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Sketch on Lifelong Learning AR Agents in U-VR Environments

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***Abstract*—In this paper, we present a lifelong learning AR agent that provides the customized assistance with a mobile user at anywhere, anytime, anything. The agent infers a user's characteristics, e.g., preference and personality, based on the context history in environments. It generates the personalized assistance by reflecting the user's characteristics. The agent also shows appropriate responses to environmental conditions where the user actually exists. To show potentials of our agent, we have developed applicable applications how we could apply it to enhance the user's learning experience in smart home environments. Therefore, we expect possibilities for the proposed lifelong learning AR agent to be used as a personalized assistant in edutainment systems[1].**

***Keywords*-lifelong learning AR agent, personalized AR assistant, situated assistance augmentation**

I. Introduction

The advancement of mobile computing and ubiquitous computing paradigm, learning can no longer be divided into a place and time to acquire knowledge (the school) and a place and time to apply knowledge (the workplace). That is, learners need not be tied to particular locations. Thus, we needs to help people to learn wherever they choose and support them in assessing how they are doing and where they want to go next. *Sharpens* mentioned that personal tools, e.g., memory aids, case archives and communication devices, are necessary to support the lifelong learning in daily life [1]. In addition, agent-based approaches have been suggested to develop the tools in the lifelong learning environments [2].

Since the animated agents has the persona effect, that the presence of the agent has positive effect on learners' learning experiences [3], many researchers have applied the animated agent into their learning systems for a variety of human learning tasks [4]. To offer more realism in the agents, there have been a number of studies pertaining to agents based on augmented reality (AR). Because AR technology allows a user to experience computer-generated content embedded in the real world [5], intelligent agents in AR settings can enhance the learner's sense of immersion from the coexistence in the same place. However, the seamless existence is not fully sufficient for key characteristics of *U-VR*, a socially wise mediated reality [6]. For this reason, AR agents need to present the wise-level adaption and social interaction skills to encourage to the learner's interactions in lifelong learning experiences.

The rest of this paper is organized as followings. Section 2 provides the overview of previous literature on AR agents in edutainment systems. Section 3 describes the proposed lifelong learning AR agent in details. In Section 4, we present implemented applications with our AR agent in the test-bed for smart home environments. Finally, we conclude with some general remarks about the proposed AR agent.

II. Related Work

The goal of our research is to develop a learning AR agent that continuously assists the user's task in customized ways. Prior to this development, we review works on AR agents in edutainment systems. Especially, we focus on considering two factors; how other AR agents perceived users' behaviors and which kind of assistance was provided by the agents in problem-solving situations.

Anabuki et al. introduced *Welbo*, an anthropomorphic agent, that helped users wearing a head-mounted display (HMD) to simulate interiors, e.g., moving virtual furniture, in a mixed reality (MR) space [7]. The agent perceived the user's speech and movement in learning environments. Since the agent was represented by a human-like robot, it guided the user by synthesized speech and animated motions with respect to the user's behaviors.

The *ARLego* presented an animated agent that demonstrated how to assemble toy blocks in a real space [8]. Based on the agent's sensing abilities, it could see and touch virtual or real blocks, or hear the sound. With respect to the sensed situation, the agent autonomously showed the proper demonstration over real toy blocks through animated behaviors. To enhance the immersion of demonstration, the agent also controlled the blocks physically if it was needed.

Wagner et al. developed *Mr.Virtuoso*, an AR expert, that taught users about art history in an educational game [9]. The AR agent showed detailed explanation associated with an art artifact through animated movements and synthesized speech. However, it only detected the identification of the artifact and could not perceive the learner's progress in the game.

Wiendl et al. developed *Ritchie*, a virtual anatomy assistant, that helped the user to experience the positioning of a

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Table I: Comparison between AR agents

	Perception	Situated interaction	User adaptation
Welbo [7]	recognize user's speech and movement	show anthropomorphic behaviors in a MR space	not supported
Virtual repairman [8]	see real or virtual blocks, hear the sound, and touch virtual blocks	demonstrate through animated motions over real toy blocks	not supported
Mr. Virtuoso [9]	perceive the identification of an art artifact	explain the artifact with animation and synthesized voice	not supported
Ritchie [10]	know a user's manipulation of virtual organs	show anthropomorphic behaviors nearby real body skeleton	not supported
ubiAgent [11]	sense virtual/real world situation	migrate available resources, control physical objects, or present animated motions	show adaptive assistance based on user preference and context

virtual organ on the proper position in human body skeleton [10]. The agent perceived the user's action, e.g., rotating or shifting organs, and showed the guidance to place the organs in proper location through animation and verbal responses.

Barakonyi and *Schmalstieg* described *ubiAgent*, a mobile agent, embodied to real and virtual objects [11]. The agent perceived the user's situation based on sensory information from environments. It also customized the assistance relevant to persistently accumulated user preference. Moreover, the agent's bodies migrated between multiple AR applications and resources to best match the needs of current context.

