Agent Augmented Reality: A Software Agent Meets the Real World

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Abstract

Agent augmented reality is proposed in this paper as a new research area that uses agent technologies for the augmentation of our real world environment by actively integrating information worlds. We introduce a special agent called a *real world agent*. A real world agent is a software agent that can support its user in performing tasks in real world environments, such as place-to-place location guidance, instruction in physical tasks, and augmentation of human knowledge related to the physical environment. In order for the agent to achieve these tasks, the agent should be aware of the user's real world situation. The detection of real world situations is performed through the integration of various methods, including location-awareness using a global positioning system, object recognition through machine-recognizable IDs (barcodes, infrared rays, etc.), and the processing of visual/spoken inputs. IDs of static objects (e.g., doors, ceilings, walls, etc.) can also give clues to the location-awareness system. When a real world agent correctly deduces the real world situation and the intentions of its user, it can access information worlds (e.g., the Internet) in the same manner as other software agents.

Introduction

Recently, the big trend in human-computer interaction has been to bridge between computer-synthesized worlds and the real world. This research area is called *augmented reality* and has as its main theme the overlay of computer-synthesized images onto the user's real world view. Examples are the work of Bajura et al. (Bajura, Fuchs, & Ohbuchi 1992) and Feiner et al. (Feiner, MacIntyre, & Seligmann 1993).

We extend the concept of augmented reality so that it covers interactive systems that can be informationally extended to the real world. Such systems support real world human tasks by providing information such as descriptions of objects as they are viewed, navigational help in some areas, instructions for performing physical tasks, and so on. Augmented reality systems essentially require the ability to recognize real world objects and situations. There are several approaches to detecting real world objects/situations, approaches such as scene analysis by visual processing, marking with machine-recognizable IDs, detecting locations using the global positioning system (GPS), communicating with physically embedded computers, and so on.

Using situation awareness, humans can naturally interact with computing systems using normal speech without having to be especially conscious of the systems' domains or regulations. In this case, language use will be more flexible and robust. By recognizing real world situations and knowing usual human behavior for these situations, the systems will be implicitly aware of humans' intentions and accurately predict future needs and actions.

On the other hand, people can and do physically move from one situation to another. When moving toward a situation, one will get information related to the new situation being encountered. This is an intuitive way of carrying out the information seeking process. Walking through real world situations is a more natural way of retrieving information than searching within a complex information space.

We extend again the concept and functions of an augmented reality by introducing agent technology that is implemented as so-called 'software agents' such as Maxims (Maes 1994) and Softbots (Etzioni & Weld 1994). We call this new concept *agent augmented reality* and introduce a special agent called a *real world agent*. A real world agent is a software agent that recognizes its user's real world situation, is customized to his/her preferences and interests, and performs tasks in the information worlds (e.g., the Internet). Real world agents can communicate with humans in natural language and with other software agents using an agent communication language such as KQML (Finin *et al.* 1992). Situation awareness will help the agents to recognize human intentions by using context-related information on their surroundings.

In the rest of this paper, we discuss in greater detail augmented reality and agent augmented reality, with some implemented prototypes.

There are some concrete examples of augmented reality systems that are currently being used. One of them is a navigation system for driving a car. Using GPS to stay constantly aware of a car's current position, the system gives the driver timely advice about the best route to follow to a destination. For example, as the car approaches an intersection, the system may say "turn left at the next corner." The system also provides some location-dependant information, such as information on good restaurants in the neighborhood, and so on. In a sense, this system augments the real world with digital maps and digital guidebooks.

We think that the proper functions of augmented reality systems include the following:

Situation awareness of the real world There are two major ways for the computer to achieve situation awareness. One is called *mobile computing* and the other *ubiquitous computing* (Weiser 1993).

