SemanticRadar: AR-Based Pervasive Interaction Support via Semantic Communications

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Abstract. Augmented Reality (AR) overlays relevant virtual information onto a real world view and allows the user to interact and virtually manipulate surroundings. Since virtual information resides not only in a virtual space, but also in a physical space, users can be spontaneously given a number of opportunities for enriched interactions with their environments. In this paper, we propose an AR-based pervasive interaction support, SemanticRadar, which allows a user to spontaneously interact with smart objects through semantic communications, leveraging the placeness of a user's current location.

1 Introduction

Augmented Reality (AR) [1] allows the user to interact and virtually manipulate surroundings by overlaying relevant virtual objects onto a real world view. A recent advent of light weight AR devices like Google glass [2] has made it possible to the daily lives of normal users. As Mark Weiser envisioned embodied virtuality [3], the advancement of information technology is turning daily objects into smart objects with storages, processors, and networking capability, making them seamlessly embodied into our environments. Due to this paradigm shift, virtual information resides not only in a virtual space, but also in a physical space. Since this embodied virtuality is able to provide additional services and information, users can be spontaneously given a number of opportunities for enriched interactions with their environments.

There have been several research efforts to understand users' contexts and provide personalized information through an AR interface [4–7]. Sentient Visor [5, 6] visualizes context information of each object based on user preference. SmartReality [4] augments related information about the objects crawled from Linked Open Data (LOD) cloud and web service repositories by leveraging user profiles and GPS data. Ajanki et al. [7] provide relevant annotations that the user is interested in by capturing user face, speech, location, and time. However, existing works do not find which interactions are suitable with objects since a space can have multiple meanings perceived by people over time based on the social activities performed in it. In other words, they do not consider varying interaction dynamics with target objects perceived by the user according to the given context. For example, a projector in a

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seminar room should augment information about a presentation assistant service when a user is having a presentation, while information about a video player service should be given when a group of users is watching a movie. For this, we need to consider the varying semantics that each place may have for different users, so-called *placeness* [8]. According to this perception difference, it is required to augment different information for suitable interactions.

In this paper, we propose a pervasive interaction framework, SemanticRadar, which enables a user AR device to spontaneously interact with smart objects through semantic communications, leveraging the placeness of a user's current location. It finds out relevant interaction semantics for target smart objects by discovering the user perceptions on the current location and exchanging contextual information with smart objects. We assume that there exists a cloud (hereafter called placeness cloud) which infers placeness by mining the interaction history of the people and other context information accumulated in the location. From this, as a user gets into a target location, SemanticRadar on a user device (hereafter called a user device) extracts the placeness that similar users have on the current location using an ontology including locations and the type of possible interactions. When a user gazes at a target smart object, the user device asks possible interactions for the given placeness and the user profile toward SemanticRadar on a target object (hereafter called a target object). Assuming the target object accumulates its interaction history, it infers and replies possible interaction types for the given user. Then, if the user selects one of the possible types, the user device requests the target object a suitable interface for the interaction type. As a result, the target object returns the visualization information to use the result interface which is to be augmented through the user's view. We call this stepwise communication procedure as semantic communications. We implement SemanticRadar on top of smartphones running Android 4.2 and smart objects (e.g. projector, curtain, LED light, and door powered by Beagle board-xM) running Ubuntu Linux.

The rest of this paper is organized as followed. Section 2 introduces related works on context-aware service provisioning which encourages user interactions with ubiquitous virtual reality. In section 3, we describe our design considerations which are necessary to resolve our challenges. In section 4, we present how our proposed scheme can release current limitations, and in section 5, we conclude this paper with our future works.

2 Related Works

Sentient Visor [5, 6] visualizes context information of each object based on user preference. In this work, they design a framework, UbiSOA, in which objects are abstracted as a virtual web service implemented with RESTful interface. On top of it, they propose an IoT browser, Sentient Visor, which is an AR-based mediator to discover nearby objects and support user-to-environment interactions. Considering the heterogeneity of smart objects and the data they exchange, to make each object understand the semantics and enable semantic interactions between them, they put ontology prefixes as semantic tags for each data into the exchanged messages. To process this semantic information and provide personalized information derived from current contexts, they deploy a web service which is responsible of hosting knowledge base and processing semantic queries from Sentient Visor. Once Sentient Visor receives what should be displayed in which format, the result about the object is augmented in user's AR interface. However, this framework just focuses on static semantics of what the target object is and how they can be understood in user's perspective in a given context, while overlooking the fact that those semantics can vary according to the user's perception on the current place. Without considering this dynamics, the likelihood that suggested interactions can satisfy the user may not be high enough, especially in a public place.

