Context-Aware Mobile Robots: Part of Smart Environment

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ABSTRACT

We propose context-aware mobile systems for managing and using services on the behalf of the user. Context-aware mobile systems perceive environmental signals, infer the context (i.e. the state of the system and its local environment) from these signals, and calculate appropriate actions for the detected context. In its simplest form, such a system can be a mobile telephone adjusting its profile based on the noise level and brightness of the environment. A personal robot equipped with a vision system and a manipulator is a more complex example of a context-aware mobile system.

Context-aware mobile systems both manage the available services and use them on behalf of the user or guide the user in using them. A portable system offers a single interface for a variety of services. The role of a personal robot is to enhance some services so as to make them more suitable to the user. Both portable and robotic systems are controlled by a system capable of recognizing the user's context and reasoning out actions that would optimally serve the user in the situation at hand.

In this paper, we will present our software architecture for context-aware service management and utilization, our approach for controlling personal robots, and our work on virtual and natural interfaces for interacting with a personal robot.

Keywords: Ubiquitous computing, personal robot, human machine interface, control system.

1. INTRODUCTION

Nowadays people can be connected to the information network practically anytime and anywhere. This leads to an oversupply of information – too much information and too many diverse sources are competing for people's attention. We claim that this is only the first symptom of a more severe phenomenon – an oversupply of resources. In addition to information, users will soon face increasing numbers of sensors, computing units and various controllable devices ranging from motorized doors to mobile robots. Telecommunication technology aims to integrate these devices into a complex network providing a vast number of services to the user.

Such a vast number of available services challenges the user and raises several questions: How is the user to remember, in a given situation, that there is a resource that could help her in that situation? Or if the user remembers the resource, how is she going to locate it? And even if she finds it, how can she remember how to use it? Or, she may even remember all the necessary details but the service might simply be too difficult to use. A further problem is that the service might require more resources from the user than she has or can afford in the situation at hand. An artistic scenario of an instance of resource overload is shown in Figure 1.

For example, a rapidly increasing number of services based on positioning are available. The responsibility for remembering the particular service useful at some location should not be left to the user. As another example, the user might remember everything she read from a video recorder's manual, but the task of setting the timer might still be too difficult. Finally, an elderly person with decreased functional capacity might otherwise be able to stay in her home, but she might need some assistance in her daily routines.

We propose context-aware mobile systems for managing and using services on behalf of the user (or guiding the user in using them). Context-aware mobile systems perceive environmental signals, infer the context (i.e. the state of the system and its local environment) from these signals, and calculate actions appropriate in the detected context. In its simplest form, such a system can be a mobile telephone adjusting its profile based on the noise level and brightness of the environment. A service robot equipped with a vision system and a manipulator is a more complex example of a context-aware mobile system. These systems transform the environment with all the devices and services into a smart environment serving the user on the basis of her needs and hiding the details irrelevant to the user in the context.

Fig. 1. Oversupply of resources and services will soon be reality.

In the above example, a portable context-aware terminal automatically offers for the user the service she needs in her current situation. The system takes the location, the user's task, and other contextual information into account when reasoning out a suitable service. Furthermore, the user can set the video recorder's timer through a user-friendly interface presented on the user's portable terminal – and then let the system take care of the details. The terminal offers a single interface for all available services. Finally, a personal robot helps an elderly person in her daily routines. The role of the robot is to enhance some services so as to make them more suitable to the user. In this example, the robot helps a user whose functional capability has deteriorated. In an office, the robot might perform tasks on the behalf of a busy worker.

In the next chapter, we present our solution for context-aware service management and utilization. Here, our work focuses on context recognition and a distributed architecture supporting context recognition and utilization. The third chapter discusses our approach for interacting with and controlling a mobile robot. We suggest intelligent teleoperation for controlling a mobile robot. In this approach, the control system takes care of low-level actions. The teleoperation approach makes it possible both to produce working prototypes (and hence applications) at an early stage and to enable the complete robotic system to be developed gradually. For interacting with personal robots (and other services), we suggest virtual and natural interfaces. We utilize mobile code to create in the user's terminal a virtual user interface for a service. Our system for tracking human skin serves as the basis for interacting with the robot using gestures and expressions. The fifth chapter describes some application scenarios, and the last chapter contains the conclusions.

2. CONTEXT-AWARE SERVICE MANAGEMENT AND UTILIZATION

We are developing a software architecture for managing and using services on behalf of the user. This Genie of the Net architecture collects information from sensors and databases, recognizes context based on this information, chooses relevant actions to serve the user on the basis of the recognized context, and performs the chosen actions. In its operation, Genie also utilizes other components of the smart environment [1].

