Real–world Oriented Distributed Human–Robot Interface System

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Abstract

In this paper, we propose the real-world oriented distributed human interface system named AIDA. AIDA supports human activities in the real-world (e.g., in offices, in houses) without restricting user's physical movements. AIDA is based on multi-agent model in which each interfacing elements (e.g., mobile robots, workstations) cooperates with each other for providing continuous support to a user. An agent is constructed by a set of behavior modules for providing reactive responses to a user. Also, with AIDA, the system can adapt to the uncertainty of user's position and the user's attention that may change in time. We have developed a laboratory guiding system based on AIDA. And we have confirmed the efficiency of AIDA by experiment.

1 Introduction

Distributed interface systems such as distributed meeting systems[5], collaborative writing systems[3], work-flow support systems[4] are increasingly evolved under the banner of CSCW (Computer-Supported Cooperative Work). However, these systems are not supporting human activities in the real-world.

For example, if we want to send a document by mail, we have to print it out, we put the copy in an envelope, then we put a stamp on it. Usually, the printer and cabinets of envelopes and stamps might be located at the distant places. In such case, a computer near to the printer or the cabinets should advice the user where to find the envelopes and stamps. Also, when someone visits a laboratory, a researcher explains an overview of the laboratory, then leads the visitor to the place of experimental equipment, and explains the research activities. In such case, a mobile robot should guide the visitor and explain the research activities.

In order to support human activities as we have mentioned above, the interface system should have the following functions. Firstly, the system should be real-world oriented one which utilizes not only electronic information but also physical information such as user's location. Secondary, the system should be composed by distributed interfaces so that it can interact with a physical moving users at several places. Thirdly, the system should not restrict the user's movement. We define such interface system as real-world oriented distributed human interface system (HIS).

In this paper, we propose the real-world oriented distributed HIS named AIDA (Architecture for Interfacing Distributed Agents). We also have developed a laboratory guiding system based on AIDA. The rest of the paper is organized as follows. In section 2, we propose a system architecture AIDA. In section 3, we describe the application based on AIDA. Finally, we conclude in section 4.

2 AIDA

2.1 Required functions for real-world oriented distributed HIS

In order to support a user who is moving in rooms or in buildings without restriction, the system should consist of distributed interfaces and surround the user with the interfaces. Distributed interfaces can be computer interfaces that can display multimedia information to a user, can be mobile robots that can follow or lead a user, or whatever it can interact with users. And each distributed interface should interact with each other for providing a continuous support to a user, as a single consistent system. Furthermore, in order to realize such a real-world oriented distributed HIS, the system should have the following functions.

- Coordination
  In order the system to support a user continuously, each distributed interface should be able to share the environmental information (e.g., current place of a user, history of interaction with a user). For that ends, the distributed interfaces should be able to coordinate with each other.
- Reactiveness
  In order to realize an interactive system, each distributed interface should interact with a user adaptively and quickly.
- Adaptation to uncertainty of user's position
  Since the system interacts with a user without restricting user's movements, it is difficult to obtain the user's precise location. Therefore, the system should adapt to the uncertainty of user's location.
- Adaptation to uncertainty of user's attention
  It is assumed that a user may not keep attention on the system while the system is interacting with the user. The system should adapt to uncertainty of user's attention that may change.

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2.2 Design concepts of AIDA

In order to satisfy the above mentioned requirements, we have designed AIDA by taking the following characteristics into consideration.

- Multi-agent system
  Each distributed interface should interact with a user autonomously. Also, they should be able to exchange information about users for coordination. Therefore, we employed multi-agent model in which each distributed interface is modeled as an autonomous agent.
- Behavior-based architecture
  In order the system to be a reactive one, we construct an agent by a set of behavior modules which are similar to SSA (Subsumption Architecture)[1].
- Sensor-fusion
  In order to adapt uncertainty of user's position, the system should use several kinds of sensors (e.g., ultrasonic sensors, infrared sensors, keyboard inputs) and integrate them. By accumulating and exchanging information derived by sensors, the system can adapt to the uncertainty of user's location.
- Belief-value
  In order to adapt the uncertainty of user's attention, we employed belief-value which represents the degree of user's attention to the system. We assumed the belief-value changes as time passes.

