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User Centered Design for Intelligent Service Robots*

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Abstract

This paper describes the development of a fetch-and-carry robot to assist physically impaired people in an office environment. Different methods of involving users are employed in the project, including task analysis, Hi-Fi simulation trials and focus group sessions. Through an iterative design process, a prototype robot system has been developed, with an enhanced robot platform including a graphical interface and a natural language interface. The users' need for continuous feedback from the robot has led to the development of an animated character (CERO), which relates the two interface components and indicates the robot's current state by using simple gestures.

1 Introduction

Designing Intelligent Service Robots (ISR) to assist users in their daily life is quite different from having robots perform tasks in the laboratory. In our view this requires the participation of end users in the design process. Working together with the Swedish National Labour Market Board (AMS) and the Center for Autonomous Systems (CAS), we are currently developing a robot that will assist users with everyday tasks such as to fetch and deliver objects in an office environment. The targeted users suffer from physical impairments that make it difficult to move around and to carry objects. An important aim of the project is to provide a transparent interface which a non-expert user could operate after a short introduction.

In our research we are using a combination of methods to guide the design of service robots. The work is multi-disciplinary and draws on methods and theories from user centered system design, industrial design, natural language processing and robotics. The design process is iterative, applying results from user trials to inform the design of a prototype or component, which is then used in new tests, and so on, refining the design of the robot at each iteration.

At an early stage, we performed a questionnaire study to assess people's attitudes towards ISRs. Then we used a framework for Task Analysis, adapted for human-robot interaction, to find out about the user needs and work tasks in our particular domain. The findings of the survey and the Task Analysis were used to guide the development of a prototype robot and interface components, which were then used in a Hi-Fi simulation study with a small group of users. The combined observations of these user trials were used to inform the overall physical design of the robot as well as the Graphical User Interface (GUI) and the Natural Language Interface. Below we will briefly describe these methods, and

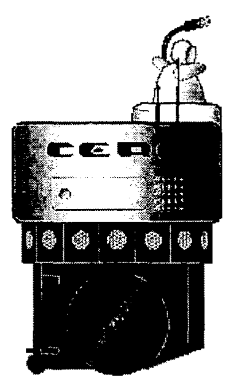

Figure 1: The robot prototype with the CERO interface character attached to the top.

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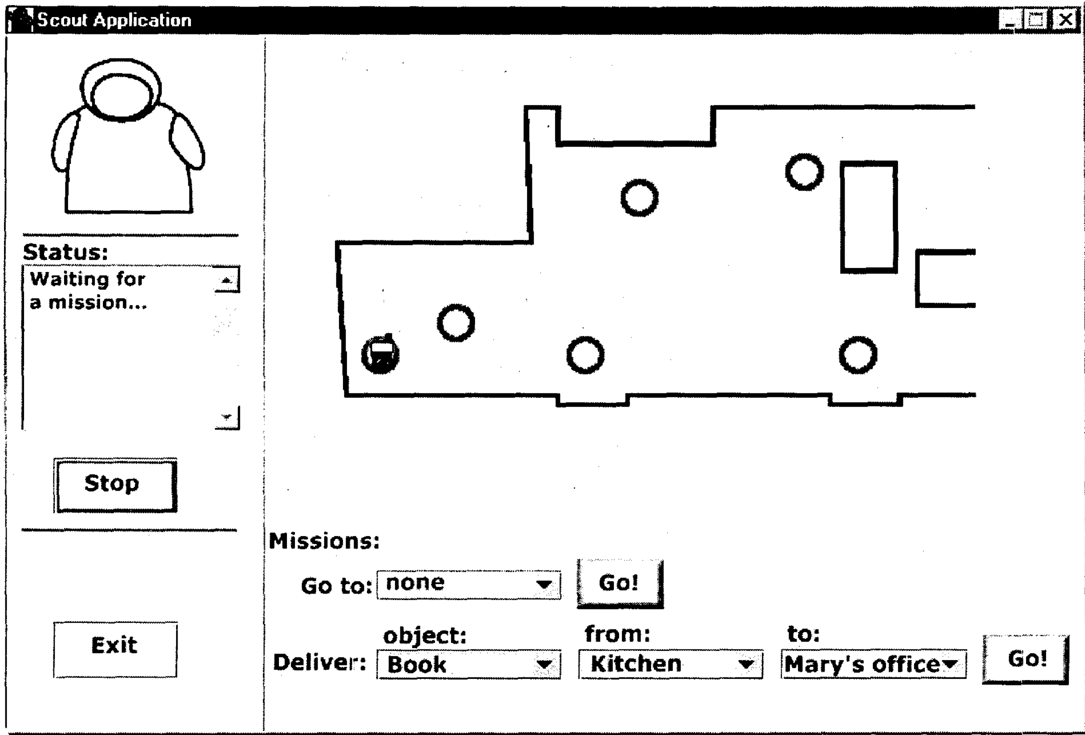

Figure 2: The Graphical User Interface

how they have been used in the design of our current robot prototype. Finally we will outline our plans for further work in the project.