The Genie of the Net architecture is presented in Fig. 2. The Sensor Agent collects and preprocesses data from sensors. The Context Agent recognizes the user's context from this data and other available information. The Information Agent offers information for the other agents and stores the sensor data and a description of the recognized context for later use. The Active User Agent exploits the recognized context in choosing actions serving the user. The agent can, for example, request the User Interface Agent to present information to the user. In addition to scanning the context, the User Agent bases its reasoning on a user model containing different kinds of information about the user: name and other basic data, access rights, habits, plans, etc. Furthermore, the User Agent cooperates with the other agents. Personal robots inhabit the environment and are controlled by the Genie system through the information network. Our aim is that robots and humans might co-operate and, in the future, even make up teams. In Figure 3, other agents include personal robots.

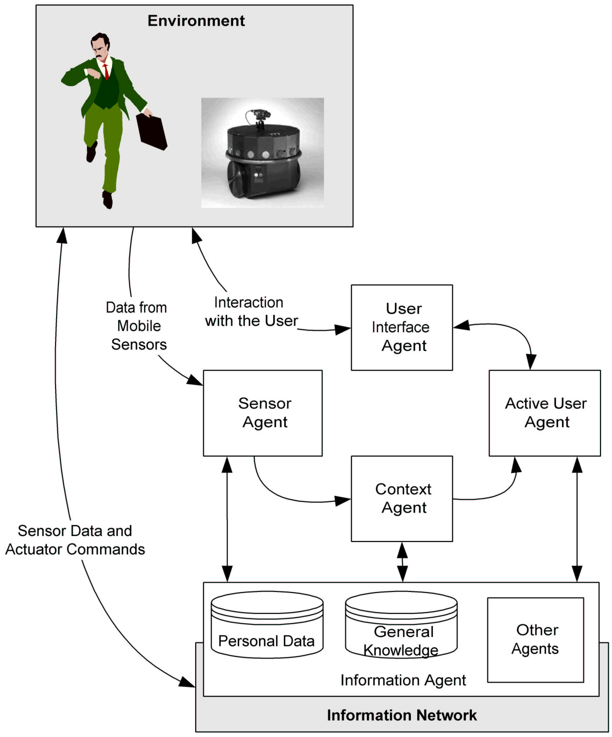

Fig. 2. An agent-based architecture for context-aware service management.

These personal robots are capable of operating in our daily environment and co-operating with humans and other robots. To implement a robot of this kind, new skills must be developed for the robot. Its control system must be able to cope with several objects and possibly other mobile agents parallel to operating in its premises. It should have a rich and dynamic description of the environment and therefore requires powerful sensors. Natural interaction with human beings is also necessary.

These robots are an essential part of the smart environment. The way they behave and operate will be strongly related to the information network available. Figure 2 has been drawn from the human agent's point of view. A similar description could also be given starting from the robot's requirements and possibilities. The robot can use the information network to accomplish its tasks. For example, co-operative action can be done more precisely by utilizing another robot's sensor.

The location of the devices, sensors and their processing units may vary. Many tasks can be performed by technologies embedded in the environment. A robot can be used to search a missing person, or the same task can be assigned to cameras placed in the environment. A robot can turn off a device, but the device can also be connected to an automatic network. Furthermore, a door may be opened by a robot, or a motorized door can be used. Devices simpler than a robot are sufficient for many tasks, provided they have the capability to communicate and can thus be reached via a network. Even a wheeled walker (walking aid) equipped with a GPS and a communicator could be such a device. Furthermore, other context-aware mobile systems (e.g. wearable systems) resemble mobile robots and operate in the same environment.

3. INTERACTING WITH A PERSONAL ROBOT

To develop a mobile robot capable of executing complex tasks in a dynamic environment, we selected the approach of first building a teleoperated robot and then gradually shifting tasks from the human to the robot. This approach enables complex tasks to be performed as soon as teleoperation is operational. This speeds up the research on human-robot interaction, as complex interactions can be analyzed at an early stage of research. Furthermore, in many applications, human operators can be left in the control loop to analyze the data collected by the robot or to solve the tasks too difficult for the robot. This means that the robot is more like an assistant co-operating with the user than an autonomously operating device.

From the opposite perspective, the robot is a resource helping the user in using the services she needs in her activities. The robot enhances the user's resources – or may even enable some services the user is unable to do by herself. The user can control the robot through a virtual interface – a user interface integrated in the user's portable terminal. Users, portable terminals, and personal robots are located in the smart environment. Both robots and portable terminals are connected to the information network in a wireless fashion. The system managing services on behalf of the user uses these devices in addition to all the other devices and information sources.

