A Location-Aware Virtual Character in a Smart Room: Effects on Performance, Presence and Adaptivity

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ABSTRACT

Location-aware ambient environments are relevant for using interactive virtual characters. However, they raise several questions about the spatial behaviors to be displayed by virtual characters, and about the perception of virtual characters by users. We designed a location-aware virtual agent that adapts its spatial behavior to users' and objects' locations during a search task in a smart room. We conducted an experimental evaluation comparing this adaptive agent with an agent that does not perceive nor use the location of users and objects. The location-aware adaptive agent elicited higher levels of perceived presence and perceived adaptivity. Furthermore, performance was less influenced by task difficulty when users interacted with the adaptive agent. Such results can be useful for the design of future location-aware virtual agents.

ACM Classification Keywords

H.5.1 [**Information Interfaces and Presentation**]: Language Multimedia Information Systems – *artificial, augmented and virtual realities*.

General Terms

Design, Experimentation, Human Factors

INTRODUCTION

Recent years have seen a growing interest in location-aware information systems, smart rooms and interactive virtual characters. A *smart room* is an accessible and habitable space for people embedded with digital services and featuring the following main properties: ubiquitous computing, ubiquitous communication and intelligent user interfaces [6]. Location-aware technologies can be used in ambient environments to provide information about the user's position and movements inside a room [17]. Interactive virtual characters combine intuitive modalities (e.g., gaze, gestures, postures, speech) to enable face-to-face communication with users [4].

IUI 2011, February 13–16, 2011, Palo Alto, California, USA.

With emerging ubiquitous and ambient technologies, several studies have considered the impact of a virtual character or a physical robot in an ambient environment [14, 15, 16]. For example, it has been observed that a virtual agent integrated with a spoken dialogue system provides a more pleasant and human-like interaction when used in an ambient environment, despite its limited contribution to task effectiveness [15]. Kamei et al. [10] constructed an experimental shop environment where robots point at and gaze to the physical environment to recommend specific items to the customer (based on the location history and gaze directions of the customers).

Interactive virtual characters might create a feeling of social presence [1, 3, 9]. *Social presence* is the "degree to which one believes that he or she is in the presence of, and interacting with, other veritable human beings" [3], or "the perceptual illusion of nonmediation" [9]. It has been observed that using empathic characters in a narrative learning environment increased student perception of presence [13]. Furthermore, making agents socially resonant (in the sense of being adaptive) can bring several improvements of human-agent interaction such as resource-free for human cognitive processing and positive rating for systems [11].

Virtual characters have been endowed with spatial behaviors such as deictics [12] or iconic gestures for route descriptions [18]. However, the adaptivity of nonverbal spatial behaviors of virtual agents to user location and to the location of real-world objects remains scarce [19]. Thus, little is known about its impact on performance, perceived presence or perceived adaptivity. Designing a location-aware virtual character that signals spatial, nonverbal cues in smart rooms raises several questions: How should we specify and adapt the spatial behaviors of a virtual character to users' and objects' locations? How should we integrate the spatial behaviors of the virtual agent with the spatial behaviors of the user? What is the impact of this adaptivity on user's performance in spatial tasks where location is relevant? Does agent adaptivity effect users' sense of agent presence? Do users perceive the adaptivity?

In this paper we explain how we designed a location-aware virtual agent that helps users find objects in a smart room. The virtual agent is able to adapt its spatial behaviors to users' and objects' locations. We conducted an experimental evaluation to compare this adaptive agent with an agent that does not perceive nor use the location of users and objects. The location-aware adaptive agent elicited higher levels of perceived presence and perceived adaptivity. Furthermore, the performance of users was less affected by task difficulty in the location-aware adaptive condition than in the non-adaptive condition.

THE SYSTEM

Smart Room and Location-Awareness

We built an intelligent room [2] for conducting evaluation studies of interaction techniques in an ambient intelligent environment. The room contains sensors that allow for context-awareness capabilities (Figure 1).

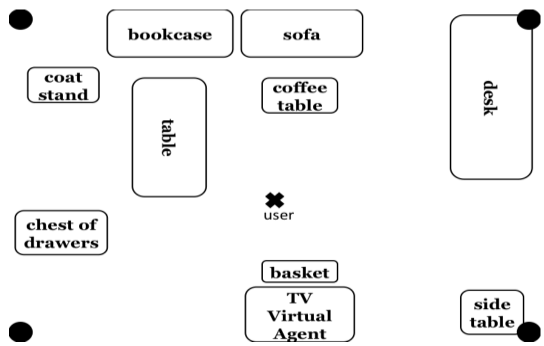

Figure 1. The ambient intelligent room equipped with four location sensors in the corners and a virtual agent display.