2 Related research

Very little research has been targeted at user centered design of mobile service robots. While studies of robot usage in office environments or public areas have been made e.g. for tasks like mail delivery [1], visitor tour-guidance [2], or focused upon natural language interaction, e.g. on the JIJO-2 robot [3], user involvement in the early design process and iterative usability assessment are yet uncommon. A stronger practice in user involvement can however be found in the field of rehabilitation robotics where for instance the man-machine interface requirements of a mobile robot were investigated by Fischer [4]. The user-driven development of the Handy 1 system, a robot system enabling the robotic assistance of everyday tasks has been reported by O'Connell and Topping [5]. To stress the importance of developing service robotics in tight cooperation with intended users, Eftring [6] has recently introduced the term useworthiness to emphasize the importance of assessing the achievements of users' high-priority needs.

3 Survey

A problem in designing for human-robot interaction is that ordinary people have little or no experience of robots which might help to form their expectations and guide their interaction with a service robot. As a pilot study, we performed a questionnaire survey with the purpose of assessing peoples attitudes towards the use of a mobile, intelligent service robot for household tasks [7]. The study included 134 participants with various background and education, and with equal participation of both sexes. The questions concerned a range of topics such as the tasks that users want the robot to perform, the preferred physical design of the robots with respect to size, height, color, and visual appearance etc., as well as safety and privacy issues. The results showed that a comparatively large proportion of those who wanted help with a household task (30-50%) were positive towards having a robot to help with it.

The survey also included questions about the preferred way of communicating with a service robot, including the choice of modality. The results showed that most participants preferred speech (82%) followed by touch screen (63%), gestures (51%), and command language (45%). Altogether, the survey showed that speech is a preferred form of interacting with a household robot, but that several other forms of interaction are acceptable as a complement.

4 Task Analysis

In traditional software engineering, task analysis (TA) is sometimes used to find the structure and contents of the tasks. The methods used are based on theories about human behavior in work situations, and many methods use structuring and decomposition of tasks for this purpose. In using Task Analysis for Service Robots we aim to capture the following information:

- The user's work procedures and tasks.
- Physical design requirements: A TA has to describe properties of the payloads for the robot, physical constraints on manipulators and body size, sensors etc. so as to provide a good basis for the physical design.
- The relation between the user's and the robot's parts of the work. Disabled users often want to do as much as possible themselves, and further the technology constrains the degree of autonomy of the robot.
- The user's expectations on the task: The quality of goal fulfillment is a large part in the usability measurement for the robot.

To obtain data for the design of a service robot, we have used interviews with end users, where their expectations on robots as well as actual needs are chartered. We have also used focus groups, consisting of people with knowledge of the particular domain of interest. In particular, we discussed the overall design and the functionality to be provided with a group of people working with Assistive Technology as consultants.

5 Hi-Fi simulation trials

For the development of dialogue models we set up an initial "Wizard-of-Oz" experiment – a high fidelity simulation, aimed at assessing the dialogue in which spoken commands are issued to the system by the user. In the Wizard-of-Oz method (cf. [8]), researchers simulate parts of interactions between users and interactive systems by substituting the (yet) missing functionality with a human operator, the so-called "Wizard". We specified a simple, but representative task, with respect to the task analysis interviews, and let the users interact with the robot prototype. A test leader acted as the robot language interface, and initiated appropriate responses to users' input using the onboard speech synthesis. The sessions were video-recorded and analyzed in order to establish a dialogue model to be used in the actual system.

One of the most important results of the study was that users need continuous feedback of several kinds. The participants in the study were often confused about the robot's state, and closely monitored its movements. The results also showed that a multimodal style of interaction (e.g. with pointing gestures) was used, even if users knew that the robot had no vision capabilities.