Situation detection by mobile computing is classified into ID-based and location-based methods. ID-based methods (say ID-awareness) mark real world objects with machine-recognizable IDs (e.g., barcodes, infrared rays, radio waves). Recognition of objects can be extended to the recognition of situations. Suppose that there is an ID on every door in a building. When the user stands in front of a door, the mobile system detects the location by scanning the ID on the door and by processing the information related to this position may derive some understanding of what the user intends to do. Location-based methods (say location-awareness) include GPS, three-dimensional magnetic sensors, gyroscopic sensors, and so on. Spatial information is also a useful input for attaining situation awareness. In contrast to ID-awareness, location-awareness is more scalable, because it doesn't require that objects are tagged. However, when the location of physical objects changes, the system has no way of recognizing this movement and so will fail to identify and call them to the user's attention properly. So, a hybrid approach that uses both ID-awareness and location-awareness to complement each other is better applied.

In ubiquitous computing, recognizing the human environment will become easier. It proposes that very small computational devices (i.e., ubiquitous computers) are embedded and integrated into the physical environment in such a way that they operate smoothly and almost transparently. These devices are aware of their physical surroundings and when humans use a physical device that contains ubiquitous computers or enter some area where physically-embedded computers are invoked to work, these computers are aware of the humans' activities. From the viewpoint of reliability and cost-performance, ubiquitous computing does not compare well with mobile computing, since ubiquitous computers require very long battery lives and are significantly difficult to maintain. In addition, when ubiquitous computers are personalized to users, as in the active badge system (Want *et al.* 1992), for example, all user personal data is processed in the shared environment, while in mobile computing, each user's personal information can be encapsulated within their own machine. So, ubiquitous computing also experiences privacy problems.

Situated interaction We use the term 'situated interaction' to mean the interaction between humans and computers can be very efficient because of sharing of situations or sometimes incomprehensible if there is no mutual awareness of the situation.

A real world situation includes the place where the human is, the time when an event occurs, living and non-living things that exist in the vicinity, and a physical action that is performed (e.g., looking at something).

Humans can move from one situation to another through physical action (e.g., walking). When moving towards a situation, the user can retrieve information related to the situation that is being confronted. This can be an intuitive information seeking process. Walking through real world situations is a more natural way to retrieval information than searching within complex information spaces. Situated interaction can be considered as matching retrieval cues to real world situations. For example, if a person wants to read a book, they naturally have the idea of going to a place where a bookshelf exists. This means that a situation that includes a bookshelf can be a retrieval cue for searching for books.

Personalization Some augmented reality systems will accompany their users like *wearable computers* and be customized to them. The system acquires its user's individual habits and preferences by observing the user's repetitive behavior and by enquiring of the user their personal information.

Personalization helps a system to implicitly recognize its user's intentions, determine the time to begin interactions, and select the information most salient to its user.

Augmentation of human memory One of the interesting functions of augmented reality systems is the augmentation of human memory. The system stores summarized descriptions of the user's behavior in association with situations (including time) where the behavior occurred. A behavior description includes time, location (or ID), and related things (object IDs and/or human IDs). It may also contain visual/spoken information, if available.

Thus, human memory can be indirectly augmented by accumulating memory retrieval cues related to real world situations. Human memories consist of mixtures of real world situations and information that was accessed in those situations. Therefore, recognizing a real world situation can be a trigger for extracting a memory partially matched with that situation and associating information related to the memory.

Related Work

We introduce some experimental systems that can be considered to have some of the functions of the augmented reality systems already mentioned.

Forget-me-not Lamming's Forget-me-not (Lamming & Flynn 1993) is a personal information management system. It is based on Weiser's ubiquitous computing. The ParcTab portable device uses infrared signals to continously send its user's ID to the ubiquitous computing environment. ParcTab can communicate with other ParcTabs through infrared. If someone wants to pass an electronic document to someone else, all they do is pass the document's ID between the ParcTabs. The system memorizes humans' activities chronologically. The main function of this system is to handle queries on information of daily activities (places visited, people met, documents submitted, etc.) by using time as a retrieval key. This system extends human memories indirectly.