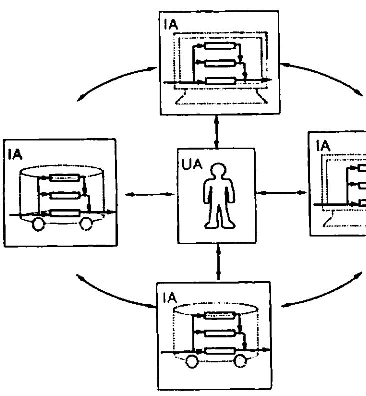

Figure 1: Multi-agent model of AIDA.

2.3 AIDA

2.3.1 Multi-agent model of AIDA

We have designed AIDA based on the characteristics described above. The multi-agent model of AIDA is as shown in figure 1. The system is constructed by User-Agent(UA)s and Interface-Agent(IA)s. UA is the agent which is prepared for each user and keeps the user's information (e.g., current position of the user, personal history of interaction). On the other hand, IA is the agent which interacts with a user as an independent module. Each agent can cooperate with each other by communication. In follows, we describe IA and UA in more detail.

2.3.2 Interface-Agent

The behavior architecture of IA is as shown in figure 2. Each behavior module consists of a sensor-part, a belief-part, and a behave-part. According to sensor information and received information from other agents, the sensor-part decides if the corresponding behavior module is activated or not. Also, according to the belief-value, the belief-part decides the corresponding module's activation. If all the conditions are satisfied, the behave-part sends control signals to output devices (e.g., drive actuators, display on monitor, speak via voice synthesizer).

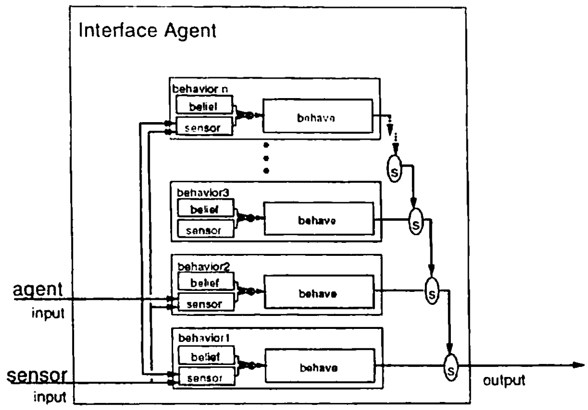

Figure 2: Behavior architecture of Interface–Agent.

Also, output lines of behavior modules can subsume other module's outputs. In the case of figure 2, higher level of behavior modules have a higher priorities. Therefore, if more than one behavior module have activated at the same time, higher level of behavior module subsumes other ones. In belief-part, belief-value is calculated by belief-function which is defined as follows.

$$b_{i_{t_{j+1}}} = \begin{cases} b_{i_{t_0}} & \text{(initial value)} \\ b_{i_{t_j}} + a_i & (0 \le b_{i_{t_j}} + a_i \le 1) \\ b_{i_{t_j}} & \text{(otherwise)} \end{cases}$$

$b_{i_{t_j}}$ denotes the belief-value of level i th behavior module at time t_j. The time difference between t_j and t_{j+1} is a sampling period of sensor devices. a_i denotes a changing ratio of belief-function. If a_i is bigger, the belief value increases more rapidly. Belief-function is initialized when user ID is recognized by ID receiver[1]. If the belief-value is above the threshold[2], it activates the corresponding behavior module.

We will explain how the activation of behavior modules changes by using belief-functions in more detail. Assume we have a computer IA consists of three behavior modules as follows.

- behavior 3 (display information):
  sensor-part: ID receiver (user ID has recognized)

[1] For user identification, we have used infrared ID receivers and ID pendants[2]. ID pendant is put on user's chest.