SmartReality [4] augments related information about the objects crawled from Linked Open Data (LOD) cloud and web service repositories by leveraging user profiles and GPS data. Once a user device recognizes an object, the object is linked to Things-of-Interst (ToI) description stored in ToI store in a server. Then, the server loads related data and services from Linked Open Data (LOD) cloud and web service repository according to a set of Linked Data crawling rules with collected context sources. These loaded entities are packed together and delivered to the user in a meaningful and useful manner through the AR interface. This work not just tries to suggest personalized interactions based on user contexts, but also expand the data retrieval range by including LOD as their information source. However, like Sentient Visor, this work also overlooks the dynamics of semantics that each place has. Because of that, the system doesn't know which interactions are likely to satisfy current user's need which could change along with the place semantics, resulting in wrong service and data hosting.

Ajanki et al [7] provide relevant annotations that the user is interested in by capturing user face, speech, location, and time. By recognizing objects in AR view, the user's location, face, speech, and finger pointing, this framework infers in which object the user is interested and what the user wants to do with it. Once they are figured out, relevant annotations which are likely to be interesting for the user are loaded from the back-end server and shown through the AR user interface. In this work, since the most of contextual cues are given as a real-time streaming, a dedicated back-end server to process the stream data in real time has been installed. While this framework tries to enrich user interactions with the environments by means of analyzing user actions as critical contextual cues, it also overlooks the dynamic semantics of each place and its possible relationships to the users or embodied smart objects.

3 Design Considerations

3.1 Extracting User Perceptions on Interaction Semantics of Current Location

In [8], a space can have multiple meanings perceived by people over time based on the social activities performed in it. We call these diverse user perceptions on the interaction semantics of a space as "placeness". In order to extract placeness associated with a location, we need to capture what type of activities people repeatedly perform there. For this, we need to collect user information such as profiles including age, role, and gender, and experiences at different places on top of social relations data among users. This information is then utilized to find appropriate interactions for a user. However, it is highly challenging to formalize a person's conceptualization of a place into a computational method. Several existing approaches to the mining of user experiences with a place can generally be put into two categories in terms of the knowledge source. These are the online cyber world and the offline physical world. In the former, some studies analyze the geospatial contents from travelogues and social media [9–12]. Although we can summarize the features of a place as a topic-based word cloud, as done by Abdelmoty et al. [13] and KUSCO [14, 15], it is difficult for their approaches precisely to extract social interaction information, including members, activities, and times from the coarse-grained tag clouds. This makes the results of dynamic interaction opportunity discovery inaccurate. In the second approach, one branch of research has considered the mining of user experience from user behavior logs in the real world [16–18]. As these works have aimed to discover important places from GPS traces, they have not supported recommendations of feasible interactions in those places. Therefore, on top of the approaches in these studies, we consider a method to extract placeness from virtual and physical worlds and exploit it to find appropriate interactions.

3.2 Augmenting Relevant Interaction Semantics via Semantic Communications

Even if the placeness is extracted, since a user has no prior knowledge about a target object in the current location, it is hard to figure out which interactions are possible with it. To do that, we need a communication procedure through which they get to know each other and eventually find relevant interaction semantics. Juba [19] introduces semantic communications which is a sequential procedure through which intelligent individuals without a common language build a shared knowledge and achieve a common goal such as solving a complex problem. Supposing that there are two intelligent agents A and B who are not sharing any common language, to communicate each other and achieve a common goal, they need to try everything they can do to understand who the other is and what he can do. If they can make even a small but common understanding, one can start asking more questions to get more hints to enlarge their shared knowledge pool. As repeating asking and replying, they can eventually reach an understanding of a common goal and start thinking of how they can solve the given problem by going through the same steps they have performed.

Considering the absence of the prior knowledge between a user and a target object, it is worth applying this Juba's semantic communication model to our problem to figure out relevant interaction semantics to be augmented. For that, we need to tune its computational model into our context. First, we need to define three main components, an intelligent individual with local knowledge base, a common goal to solve together, and communication procedures. Next thing to do is setting up assumptions which may help us take the first step. In our context, SemanticRadar in a user device or a target smart object is an intelligent individual with its local knowledge. In this definition, in order to focus on the communication steps, we assume our intelligent individuals are sharing a common language, which means they can at least communicate each other. The common goal to solve in our work is providing users with personalized interactions with a target object. For the communication procedures, since we assume the existence of common language between individuals, we can only focus on how they can leverage their local knowledge to decide what to ask and its answer.