Acquiring location information in open spaces has been studied from the beginning of ubiquitous computing, resulting in various models and techniques [7, 8]. The Ubisense® system relies on a network of sensors (4 sensors in our case) and a set of tags that can be attached to objects or to users. Contrary to other solutions using video processing, this location system is robust to occultation: the tags do not need to be visible to be detected. This feature can be useful for search tasks in that objects can be hidden in drawers. The average precision is 20cm, though it is variable depending on the location. The system can track objects' locations continually and detect if an object has entered a certain zone or collided with another object.

A Virtual Agent that Adapts its Spatial Behaviors

We integrated the virtual agent platform MARC [5] with the smart room environment. This virtual agent platform includes editors for specifying facial expressions and body-postural animations. These behaviors can be blended and interrupted during real-time rendering. We also developed a new component that receives location events sent by the Ubisense sensors, analyzes them and generates a command that is sent to the virtual agent module.

The head movements, gestures, body orientation and gaze of the virtual character can be directed toward a specific location in the room (such as the user's location or an object's location). Four communicative acts were selected as being relevant for the search task: point, confirm, disapprove and congratulate. For each of them, several postural expressions were designed based on a video corpus that we collected previously. A test was conducted with eleven subjects rating these postural animations in terms of perceived communicative acts. No background was displayed behind the virtual agent to avoid distracting the user from the behavior of the virtual agent. The postural animation that best expressed each communicative act was kept for the user study described in the next section (see Figure 2). An animation was also designed to have the virtual agent walk, simulating an "approach" behavior towards a location in the real world.

Figure 2. Some illustrations of postures designed and validated for the following communicative acts (from left to right): point, disapprove, congratulate.

STUDY DESIGN

We selected a procedural task in which the user has to find objects in the smart room. We chose this task because the user would have to move around the room and thus provide rich, continuous location information to the system.

Six target objects were equipped with Ubisense® tags so that the system knew how far the user was from each of these objects (adapter, envelope, jacket, DVD, medicine box and folder). Some objects were hidden (e.g., a medicine box in a drawer), whereas some others were visible (e.g., the envelope laid on the coffee table). The initial position of each object was the same for all users. Target object positions were chosen so as to take advantage of the whole space and require the user to move across the entire room. Three distractor objects (objects that look similar to target objects) were also equipped with Ubisense® tags. Task difficulty for searching for a target object was estimated by considering the number of distractor objects. Users performed tasks in the same order of increasing difficulty. The virtual agent was displayed on a flat 42-inch TV.

Before the session, users were briefed about the search task. There was a time constraint as the story was about a friend stuck at the airport and asking for some objects from his flat. The user received a Ubisense® tag to attach to his/her clothes. At the beginning of the session, the agent welcomed the user and described verbally the first object to look for. The system "knew" where the target object was, knew when the user was close to the target object, and knew when the user grabbed the target object or a distractor object. When the user found the object, the agent would ask the user to drop it into a basket in front of the TV and would describe verbally the next target object to look for. At the end of the session, we recorded the duration of each task (the time the user took to find each object). The user also had to answer a five-point Likert scale questionnaire (from 0; strongly disagree, to 4; strongly agree) about the perceived presence and adaptivity of the virtual agent. The first section measured the perceived presence of the virtual character using four items [1]: "*I perceive that I am in the presence of another person in the room with me.*", "*I feel that the person is watching me and is aware of my presence*", "*The thought that the person is not a real person crosses my mind often*", "*The person appears to be sentient (conscious and alive) to me*". The second section of the questionnaire consisted of five questions that we added to evaluate the perceived adaptivity of the agent: "*The activities of the avatar meet my needs*", "*The avatar expresses emotions based on what I do*", "*The avatar adapts its gaze to my actions*", "*The avatar adapts its position to my actions*", "*The avatar adapts its bodily expressions by my actions*".

We compared two conditions, adaptive agent (spatial communication) and non-adaptive agent (without spatial communication) (Table 1), in a between-subjects design. In the non-adaptive condition, the agent provided information only through speech and facial expressions. In the adaptive condition, the agent used its knowledge about objects' and user's locations to select prescribed spatial nonverbal behaviors. The adaptive agent was thus able to look at the user, to look and point in the direction of the target object, to turn its body towards an object, and to approach in the direction of an object. Those different spatial behaviors were used incrementally and progressively when the user displayed difficulties in finding the target object in the room. The hypotheses were as follows:

H1: Users in the adaptive agent condition will report a stronger feeling of agent presence than users in the non-adaptive condition.

H2: Users in the adaptive agent condition will report a stronger feeling of agent adaptivity than users in the non-adaptive agent condition.

H3: Users in the adaptive agent condition will perform difficult tasks more quickly than users in the non-adaptive agent condition.