[2] In this paper we assumed the threshold as 0.5.

belief-part:

$$b_{3_{t_{j+1}}} = \begin{cases} 1 & \text{(initial value)} \\ b_{3_{t_j}} - a & (0 \leq b_{3_{t_j}} - a \leq 1) \\ b_{3_{t_j}} & \text{(otherwise)} \end{cases}$$

behave-part: explain to a user

- behavior 2 (find a user):
  sensor-part: ID receiver (nothing has recognized)
  belief-part:

$$b_{2_{t_{j+1}}} = \begin{cases} 0 & \text{(initial value)} \\ b_{2_{t_j}} + \frac{a}{2} & (0 \leq b_{2_{t_j}} + \frac{a}{2} \leq 1) \\ b_{2_{t_j}} & \text{(otherwise)} \end{cases}$$

behave-part: request other IAs for user information

- behavior 1 (ascertain user's attention):
  sensor-part: ID sensor (nothing has recognized), keyboard
  belief-part:

$$b_{1_{t_{j+1}}} = \begin{cases} 0 & \text{(initial value)} \\ b_{1_{t_j}} + a & (0 \leq b_{1_{t_j}} + a \leq 1) \\ b_{1_{t_j}} & \text{(otherwise)} \end{cases}$$

behave-part: ask keyboard input to a user

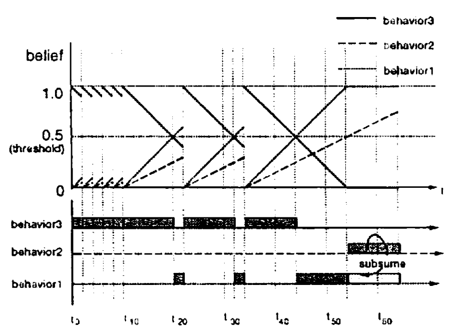

Figure 3: Belief functions and dynamics of behavior activations.

The upper part of figure 3 shows the change of belief-function and the lower part of figure 3 shows the activated behavior modules, respectively. Between t_0 and t_{10}, there was a user in front of IA. Therefore, IA recognized the user and each time it initialized belief-value. And IA explained to the user by using behavior module 3.

On the other hand, between t_{10} and t_{20}, IA could not recognize the user from ID sensor, so the belief-values were not initialized. Thus, at time t_{20}, the belief-value of behavior module 3 became below the threshold and the belief-value of behavior module 1 became above the threshold. Therefore, behavior module 1 has activated and IA asked the user to input from keyboard for ascertaining the user's attention. In this case, the user input keystroke, so the belief function has initialized. Thus, IA resumed to explain the user with behavior module 3.

Furthermore, between t_{34} and t_{44}, IA asked the user for keyboard inputs again. But in this case, the user was not paying attention to the system and did not respond to the system. So, at time t_{54}, the belief-value of behavior module 2 became above the threshold and behavior module 2 subsumed behavior module 1. Thus, IA made requests to other IAs to find the user. As described above, with multi-agent model of AIDA, distributed agents can adapt to the user's attention by utilizing belief-functions and can provide reactive responses to the user by utilizing behavior-based architecture.

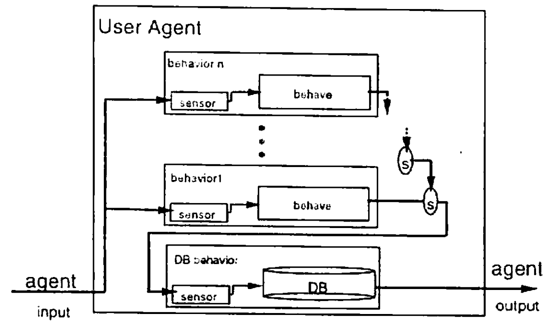

Figure 4: Behavior architecture of User–Agent.