Chameleon Fitzmaurice's Chameleon (Fitzmaurice 1993) is a spatially-aware palmtop computer. It shows situated information according to its spacial location and orientation on a small LCD display. This system is not as robust as others because it is aware of the situation only from its own location and when the location of physical objects change, it cannot adapt to or recognize this movement.

NaviCam and Ubiquitous Talker Rekimoto's NaviCam (Navigation Camera) (Rekimoto 1995; Rekimoto & Nagao 1995) is a portable system that consists of a CCD camera for recognizing the color-bar ID codes on real world objects, and an LCD display which reproduces an image of what the user is looking, as if through transparent glass. A basic principle of NaviCam is the *magnifying glass metaphor*. An object, recognized by its ID tag, has some electronic information added to it on the screen, magnifying it not visually, but informationally.

Our Ubiquitous Talker (Nagao & Rekimoto 1995) is an extension of NaviCam that is integrated with a spoken dialogue system.

NaviCam and the Ubiquitous Talker augment reality with some additional information related to a recognized object/situation. Such information is conveyed by using the LCD display and voice (in the case of the Ubiquitous Talker). The Ubiquitous Talker accepts and interprets user voice requests and questions. The user may feel as if they are talking with the object itself through the system.

Agent Augmented Reality

Integrating the augmented reality and agent technologies creates a new research field called *agent augmented reality*. This field requires a special agent that recognizes real world situations, moves around in the information worlds, searches for information related to the intentions of the user, communicates with humans and other agents, and performs, on behalf of the user, some tasks in information space. We call such agent a *real world agent*.

A real world agent is a kind of software agent that can support the user's tasks in the real world environment, such as location guidance from place-to-place, instruction in physical tasks, and the enhancement of human knowledge related to the physical environment. After a real world agent detects the real world situation and the intentions of the user, it can access the information worlds (e.g., the Internet) like other software agents. So, it can dynamically integrate the real and information worlds.

One of the most important problems for software agents is to clarify the user's requests. Communication between agents and humans should be more flexible and robust. Recent advances in multimodal interface techniques must be introduced into human-agent interaction. One direction is anthropomorphic agents. Nagao and Takeuchi (Nagao & Takeuchi 1994) developed an agent that has a computer-synthesized anthropomorphic appearance and behavior. It can communicate with humans using voice, facial expressions, and head movements. However, this approach requires much more research in the fields of psychology and sociology, because humans' reaction to and acceptance of such interfaces is a highly delicate matter.

On the other hand, our real world agent does not have an anthropomorphic appearance. The agent accompanies its user and stays aware of the surroundings and activities of the user. So, the agent has a rich source of clues with which to clarify its user's requests and to interpret intentions. An efficiency of communication is caused by situated information and it can also be a cause of ambiguity in messages. Situation awareness, a main function of real world agents, can also play a role in 'disambiguation.'

Another important function of real world agents is user personalization that determines the system's behavior according to the user's habits and preferences. This function is useful for determining what tasks are to be performed and at what time to begin them as well as the contents of information to be presented and the timing of the presentation. For example, while walking in a town, one suddenly is consumed by desire for a hamburger and expresses this craving, resulting in the agent searching for the most favored (according to the user's own preferences) hamburger shop in that locale (this is done by using the Geographic WWW Server, which will be described later) and placing the user's usual order with that shop.

Other functions of real world agents are as follows:

Situated conversation Conversation in spoken language is an important function of real world agents. Speech is usually based not only on linguistic contexts but also on non-linguistic contexts which relate to the real world situation. This is called *situated conversation*. In situated conversation, the topic and focus of speech depends on the situation and is easily recognizable when the participants are aware of their surroundings. Our agents can handle situated conversation by virtue of the basic properties of augmented reality systems.