Thirty-two participants completed the experiment: 16 female, 16 male; aged 20-58, average 30.5; 18% African, 75% European, 3% American and 3% Asian. 40.6% of participants had little or no interaction with a virtual character beforehand. 59.3% of participants had not heard of ambient intelligence. All users found all six objects.

RESULTS AND DISCUSSION

Cronbach's alpha indicates the degree to which a set of questions measures a single one-dimensional latent construct. We used it to validate the questionnaire. We computed a value of 0.80 for the section about presence, and 0.85 for the section about adaptivity. The American Psychological Association considers a questionnaire reliable when the alpha coefficient is above 0.7 ($0 < \alpha \leq 1$).

We performed one-tailed Student's *t* test to compare the two conditions on interaction and post-interaction measures. We assumed that the two samples came from normal distributions with unknown and possibly unequal variances, and used Satterthwaite's approximation for the effective degrees of freedom.

BEHAVIORS		**CONDITIONS**	
		NON-ADAPTIVE AGENT	**ADAPTIVE AGENT**
Spatial behavior	Proximity (moving towards objects or users)	NO	YES
	Orientation (head and gaze turn towards objects or users, point)		
Posture	Communicative postures (disapprove, congratulate, confirm)	NO	YES
Facial expressions	Positive and negative emotional facial expressions	YES	YES

Table 1. Two experimental conditions: non-adaptive vs. adaptive agent.

H1: Social Presence

We observed a significant difference in the answers to one item of the social presence section. Unlike users interacting with the non-adaptive agent, users interacting with the adaptive agent felt that the agent was watching them and was aware of their presence ($t(16)=3.007$, $p=0.003$).

H2: Perceived Adaptivity

The adaptivity of the virtual agent was perceived as significantly higher by users in the adaptive condition than those in the non-adaptive condition ($t(16)=2.046$, $p=0.025$). Users interacting with the adaptive agent felt that the agent reacted to their needs ($t(16)=1.781$, $p=0.043$), and that depending on the user's actions it expressed emotions ($t(16)=2.851$, $p=0.004$), gaze ($t(16)=3.128$, $p=0.002$), location ($t(16)=1.980$, $p=0.029$) and bodily orientation ($t(16)=2.074$, $p=0.023$).

H3: Performance

We did not observe any difference in the duration of the whole session across the two conditions ($t(16)=0.044$, $p=0.483$). Yet, we did observe an effect related to task difficulty. Users interacting with the non-adaptive agent took more time to complete difficult tasks (Task 4, 5, 6) than easy tasks (Task 1, 2, 3). They performed Task 2 significantly faster than Tasks 4, 5 and 6 ($t(16)=-2.378$, $p=0.016$; $t(16)=-2.595$, $p=0.009$; $t(16)=-5.082$, $p=0.0001$) compared to those interacting with the adaptive agent ($t(16)=-4.821$, p=0.209; $t(16)=-1.642$, p=0.060; $t(16)=-2.918$, p=0.005). Task 3 was performed significantly faster than Tasks 4, 5 and 6 ($t(16)=-2.3412$, $p=0.017$; $t(16)=-2.086$, $p=0.024$; $t(16)=-4.948$, $p=0.0001$) compared to the condition of the adaptive agent ($t(16)=-1.333$, p=0.098; $t(16)=-0.587$, p=0.280; $t(16)=-2.563$, p=0.009).). Task 1 was performed faster than Task 4 and Task 6 ($t(16)=-2.009$,

p=0.031; $t(16)$=-3.99, p=0.0004), but not Task 5 compared to the condition of the adaptive agent ($t(16)$=-4.528, p=0.001; $t(16)$=-1.522, p=0.073).

CONCLUSIONS AND FUTURE DIRECTIONS

We described a virtual agent that adapts its spatial behavior to users' and objects' locations in a smart room. Our assumption was that spatial nonverbal behaviors such as proximity, body orientation and posture might provide an intuitive aid to users in a spatial search task. Evaluations were performed in terms of objective performance (task duration) and subjective perception (of the presence and adaptivity of the agent). The results confirm that the adaptive functions of the virtual agent increase the perceived presence and adaptivity of the virtual agent, and reduce the impact of task difficulty on performance.

The impact of proximity, orientation and posture (in terms of location-awareness and social behavior) was not differentiated. We plan to conduct studies with control conditions chosen to allow this differentiation. Moreover, we observed that several users in the adaptive-agent condition demonstrated less initiative in completing the tasks. For example, they did not open the drawer until the agent provided cues to do so. Thus, additional investigations will be conducted on the collected video recordings and spoken interviews to explore such social interactions between users and the virtual agent.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Community's 7th Framework Programme under the ATRACO project n° 216837.

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