We found that the spatial and communicative relationships between users and the mobile robot challenged a common assumption in the Wizard-of-Oz technique as it is usually applied, namely that the user and the robot are co-located. In our study this was not always the case, because the robot (and sometimes also the user) is moving around in the environment. Employing this method for human robot interface design requires that the set up of the experiment is carefully thought through. In our view special consideration must be given to what degree one should allow full freedom of movement, both for the participants and the simulated robot system.

6 The prototype system

The user studies have led to the conclusion that a combination of a graphical user interface and a spoken language interface will support efficient interaction with the robot system. The speech interface is thought to be the primary interaction modality when the robot is close to the user, otherwise the user will control and monitor the robot via a graphical interface.

As a robot platform, we use a standard Nomadic Super Scout II equipped with 233 MHz industrial PC and a radio modem. The prototype system uses a hybrid deliberate/reactive control system, developed by CAS [9], for navigation and localization. Using its 16 ultrasonic sensors, the robot localizes its position in a predefined map by detecting landmarks in the environment, which are used for triangulation together with readings from the onboard odometer [10].

From a functional perspective the prototype robot is built out of a number of different system components, which exchange messages using a CORBA based distributed software architecture (see Figure 3). The software interface component of the robot consists of the Graphical User Interface and the Natural Language Interface. The navigation and task planning are handled by their respective planning components.

We consider the physical design of the robot as being an important part of the interface. The robot should have a functional form, and also be attractive from an aesthetic point of view. Working together with an industrial designer, we have constructed a full-scale robot prototype (see Figure 1) which is currently used for user trials. The enhanced platform includes a compartment to hold objects either on top or hidden inside (e.g. when transporting keys, easily breakable or valuable items). The top of the robot also includes a directed microphone and loudspeakers for the speech interface.

The need for continuous feedback and a visible front

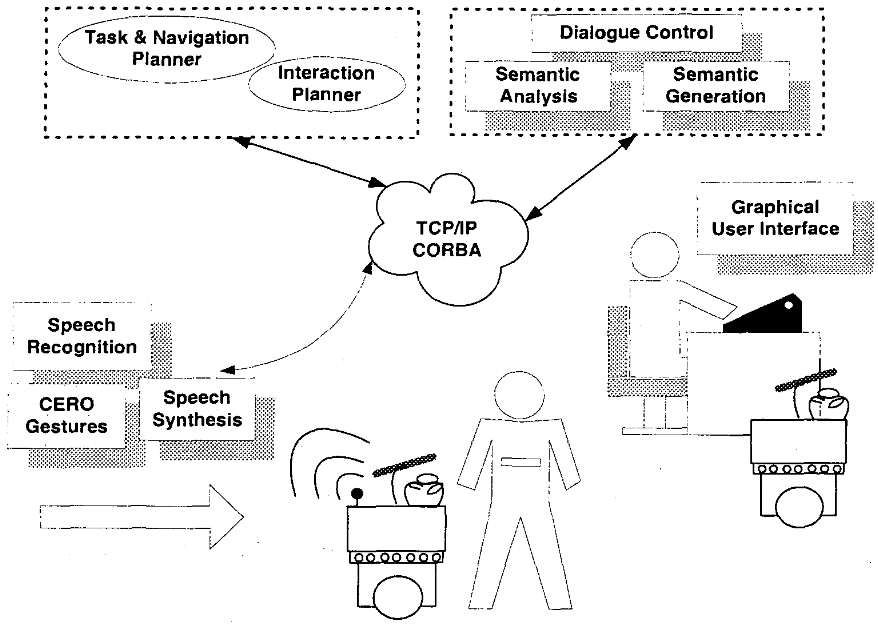

Figure 3: A conceptual view of the different system components.

of the robot have led us to the development of a life-like character, CERO (see Figure 4), which is attached to the robot, and which can contribute to express the robot's state by its movements. An animated version of this character is also used in the GUI to provide a coherent expression of the visual interface and the robot system as a whole.

7 Design of the Graphical User Interface

The design of the graphical interface (see Figure 2) was guided by the principle of simplicity, in order for a non-expert to be able to operate the robot after only a short introduction. This required an absolute minimum of necessary functions, and clear feedback to the user of the robot actions. To guide the design by involving users during the development of the prototype, we conducted a "thinking aloud" walkthrough session of an early version of the Graphical User Interface. We later applied known heuristics [11] and accepted Interface Design Guidelines, e.g. [12], to come up with a highly intuitive and usable interface.