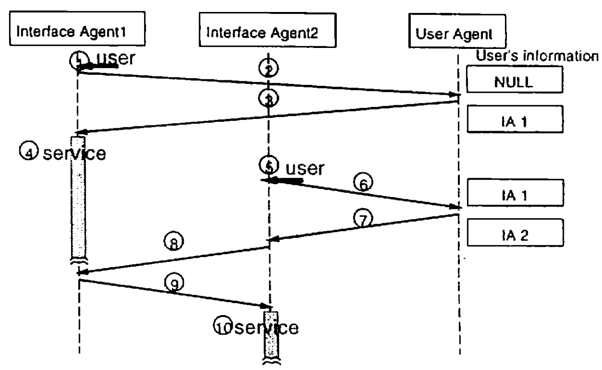

Figure 5: IA's coordination by using UA.

2.3.3 User-Agent

UA is prepared for each user (who has ID pendant) and manages the information of the user. As shown in figure 4, UA is also consists of behavior modules, but it can have database (DB) behavior in order to manage user information. A sensor part of DB behavior module inputs requests such as modify, retrieve, and send information to other agents. In order the distributed interfaces to support a user as a single consistent system, IA takes the following procedures. 1) When IA recognizes a user, it asks the corresponding IA for the user's information. 2) UA transfers the user's information to the IA. 3) According to the information, IA interact with the user.

By utilizing UA, the system can support a user continuously. We will explain it by using an example. Assume there are two IAs and a UA which has the history of user's interaction to the system so far. The communication among agents could be as follows (see also figure 5).

1. A user is recognized by IA1's ID receiver.
2. IA1 queries corresponding UA for the user's information.
3. UA transfers the user's information to IA1.
4. In this case, there is no information about the user,IA1 begins a service to the user as the first met visitor.
5. The user moves to the place of IA2 and it is recognized by IA2. (But IA1 could not recognize it.)
6. IA2 queries the UA for the user's information.
7. The UA transfers the user's information to IA2.
8. The obtained information denotes that the user is being serviced by IA1. So, IA2 informs IA1 the user's movement.
9. IA1 quits the service and sends acknowledgment to IA2.
10. IA2 begins a service by taking account of the interaction that IA1 has already done.

3 Laboratory guiding system

3.1 Overview of laboratory guiding system

In order to examine the efficiency of AIDA, we have developed the laboratory guiding system based on AIDA. The guiding system explains the overview of the laboratory to a visitor (user) near the entrance, then leads the user to the demonstration places located in inner part of the room, and explains the research activities. In such case, the system should adapt the uncertainty of user's position which may move while guiding, and the uncertainty of user's attention which may fade away while explaining to the user. Also, the user may suddenly appear in front of arbitrary IAs. So the system should explain to the user by referring the history of interaction (e.g., omitting the explanation that has done so far).

We have developed three kinds of IAs, i.e., Robot-Agent (RA) which leads a user to the demonstration places and looks for a user, Computer-Agent (CA) which explains to a user by using display and speaker, and Environment-Monitoring-Agent (EMA) which monitors the user's movement by ID sensors. Also, we used UA for each user.

In this system, we assumed that a user wears ID pendant[2] on his/her chest in order to recognize the user's current position. Therefore, by using ID receivers, the system can obtain user's position roughly.

3.2 System configuration

3.2.1 Robot-Agent

RAs are realized mobile robots. It leads a user to the demonstration places or looks for a user by responding to other agents' requests. The behavior architecture of RA is as shown in figure 6. As the sensors, RA has ID receiver for user recognition, infrared and ultrasonic sensors for recognizing the position of RA and the distance from a user, and encoder for dead-reckoning. These sensor information and the information received from other agents are input to sensor-part. As behave-part, behavior module sends command to output devices, such as DC servo motors to move, speaker with voice synthesizer, and communication devices. Each behavior modules are constructed as follows.