Learning and adaptation Similar to the work of Maes and her colleagues (Maes 1994), our agent should also have mechanisms for learning and adapting. In this case, to learn is to acquire the user's habits, preferences, and interests and to adjust the parameters of probabilities, utilities, and thresholds like Maes's tell-me and do-it thresholds. To adapt is to change behavior according to environmental variables, such as the user's attitude (hurrying or not), the location, time, availability of network communication media (e.g., infrared signals, digital cellular, etc.).

Agent learning can also have a role in the augmentation of human memory by maintaining a record of the user's daily activities. It accepts user inquiries about places visited, people met, and so on.

Collaboration A real world agent collaborates with other agents as in a multiagent system. The agent communicates with such Internet agents as Softbots (Etzioni & Weld 1994) when searching for information on the Internet. It also communicates with other people's real world agents to gain knowledge about the humans whom its user is talking with or planning to meet.

Collaboration among real world agents also contributes to group gathering. In this case, the agents inform each other of their users' current locations, and collaborate in determining an appropriate meeting point, then navigate their user to the place decided upon. Since real world agents are always aware of their users' real world situations, they can work on not only meeting scheduling but also coordinating physical meetings.

Issues

An architecture for the real world agents must consider the following issues:

1. Connection between the real world and information worlds
2. Conversation with humans
3. Communication with other agents
4. Learning for personalization
5. Personalized information retrieval and filtering
6. Protection of the user's privacy

As mentioned before, recognition of the real world situations is done using several methods for ID-awareness and location-awareness. We prepare associations between IDs/locations and online resource identifiers in a uniform format similar to the Uniform Resource Locators (URLs) on the World Wide Web (WWW). An example of an association between physical locations and URLs is realized by the Geographic WWW Server described in the next section. Real world agents retrieve such associations through a wireless network.

An agent-human conversation mechanism is designed to integrate linguistic and non-linguistic contexts. The situation awareness module closely interacts with the conversation module. As mentioned before, situated conversation will be more flexible and robust than ordinary conversation. Thus, the potential for cognitive overload of humans during communication will be greatly reduced. Also, computational resources for spoken language processing will be kept to a tractable size by changing to the appropriate phonetic/linguistic dictionaries and knowledge bases according to current situational needs.

Communication with other agents is based on an extension of the Telescript technology (White 1994). Agent communication is done at special computational fields called *places*. In our architecture, places are categorized into two classes. One is called a *public place* and the other a *personal place*. As their names indicate, agents in the personal place can access any personal information resources (e.g., ID number of a credit card) and agents in the public place cannot access such personal information but can use some public information resources (e.g., product catalogs). Agent communication occurs when the agent obtains an online resource identifier (e.g., URL) from a recognized object/location and the identifier is related to a place and its inhabitant agent(s). In this case, agent communication occurs at the public place, as shown in Figure 1. Agent communication also occurs when some agents visit someone's personal place to contact with the real world agent of the person. For example, when a salesman agent of a shop recognizes guests who entered the shop (this is done by broadcasting the guests' personal IDs from their real world agents), the shop agent will try to customize the advertisement for the guests by using their personal information and communicate with them being mediated by their real world agents. This is illustrated in Figure 2.

Learning for personalization requires memory-based and reinforcement learning mechanisms. The agent memorizes user's behavior related to real world situations and do certain actions that will help the user to act in the real world. The user can give some emotional feedback to the agent by voice, hand, or head action.