4 Proposed Scheme

4.1 Overview

SemanticRadar has three components to extract placeness and find personalized interaction semantics as shown in Fig. 1. Placeness cloud, accumulates user interaction history at different locations in its Knowledge Base (KB). Then, the core service module, Placeness Inference Service, infers how people perceive that place and which interactions they usually do by leveraging the history data through a mediator module, Context Manager (CM) which loads and manages the stored history data. SemanticRadar on a user device is a personal mobile device with AR user interface. It captures every user interaction with a smart object and reports that interaction log to the cloud with the user profile such as age, gender in Context Manager (CM), and location information. When the user wants to interact with a target object, SemanticRadar extracts the placeness from the cloud and goes through the semantic communications with the target object to find personalized interaction semantics. During the semantic communications, the network sessions and stepwise procedures are managed by Semantic Communication Manager (SCM). SemanticRadar on a smart object provides users with interaction services. It accumulates which interaction and interface it served for each user profile and placeness before in its KB. By means of this knowledge base which is managed by Context Manager (CM), it infers which interaction interface should be given for a user by going through semantic communications

4.2 Extracting Placeness: Mining User Activity Context

When a user enters a certain location, he requests the placeness of the current location with his user profile to Placeness Cloud. Then, the cloud extracts the placeness from the collected experience data set. For this, we exploit the experiences of people who have been to the place and share similar profiles with a target user. This is based on the finding of Magnusson and Ekehammar such that people behave similarly in similar situations [20]. Thus, Placeness Cloud continuously logs experience data consisting of user profiles, interactions, other contexts, and location information with keywords extracted from the Internet as shown in Table 1. Since the placeness is diachronic and generalized for common users, Placeness Cloud select users in the cloud and co-located users, whose profiles are similar to a given user based on k-nearest neighbors algorithm [21], and analyze how they perceive the given location based on what interactions are frequently performed by them. For example, from Table 1, the cloud extracts ‘workspace’ as placeness from interaction experiences such as ‘presentation’ and ‘system checking’. More detailed explanation can be found in [22].

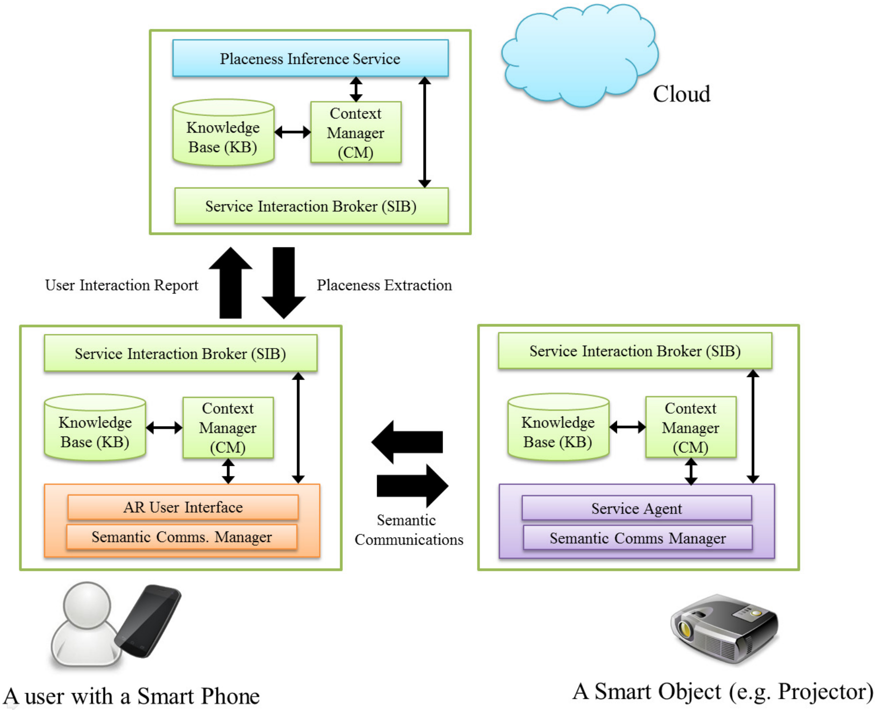

Fig. 1. An Overall Architecture of SemanticRadar Framework and Participants

Table 1. Examples of User Interaction History Data

User			Interaction		Location
Age	Gender	Role	Interaction Type	Time	Place Characteristics
…	…	…	…	…	…
28	Male	Student	Presentation	2012.11.30 14:24 PM	Seminar Room = {seminar, presentation, smart environment, …}
…	…	…	…	…	…
44	Male	Admin	System Checking	2012.12.17 9:14 AM	Seminar Room = {seminar, presentation, smart environment, …}
53	Male	Student	Movie Watching	2013.1.4 10:15 PM	Seminar Room = {seminar, presentation, smart environment, …}
…	…	…	…	…	…