Providing for the user a single interface to all (or, at least, most) available services is essential in managing the service overflow. For this purpose, we have developed a technique based on a mobile code paradigm, which allows humans to use a single control device to interact with robots and other ubiquitous embedded systems [2,3]. To realize a view for teleoperation, virtual reality glasses with a mapped view of a hemispherical image can be used [4,5]. A hemispherical camera system with virtual reality glasses seems to provide a natural way of viewing. A remote monitoring application of this kinds is well compatible with mobile systems due to its real-life characteristics. Although providing sufficient video image rates through wireless channels requires more work and the quality of the image provided by omni-directional cameras is not adequate for all applications, preliminary systems can be created with the existing technology.

The role of a control system is important even when the robot's operation is partly controlled by humans. The mobile robot should have a reactive control system to regulate its operation. This means that a context-aware control system is required. It should also have a goal-oriented part to be able to do some tasks autonomously. The reactive part of the control system makes teleoperation intelligent in the sense that it can overrule human commands that would cause the robot to collide. The challenge for the goal-oriented part is that, in order to be useful in practice, a personal robot should be capable of learning.

The following sections describe our work on virtual and natural interfaces. The last section presents our approach for intelligent teleoperation.

3.1 VIRTUAL USER INTERFACE

In the future, interaction between humans and personal robots will become increasingly important, as robots will, more and more, operate as assistants that help us in our everyday life. Because of this, there will be a need for convenient, flexible, and general-purpose interaction techniques to be used between robots and humans. In addition, these same techniques should also be used to interact with other ubiquitous embedded systems in smart environments. In the following paragraphs we will introduce a technique utilizing mobile code and mobile augmented reality to create a virtual user interface for mobile robots. The main sensor has vision realized by an omnidirectional camera.

We use a handheld control device to control various embedded systems that are located in our environment. We assume that a personal mobile robot is just another embedded system. The device contains processor, memory, and display capacities that are comparable to, or even exceed, those in the current laptop computers. It communicates with embedded systems by using a high-speed wireless communication link that has a very limited range, perhaps only up to 10-20 meters. The control device also contains a temporal Internet connection.

When the user wants to interact with an embedded system, the control device first downloads, by using a mobile code protocol and a local link, a mobile code from the selected system. Once executed in a corresponding execution environment, this code creates a virtual user interface (VUI) for the system. During its execution, the code uses the services provided by the control device to communicate with the corresponding embedded system. This communication can utilize any internal protocol available between the VUI and the embedded system. Figure 3 shows how mobile code can be used to create a virtual user interface with an embedded system, in this case a mobile robot. The resulting user interface is also shown in Figure 3.

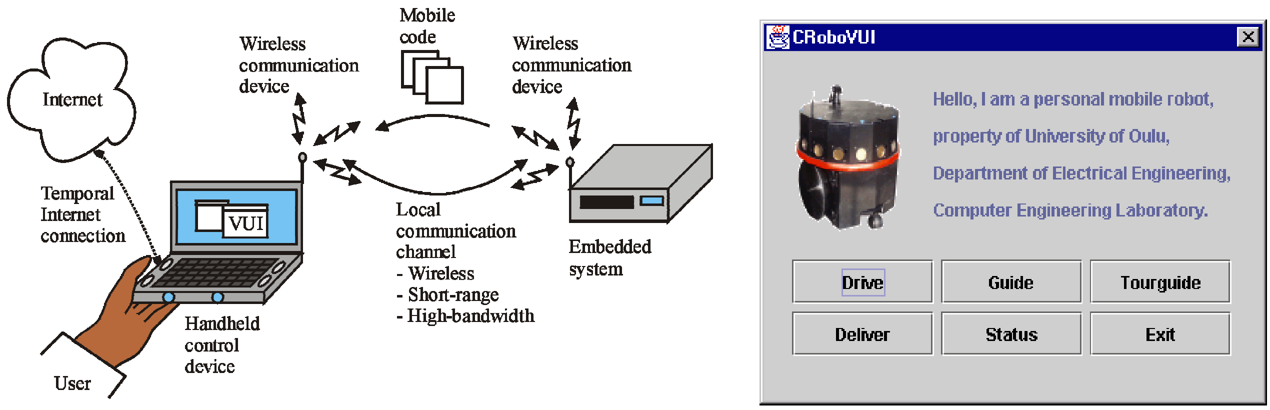

Fig. 3. Mobile code is used to create a virtual user interface between a client and an embedded system.

Mobile augmented reality can be utilized as a user interface to the environment, as it enhances the user's perception of the situation compared to other interfacing methods and allows the user to perform other tasks while controlling the intelligent robot. Augmented reality is a method that combines virtual objects into the user's perception of the real world.