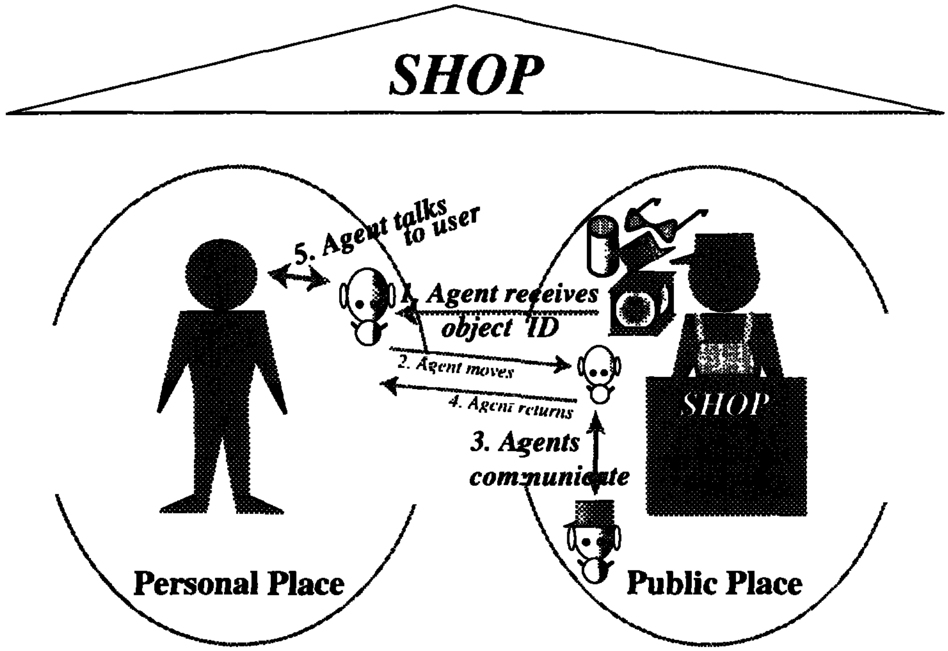

Figure 1: Agent Communication at the Public Place

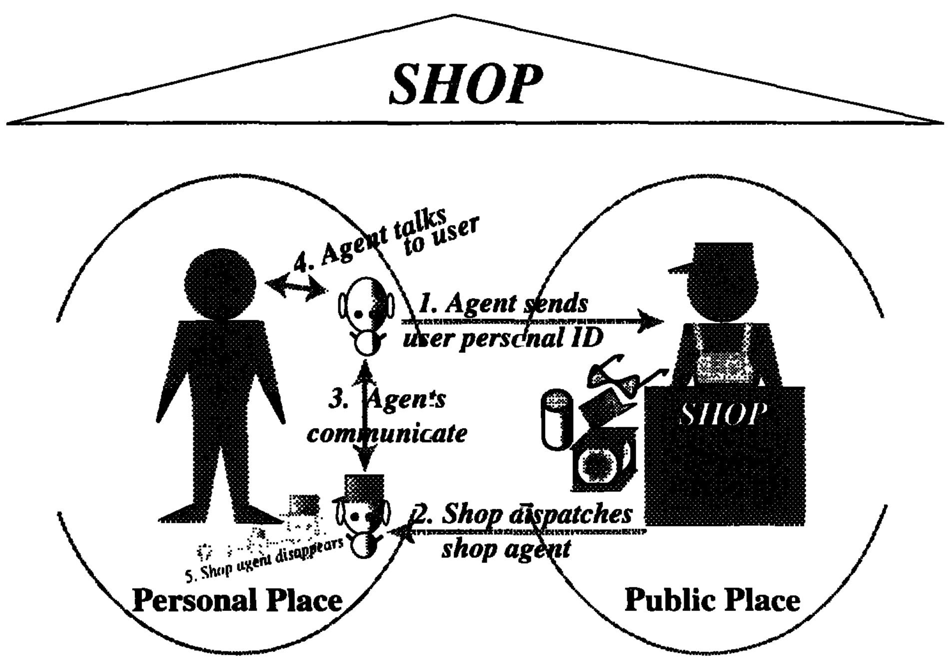

Figure 2: Agent Communication at the Personal Place

They are regarded as reinforcement signals for the agent. It is hard to teach the agent which action of the user is a reward and which action is a penalty. However, there are some hints to facilitate this decision such as using prosodic features included in human's angry and pleased voice tones and behavioral feature of body movements.

The main task of the agent is the retrieval and filtering of information that is related to the user's real world environment and preferences. There are some techniques for customizing the retrieval and filtering. One is a user profile that includes some keywords and category markers of frequently accessed information (e.g., Web pages, online documents, etc.). Through the utilization of learning mechanisms, the agent acquires its user's profile and uses it for information retrieval and filtering.