As shown in Table I, most AR agents allow a user to feel as if they exist together in the same place by augmenting assistance over real environments. To assist the user in understandable ways at anywhere, anytime, and anything, these works have following limitations. Even though knowing a user's characteristics is one of key requirements to provide a user-adaptive assistance, these agents limit to perceive the learners' explicit behaviors and do not support the high level of awareness, e.g. reasoning of user preference. While different users present dissimilar meaning or intention through same behaviors, the current AR agents interpret same behaviors from different learners to equal meaning and overlay consistent assistance with respect to the behaviors. Since this kind of misunderstanding sometimes disturbs learners, the agents should infer the user's characteristics and determine appropriate information and presentation format–relevant to the user's characteristics–to support effective aids in understandable ways. To enhance the coexistence with a user, the agent needs to adaptively present responses by reflecting environmental conditions where the user actually exists.

III. A Lifelong Learning AR Agent

We present a lifelong learning AR agent that offers customized assistance to help a user's tasks. It exhibits social interaction skills, i.e., understands a user's situation and shows appropriate responses to the circumstance. That is, the agent accumulates the history of user's context and reasons the user's characteristics based on the history. It dynamically updates the knowledge related to its existing environments and autonomously generates assistance suitable for the user's characteristics. In particular, our agent overlays the assistances over associated real environments in natural manners. Figure 1 shows the overall procedure of the proposed agent to superimpose the personalized assistance in U-VR environments.

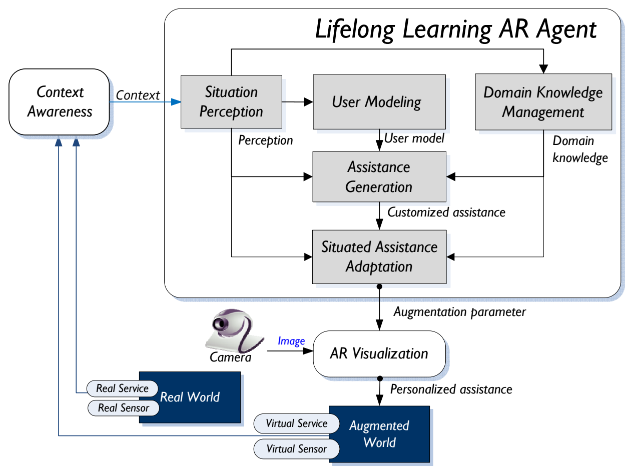

Figure 1: The overall procedure for customized assistance augmentation.

A. User Modeling for Adaptation

As a key requirement for a lifelong learning AR agent, the agent should have the ability to understand the learner in learning environments. As shown in Figure 2, our agent manages the user's model as three levels of details; the behavioral level, the epistemic level, and the individual level. To be aware of user's explicit behaviors, we exploited *UCAM* [12], a framework for developing context-aware applications, so that our agent gets contextual cues from heterogeneous sensors in environments. Since each contextual information pertains to the user's context as well as environmental context, our agent can perceive not only the user's actions but also situational information from the collected context. To infer the user's epistemic information, our agent keeps track of the user's context and infers the user's preference, especially interest and capabilities, associated with the situation. Furthermore, based on the context history, it learns the user model describing user's personality in learning experiences.

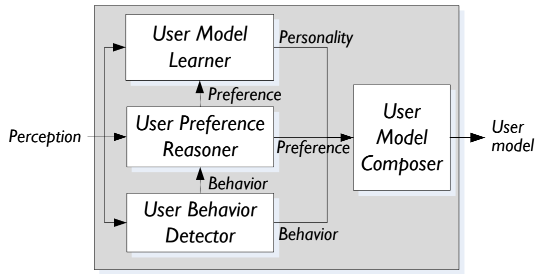

Figure 2: The layered user modeling.

B. Customized Assistance Generation

To make a lifelong AR agent available where the user needs the help, our AR agent should know the knowledge associated with the place where the user exists. Basically, we assume that domain knowledge related to the entities existing U-VR environments is managed globally. Based on the user's context, the agent retrieves domain knowledge for its existing environments from domain knowledge base. For example, when a user watches the book with a camera, the agent loads the domain knowledge related to the book or the content with the book. In addition, to seamlessly generate appropriate assistance according to the user's variable context in real time, the agent updates the domain knowledge dynamically when the context is changed. That is, when a user changes to see a map with a camera to get geographical information, the agent updates the domain knowledge related to geographical features of the area represented on the map.