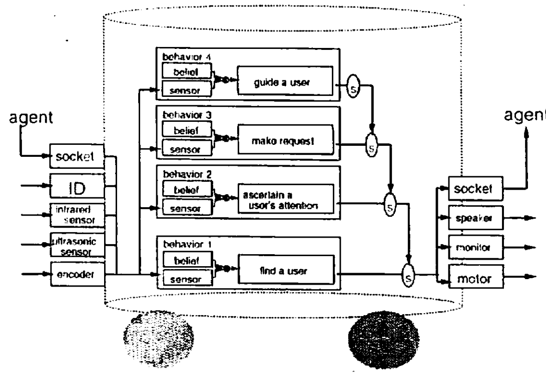

Figure 6: Behavior architecture of RA.

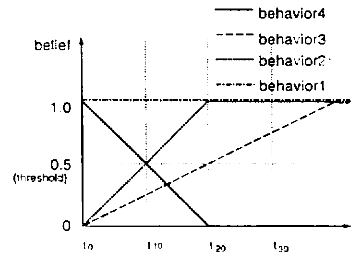

Figure 7: Belief function of RA.

- behavior 4 (guide a user):
  When ID receiver detects a user ID (recognizes a user), this behavior module is activated. Then, it notices the user to follow the robot via voice synthesizer and moves by driving motors.
- behavior 3 (make request):
  When ID receiver could not detect a user ID while leading the user, this behavior module is activated. Then, it makes request to other IAs for supporting the user via communication devices.
- behavior 2 (ascertain a user's attention):
  When ID receiver could not detect a user ID while leading the user, this behavior module is activated. Then, it asks some questions to the user via voice synthesizer and recognizes if the user is still paying attention to the RA or not.
- behavior 1 (find a user):
  This behavior module is activated when requests for finding a user from other agents have detected, or when ID receiver could not detect a user ID while leading the user. Then it moves by driving motors and looks for the user.

The belief-function of each behavior modules are defined as shown in figure 7.

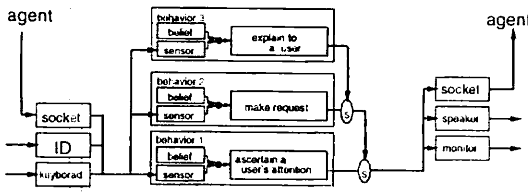

Figure 8: Behavior architecture of CA.

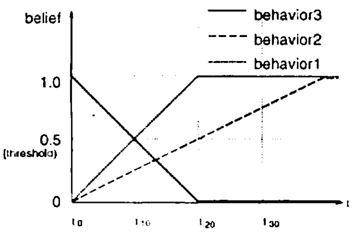

Figure 9: Belief function of CA.

3.2.2 Computer–Agent

CAs are arranged at demonstration places and aisle. When CA recognizes a user, it explains the demonstrations or it directs a user to move, by showing text and figures on monitors and by speaking the explanation from speakers. The behavior architecture of CA is as shown in figure 8.

As the sensors, CA has ID receiver for user recognition and keyboard for getting information from a user. These sensor information and the information received from other agents are input to sensor-part. As behave-part, behavior module sends command to output devices, such as display to show text and figures, and speaker to output voice. The behavior modules of CA are constructed as follows.

- behavior 3(explain to a user):
  When ID receiver detects a user ID, this behavior module is activated. Then, it explains the demonstration to the user or asks the user to move to the next demonstration places, by showing information on display and by speaking.
- behavior 2 (make request):
  When ID receiver could not detect a user ID while speaking to the user, this behavior module is activated. Then, it makes request to other IAs for supporting the user via communication devices.
- behavior 1 (ascertain the user's attention):
  When ID receiver could not detect a user ID while speaking to the user, this behavior module is activated. Then, it asks some questions to the user via speaker and recognizes if the user is still paying attention to the CA or not.

The belief-function of each behavior modules are defined as shown in figure 9.

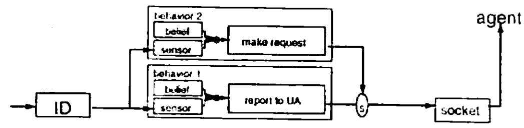

Figure 10: Behavior architecture of EMA.