When the agent uses personal user data for information processing, it may share this information with other agents for some tasks. However the agent must cover up certain information that is used for identification of the individual person. So the agent always takes care of the management of personal information especially when the agent is in public places. In another case, some agents may visit other agent's personal place and retrieve the personal data. Our architecture prohibits any agents visited other's personal places leave from there. So when agents visit personal places, their behaviors are restricted so that they can only access partial personal information and provide messages, and cannot retrieve responses. If any response is needed, the visiting agent sends a request to the inhabitant agent of the personal place. There are some cryptographic techniques used in data communication, such as public key cryptosystems. For stronger protection of privacy, agent communication will require some security architecture based on cryptographic techniques.

Examples

We have been developing the following two experimental systems based on the concept of agent augmented reality.

ShopNavi (Ubiquitous Talker II)

ShopNavi is a system for commercial information guidance and navigational help in shops. ShopNavi is also functional as a real world agent. Since shopping is a very personal affair, personalization of each user's own ShopNavi is essential. The ShopNavi unit consists of a wireless tag reader (this is similar to a barcode scanner) for object identification, three-dimensional sensors for the recognition of head orientation and hand position, an infrared receiver for location detection, a portable LCD for information presentation, a wireless data communication facility, and a spoken dialogue system.

Figure 3 shows a snapshot of the ShopNavi in use, and Figure 4 its example screen.

Figure 3: ShopNavi in Use

Figure 4: Example of the ShopNavi Screen

ShopNavi uses infrared IDs (location beacons) for location-awareness. These IDs are continuously transmitted from critical points around the store, for example, the entrances, counters, sales floors, and so on. The ShopNavi portable module keeps its user's personal information such as today's menu plan, a budget, past shopping records, favorite items, and shopping habits.

When a user enters a shop equipped with ShopNavi, the system can supply up to date information on products in the shop. This is done with special consideration given to any differences between past and present visits and the particular shopping requirements of the day. Next, after a preference order has been established, the user is navigated around the different sales areas to the desired items. If necessary, the user can talk things through with the ShopNavi, in a fashion similar to the Ubiquitous Talker mentioned earlier. The system recognizes things by scanning their tags and prepares appropriate resources for a spoken dialogue with the user. In this case, the system has to deal with a situated conversation in which most of the contextual information is conveyed implicitly. The system should be aware of the surrounding situations, including the user looking at an object, locations, hand gestures, head orientation, and so on. Furthermore, the system also memorizes the user's activities, for reference and utilization on future shopping trips. This mechanism can also record mnemonic triggers, acting as the user's back up memory. This is an important function of augmented reality systems.

The agent that inhabits the ShopNavi has the task of searching for information in a network that connects the shops, suppliers, and product manufacturers. This allows the user to make queries for information on an item's place of origin, the identity of its manufacturer, and how it was made. The ShopNavi manages the user's personal information, the shop's public information, and information on the network between shops and their surroundings.

WalkNavi (Walker's Navigator)

WalkNavi is a location-aware interactive navigation/guidance system. It detects its user's current location by using GPS and infrared IDs, recognizes the user's intentions from voice inputs, retrieves location-related information from WWW, and provides navigational help and guidance information. In order to relate real world locations with URLs, WalkNavi accesses the Geographic WWW Server that has a network-accessible database of latitude/longitude information and URL links connected to location-related WWW pages. So, WalkNavi is a networked navigation system for pedestrians rather than drivers that uses digital maps/guidebooks.

WalkNavi gives its user advice on route navigation to the desired destination by showing photographs of landmarks that can be used for navigation. It also provides information on notable places and buildings along the way.

WalkNavi is also provided with agent-oriented functionality. It uses an agent to gain access to on-line services such as reservations at restaurants and electronic ordering of goods at shops through a wireless network. Using situation awareness, the agent will be able to recognize its user's intention implicitly.