4.3 Finding Personalized Interaction Semantics: Semantic Communication with a Target Object

When the user device gazes at a target object, it starts semantic communications with the target object to find a personalized interaction interface for the user's profile. Fig.2 describes messages exchanged in semantic communications between the user device and the target object through an example. In the example, a student enters a seminar room and extracts the placeness, '*Workspace*' and '*Entertainment*'. Out of various smart objects installed in the seminar room, as the user gazes at a projector with his smartphone, it starts semantic communication session with the target projector by sending a query about the possible interactions under the given placeness and its user profile. Then, based on the local interaction history, the projector infers interaction types, *Presentation*, *System Checking*, *Movie Watching*, etc., that similar users performed. When the user chooses an interaction, the user device requests the projector the interaction interface which is suitable for the received user profile. As the result, the information on how to visualize the interaction interface is replied and the user can start presenting a slide with the personalized projector interface.

5 Prototype Implementation

We implement SemanticRadar on top of smartphones running Android 4.2 and smart objects running Ubuntu Linux. We use Protégé 4.2 beta to design our ontology and Jena framework to host ontologies and handle SPARQL queries. For the user smartphone, we leverages androJena framework to handle semantics. To verify

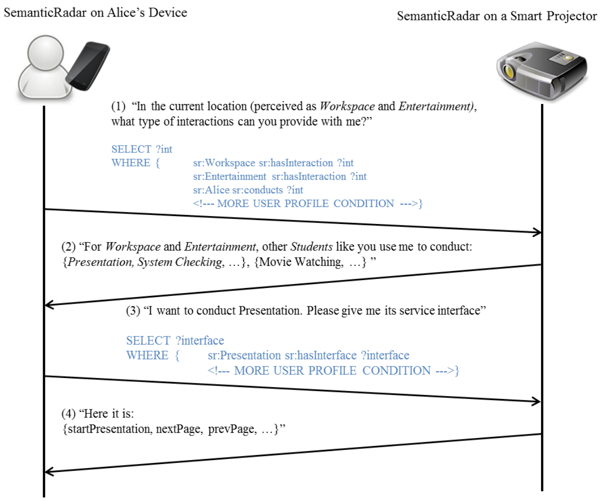

Fig. 2. Semantic Communications to Find Interaction Interfaces along with an Ontology Path

placeness-based personalized interaction support via semantic communications, we build a testbed [23] and install smart objects such as a smart projector, a smart curtain, LED lights, etc. powered by Beagle board-Xm. Fig. 3 depicts how SemanticRadar differentiates interaction interfaces of a target object, projector. The left side is the projector interface augmented for a Lecturer who wants to start a presentation, while the right side interface is for a Student who wants to watch a movie with the projector in the testbed. As shown in the picture, the presentation slide and projector controller interface is given for the Lecturer, while the video controller interface is given for the Student who wants to watch a movie. This final interface comes through the placeness extraction and the semantic communications. Fig. 4 shows how long it takes from the start of semantic communications to interface visualizations.

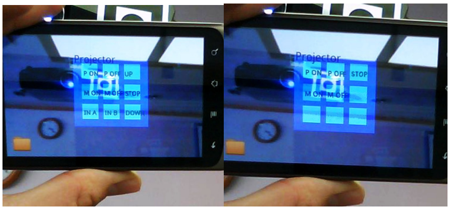

Fig. 3. Personalized Interaction Interfaces on User's AR device

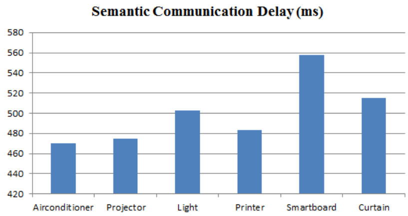

Fig. 4. Semantic Communications Delay (ms)

6 Conclusions and Future Work

In this paper, we present SemanticRadar, an AR-based pervasive interaction framework via semantic communications. Based on user interaction history mined in the placeness cloud, SemanticRadar extracts how similar users perceive the current location. Then, it finds personalized interaction semantics via semantic communications with a target object and visualizes the interaction semantics through an AR interface. We implement the prototype testbed upon a seminar room and show SemanticRadar provides different interaction interfaces to different users. In this work, we assume that our participants can communicate with a common protocol and they can lean on a shared knowledge base, placeness cloud. To overcome the limitation coming from the absence of a common protocol, we will design a cross-layer semantic communication protocol to incorporate with smart objects with heterogeneous protocols as our future work.

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