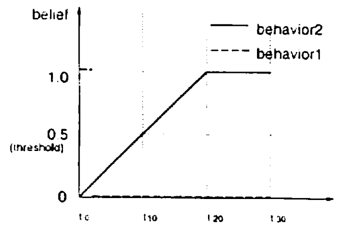

Figure 11: Belief function of EMA.

3.2.3 Environment–Monitoring–Agent

EMAs are arranged at demonstration places and aisle. And it detects users' appearance. The behavior architecture of EMA is as shown in figure 10. As sensor-part, EMA has ID receiver for user recognition. As behave-part, behavior module reports the user's detection to other agents via communication devices. The behavior modules of EMA are constructed as follows.

- behavior 2 (make request):
  When ID receiver detects a user ID, this behavior module is activated. Then, it makes request to other IAs for supporting the user via communication devices.
- behavior 1 (communicate with user-agent):
  When ID receiver detects a user ID, this behavior module is activated. Then, it informs the user's appearance the corresponding UA via communication devices.

The belief-function of each behavior modules are defined as shown in figure 11.

3.2.4 User–Agent

UA is prepared for each visitor and manages the information of the visitor. The behavior architecture of UA is as shown in figure 12. As sensor-part, UA has communication devices for receiving data from other agents. As behave-part, behavior module transfers the user's information via communication devices. The behavior modules of UA are constructed as follows.

- behavior 2 (store user information):
  When UA receives new user information from IAs, this behavior module is activated. Then, it sends out "write" commands to DB behavior module.

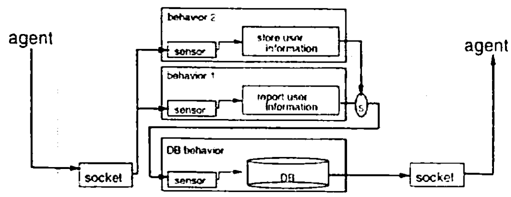

Figure 12: The behavior architecture of UA.

- behavior 1 (report user information):
  When UA receives inquiry from IAs, this behavior module is activated. Then, it sends out "retrieve" and "send" commands to DB behavior module.
- DB behavior:
  When DB behavior module receives requests from other behavior modules, this behavior module is activated. By referring the requests, it adds, modifies, and retrieves data, then transfers retrieved information to other IAs if necessary.

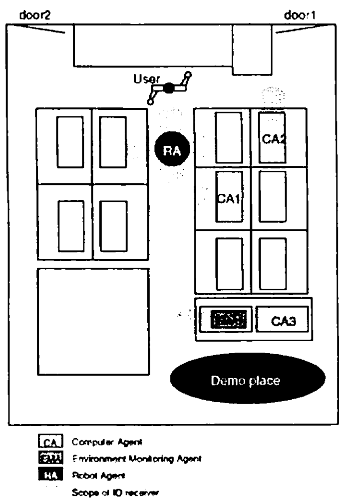

Figure 13: Agents' layout for the laboratory guiding system.

3.3 Implementation

By using the agents described above, we have implemented the laboratory guiding system as shown in figure 13. We implemented RA by using autonomous mobile robot *ASPIRE-II* [6] (see figure 14), CA by using SUN workstations, and EMA by using infrared ID receivers. And by experiment, we have confirmed that the system can guide a user as shown in figure 14 and 15.

4 Conclusion

In this paper, we proposed the real-world oriented distributed HIS named AIDA. The characteristics of AIDA are coordination based on multi-agent model, reactiveness based on behavior-based architecture, and adaptation to the uncertainty of user's position and user's attention. We have developed the laboratory guiding system based on AIDA and confirmed its efficiency.

Figure 14: RA which is guiding a user.

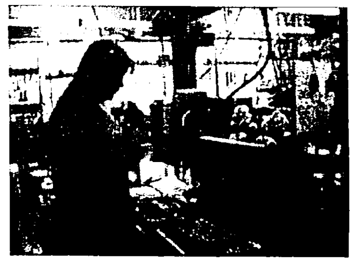

Figure 15: CA which is describing to a user.

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