses multiple criteria to discover and filter relevant multimedia contents. Some criteria are the available time for the visit, the user's position, the device technology, the user interests. The service is implemented by independent filters. Filters are executed on the occurrence of such event that update the user knowledge, or by direct asynchronous request from the user himself.

For example a change of the user position is used to filter POIs which are close to him or are relevant to her/his position. We could get information about a building located close to the user or about some other buildings located elsewhere but that have been designed by the same architect.

When the user shoots a new picture, a search by sample facility is used to find the images that are similar to the the current subject. This can be used to suggest a new set of contents, which are relevant to what the user is looking at.

Each time the interest of the users changes, or also when any other event occur, a reasoner generates dynamic SPARQL (SPARQL Protocol and RDF Query Language) queries, by which the repository is searched, and organizes the retrieved contents according to their relevance. The ontology is used to perform additional reflexive reasoning.

Additional filtering rules can be implemented using time information if they are available. For example it could be relevant to know the current time (to suggest a sunshine rather than to avoid a closed attraction or museum). The available time for the visit is important to limit the number of contents and to plan an itinerary. A delay is important to dynamically cut what is less relevant and cannot be exploited anymore.

We have implemented a search by sample filter that use the position of the user to select all the picture which represent the subjects s/he shoot, such as landscapes, monuments or buildings around him. Within this set a matching algorithm is able to identify an image that is the most similar to the picture. All the annotation for that image are also matched with on the display of the user's device.

Instead, some example of SPARQL query which are processed and whose results depends on the user's interest, are provided automatically by the software guide.

F. A Mobile Archaeological Guide

At client side, to implement a value added guide, we have extended an open source software navigator called Navit (available at: http://www.navit-project.org/). We used the android version. The navigator provides basic facilities for map visualization and to guide the user along some predefined itineraries by using the on-board GPS receiver. By new extensions the guide is able to sense the environment by the available peripherals, to understand the situations according to which the visit will be adapted, and to enhance the user experience. Even if many experiences on augmented reality are proposed nowadays, the exploitation of vision is used only to overlap real and virtual images. The extensions provide the following functionalities:

- access to device peripherals to sense the environment and to update the representation of the user's knowledge about the reality around him;
- access to remote services to update the user knowledge and to ask for available contents
- a local cache of objects for exploiting the visit without connection;
- a limited reasoner that is able to organize the content by itself when the connection does not work.

Perceptors are implemented by:

- GPS positioning to localize the user in open spaces and to guide him on cultural itineraries;
- RFID for positioning and detection of nearby POIs. This technology can be used to alert the user but also for her/his positioning in indoor environments;
- CODEBAR recognition to get information about artifact, monuments, ... when a RFID reader is not available;
- image recognition by search by sample techniques which are speed-up and improved using a position based filtering;
- monitoring of device resources and configuration;
- collection of user interest by feedback and by an analysis of her/his behavior;
- time monitoring.

On the other hand a list of functionalities are provided to deliver contents and to guide the visit. Content management

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(discovery client,organization and fruition) is supported both at client side and at server side. Knowledge visualization and management to allow the explicit specification of user's own interest is provided. The output of the camera is used as a component of the user's knowledge as well as a map on which semantic additions are anchored, not simply superposed.

The user will be able to ask for and exploit available multimedia contents, which are related to points of interest, or to personal interests expressed by semantic concepts. Multimedia content will be adapted at server side according to the device/user/session profile to provide to the user the best quality of service.

Figure 7 shows the output of the result of the content discovery service. The service invocation starts the camera that is used to take a photo of the landscape or of a subject of interest. In background, the client upload the image and wait for the content retrieval. The discovery of relevant contents and the download of retrieved information run in background meanwhile the user is interacting with other facilities provided by the client. The list of contents are presented to the user when they are available. Other events which open dialog for suggesting action, itineraries, POIs or media can be related to new perceptions.

Figure 7. Content retrieval

VIII. Conclusion

In this paper we presented an approach for delivering of context aware services in pervasive environment. Services adapt applications and contents to be delivered in order to optimize the user's satisfaction by augmenting and improving her/his perception of the reality. An ontology driven methodology has been used to describe the environment, the user's knowledge and application/contents to be delivered. Personal devices have been exploited to interact with the environment, to run interactive applications and to present contents to the user. Perceptions which come from on-board peripherals, from user's feedbacks and actions are communicated to context aware services to update the remote image of the user's knowledge, and are used at client side by the client application to adapt itself. We described a framework that implements the proposed approach. It represents preliminary research results about the aided exploitation and context awareness of complex archaeological sites by mobile devices. The framework that supports the experts in the domain of the Cultural Heritage to augment the archaeological site with a set of multimedia contents which are delivered by innovative services to the visitors in order to guide their tour and to enhance their knowledge of the reality. We are extending the framework using intelligent agents technology and modeling the interaction between the two agents according to learning by teaching approach: a student on the device and a teacher in remote. The teacher agent produces contents that the student agent consumes presenting them to the user. Future developments of this work could be the storing of user's information about the tour, so allowing for multiple visits, as well as the addiction of the possibility of exploiting the visit at home, or simply planning it before the trip.

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