Our lifelong learning AR agent customizes the assistance according to the user's context. The agent monitors the user's performance and automatically detects when the user seems to require the assistance. Based on the fact that different users present inconsistent tendencies to request the support due to dissimilar social openness to others, our AR agent adjusts the timing for the help according to the user's personality. Additionally, to help the user's tasks in comprehensible manners, the proposed learning AR agent differentiates the format of assistance with respect to the context. For example, anthropomorphic agent is effective when the human support is needed. Even though anthropomorphic assistance is suitable, human-like assistance is appropriate to education settings and cartoon-like representation is useful for entertainment applications. Sometimes, symbolic guidance, e.g., arrow, diagram, is more effective to assist the user than the anthropomorphic support. Then, it adaptively configures the response space composing of available assistances and selects an appropriate assistance to the context. Figure 3 describes how the agent generates the assistance to the perceived situation.

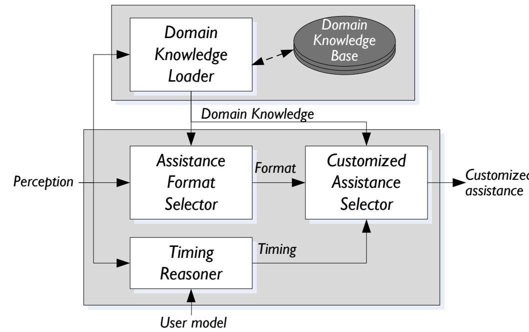

Figure 3: Customized assistance generation.

C. Situated Assistance Augmentation

Toward immersive augmentation, our AR agent should be realistically superimposed on environments where a user actually exists. To make a learning agent being situated in real world, we concern on adaptive augmentation proper to situated environmental conditions. Our learning AR agent understands complex real world and visualizes the response suitable for the world. In literatures, many researchers mentioned that how the common knowledge can be adaptively applied in local and situated conditions [13]. Our learning agent supports adaptive visual representation where the agent's response fits into current scene in AR environments through the intelligent view management. In Figure 4, the agent firstly interprets domain knowledge to understand current environmental conditions, e.g., device characteristics, lighting condition, the size of display image, and learning contents. Then, the agent generates rendering parameters for overlaying over the real environments properly. In particular, the agent freely moves and interacts with real or virtual entities to enhance the coexistence with the user during the learning situation.

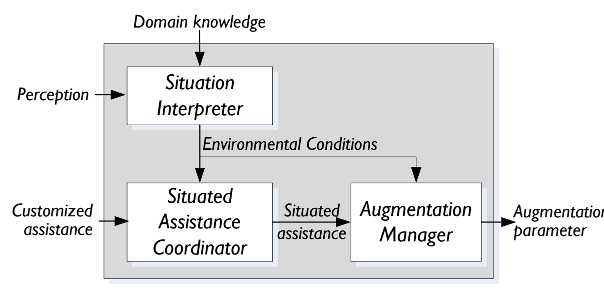

Figure 4: Augmentation parameter generation.

IV. Applications

We developed prototypes with the proposed AR agent to an ultra mobile PC (UMPC) which was equipped with 1.33 GHz CPU and 1GB RAM. We exploited *OpenScenegraph* [14] to render the content with the UMPC, and especially we used *Cal3D* [15] for realization of the animated movement of

AR agent. Then, we enabled the user to experience learning situation with the implemented AR agent in the *ubiHome*, a test-bed for smart home environments,

In these experiences, our AR agent adaptively changed its own representation according to the context and assisted the user to complete daily tasks. As shown in Figure 5, we made an implement bluebird as a learning collaborator in a physical book. In this case, we augmented a picture with the bluebird in *ARGarden* (5a) that provided the user with a chance to explore flower gardening [16]. The bluebird presented anthropomorphic responses to support flower gardening experience. As another example, when a user tried to get the knowledge related to medicine at the first-aid box, our AR agent showed the instruction to a user through simple annotations, e.g., putting O or X on medicine boxes (5b).

(a) (b)

Figure 5: Assistance with the implemented lifelong learning AR agent; (a) collaboration in learning task over a real book and (b) instruction on the first-aid box.

Even though we could see how we applied a lifelong learning AR agent into smart environments through the implementation, following issues should be concerned. We need to verify the effectiveness of the layered user modeling to reason user's characteristics. In addition, developing an effective way to retrieve domain knowledge associated with the context is required to enhance the seamless assistance. While the implemented agent limits to adjust the timing of assistance according to personality, we should consider how to customize the type of assistance suitable for the user model. Moreover, important aspects lie in the evaluation of user's impression on situated assistance augmentation.

V. Concluding Remarks

In this paper, we described a lifelong learning AR agent that supported seamless assistance when and where the user needs to do it through the situated augmentation. To show the effectiveness of our agent, we implemented the agent on the UMPC and made the agent interact with a user in the test-bed for smart home environments. Finally, we outline directions for future realization of our lifelong learning AR agent as a personalized assistant in U-VR environments.

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