Figure 5 shows a snapshot of the WalkNavi in use, and Figure 6 its example screen.

Figure 5: WalkNavi in Use

The system consists of the following three basic components and the Geographic WWW Server.

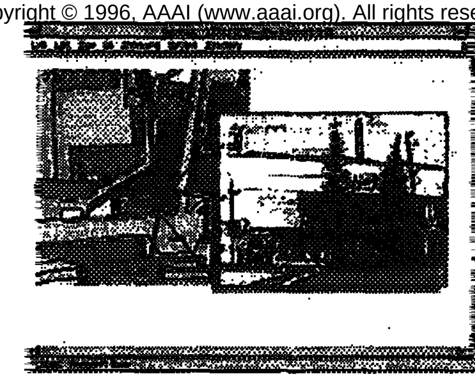

Figure 6: Example of the WalkNavi Screen

Location-awareness
Location-awareness is achieved using GPS and infrared IDs. GPS gives the system geographical information including the current latitude and longitude. Locational information from GPS is purposely designed to be accurate to only about 100 meters, but additional information from nearby landmarks, given by location IDs and/or human voice input helps the system to refine the current position estimate.

Spoken dialogue system Voice is an essential input modality for mobile computers, because it is difficult for walking people to keep their attention on the computers for a long time and spoken language reduces the cognitive load of interaction with the computer. The WalkNavi module implements a mechanism of situated conversation. It integrates linguistic and non-linguistic contexts and manages system resources in accordance with real world situations.

Location-oriented mobile WWW browser The outputs of the system are presented through a WWW browser, because we use the WWW as a major information resource. The WWW includes location maps, related information (HTML texts, photographs, and sounds). The mobile Web browser accesses the Geographic WWW Server mentioned below via wireless network using a digital cellular phone. Then, it retrieves location related Web pages, selects the most appropriate one by using categorical indices, and shows them on a portable LCD (palmtop monitor screen).

Geographic WWW Server Our Geographic WWW Server relates latitudes/longitudes to physical addresses with URLs. The mobile Web browser accesses the server and retrieves URLs related to the current location through a wireless network. When a place's URL is registered with the server, the name of place, its latitude/longitude, its category (e.g., scenic view, restaurant, etc.), its physical (snail-mail) address, and any additional comments are all input. When one accesses the server, URLs are obtained by querying the server's URL using the parameters of latitude, longitude, distance, and category.

Location can also be used for information filtering. Since a query by keywords without some conditional restriction will often result in a great deal of useless information, locational restriction (i.e., a radius of X meters from the current position) can implicitly reduce the number of query candidates and make retrieval more efficient and intuitive.

Final Remarks

In this paper, we have discussed a new approach to introducing agent technologies that support everyday tasks such as walking and shopping with navigational aids and information. The main objective of this research is to integrate the real world and information worlds seamlessly, not just in a visual sense. We think that combining the technologies being pursued in the research areas of augmented reality and software agents is a very promising approach.

Interaction between humans and agents is one of the most important issues of software agents. Since real world agents detect their users' physical environments, the agents could be aware of users' potential desires and implicitly deduce their concrete intentions when they say or do something.

We have described two implemented prototype systems based on the concept of real world agents. Of course, they are not yet practical because of the lack of adequate technology and open experimentation. There are some obstacles to be overcome in scaling up these systems. One problem is the use of wireless network communication. Current digital cellular phones only support a maximum communication speed of 9600bps. In addition, the common TCP/IP protocol has too much overhead and is unreliable (easily disconnected) networks. Consequently, we gave up mobile network computing during the movement phases (walking, etc.). While traveling along a path, our prototype system was able to download most resources whenever the user was standing still, before continuing to the next point.

Future work includes a more detailed analysis of situated conversation and agent learning and collaboration. Since we have implemented them in a rather ad-hoc way, a more general mechanism that better realizes the true functions of a real world agent needs to be pursued.

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