The present version of the interface is a standard Java application. In the upper left hand corner, a CERO-figure is animated to indicate the robot's status. Below, a clear-text field gives feedback about the mission status, followed by an emergency switch in the form of a "STOP"-button. The content-screen to the right is divided into two major areas. On top is the dynamically updated map of the environment in which the robot can move, where the known places to visit are marked by red circles. Below the map, two basic types of missions can be activated, either a "GoTo"-mission or a "Delivery"-mission. The desired option is executed by selecting fields in a drop-down menu and clicking on the "Go"-button. The user can then monitor the robot's movement in the graphical map of the environment.

We chose the concept of issuing commands in an imperative, sentence-like structure with buttons and drop-down selection elements (e.g. "Deliver the book to Mary's office"). The reason is that we wanted the design features of the speech interface and the GUI to be consistent with respect to each other. We also wanted to support the user by providing some words and phrases that can be used when commanding the robot using the spoken language interface.

Feedback on system status in the GUI is given by the image of the CERO character in the upper left corner, which displays a series of animations to inform the user about robot status, e.g. "attention", "busy on a mission", "free". The image of CERO in the interface and the actual CERO character on top of the robot are to be seen as two parallel ways of providing status information.

8 Design of the Natural Language Interface

In the sense we use natural language dialogue the term is taken to cover more than just the issuing of spoken commands which are directly interpreted and executed by the system. In human-to-human dialogue the participants are engaged in a joint co-operative behavior to achieve a common goal [13] [14]. In this process grounding is an important way of establishing successful communication [15] [16].

Using dialogues based upon likely scenarios in the design process is important for the development of the natural language interface. The example dialogue (Table 1) is based on a general fetch and deliver scenario in which the robot should get some object for the user. The robot acknowledges the user's request by reformulating it as a question. This in turn is accepted by the user which has the effect that the robot actually performs the mission. The gestures of the CERO character (see Section 9 below) provide simultaneous feedback of the robot's status.

user:	*robot, get coffee in the kitchen!*
robot:	*get coffee in the kitchen?*
CERO:	⟨*displays gesture attention*⟩
user:	*Yes, please*
robot:	Going to get coffee in the kitchen

Table 1: A sample dialogue with the system and the CERO interface doll.

The system tries to map verbs to semantic predicates that aggregate the planning component of the whole system. At the level of the language interface, a consistency check assures that only fully specified planning constructs are sent to the planner. The process of building up a sufficiently specified predicate is the force that drives the dialogue once it has been initiated (either by the user or by the system). Apart from assisting the user for building up the planner instructions, the robot also needs to approach users and draw their attention. One challenge for any system that tries to approach the user is to detect if there are any users present. At present we have no way of doing this using the current sensors of the system. Instead we rely on the co-operation from other users to assist the primary user in supplying desired objects or information to the robot.

9 The CERO character

As already mentioned, we are exploring ways of providing non-intrusive visual feedback by means of a life-like character, CERO[1] (Figure 4). The movements (see Table 2) of the CERO character are designed to be integrated with the speech system so that it is both capable of issuing conversational gestures (e.g. raise or lower its head) reactively, based on system states, and co-expressive conventional gestures (e.g. emblems: nod or shake its head, call for user attention). An example of this is showed in Table 1 (above).

[1] Co-operative Embodied Robot Operator, pronounced [sero]

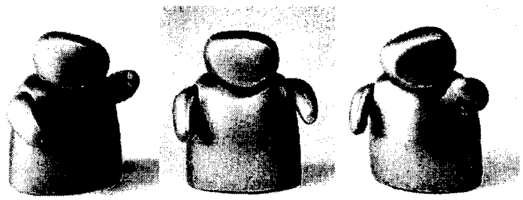

Figure 4: The CERO character from three different angels

Physical design and photo by Erik Espmark.

System state	CERO action
On	Body still
Audio signal received	Attention (head raised)
Parsing	Small head nods
Completed	Nod head
Parse failed	Shake head

Table 2: The system states triggering actions of the CERO character.

10 Conclusion

Above, we have tried to describe the difficult process of integrating user requirements and experiences into the design of a human-robot interface. It is clear that the design must take explicit account of the user's everyday work situation and tasks. But also, the technology available in terms of robot platforms, sensors and processing power constrains the behaviors of the robot and provides necessary input in the iterative design process.

The work in this project is still ongoing, and we have yet to perform an evaluation of the complete system. A particularly challenging issue for robot design, emerging from our studies, is the need for clear and explicit feedback to the user, both in terms of system states and grounding of user requests. In our continued studies we will explore further how human-robot interaction research can take the multimodality and richness of human communication into account, to cater for this needs on the part of users.

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