The robot can send an omnidirectional view of its surroundings and sensor data to a remote site. The motions of the user's head are tracked and the projection of the omnidirectional image is then calculated and displayed to the user. A scenario of the teleoperation of a robot is shown in Figure 4.

AR-based teleoperation of an intelligent robot allows the user to operate the robot from anywhere. The robot uses its sensors to monitor its surroundings, and images of the environment are transmitted in a video stream. By using omnidirectional cameras, the person operating the robot can survey the environment in the same way as she could if she were on the spot where the camera is mounted. The data from the sensors as well as other information from the robot are augmented in the Head Mounted Display (HMD) of the user, being easily readable all the time.

The omnidirectional camera on top of the robot digitizes the panoramic view (360°, a hemisphere) into a single video stream, which is processed by the computer of the robot and transmitted to the user via the WLAN connection. The person using our wearable computer to control the robot can see what is happening around the robot by simply looking at different directions. The position of the user's head is tracked and the correct projection from the video stream transmitted by the omnicam is calculated based on that information. The resolution of the projection depends largely on the resolution of the camera used to digitize the image. Because the resolution of each projection is only approximately 10 % of the resolution of the original image, a low-quality camera will lead to inadequate control.

The use of augmented vision equipment requires several components to work smoothly. The glasses are worn like spectacles, and the image is projected onto the glass screens. By turning one's head in the desired direction, the user can see the corresponding remote image. This requires the head-mounted display and the remote video image to be carefully oriented to time and place. This is accomplished by providing reference points from the mapped image to the display unit. By tracking the orientation of the user's head, the reference points can be used as pointers to specific areas of the image. As the image is provided by an omni-directional camera, rotational latency is minimal.

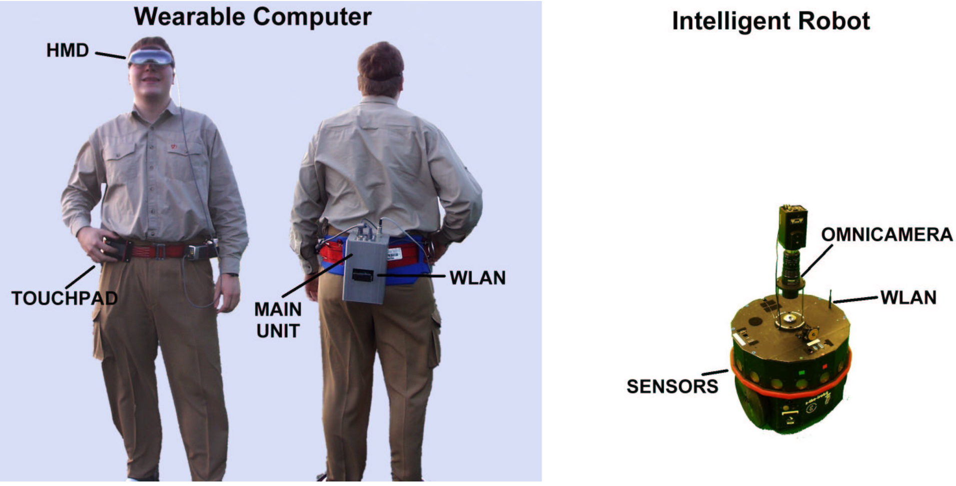

Fig. 4. Teleoperation of an intelligent robot via an AR-enhanced mobile terminal.

3.2 NATURAL INTERFACE

The first requirement for a personal robot to communicate naturally with humans is to understand our natural way to act. That means, for example, that a robot can follow what a human being is doing and also recognize the human. Our approach is based on vision. As a first step, we are developing visual tracking of multiple objects. We are especially interested in methods capable of detecting people and objects handled by them. Our approach is based on colours, since people can be located efficiently from colour images on the basis of skin colour and objects handled by humans can be located by colour-based segmentation methods.

We have developed a general architectural solution for concurrent real-time colour-based tracking of multiple objects, Cocoa [6]. The architecture is based on markers and colour judges. Markers are a situated representation of the robot's environment. A marker maintains information about an object (or several similar objects) in the environment. In our architecture, markers are components of the architecture acting as an interface between the image processing and control systems. The control system assigns tasks to the image processing system via markers. Colour judges are components of the image processing architecture, which differentiate colour-based segmentation methods from the process of labelling images. In this way, different segmentation methods can be used dynamically and the switching between them can be done based on context awareness.

In the implemented system, markers track multiple faces and hands in real time (40-60Hz for 176*132 images and 22-25Hz for 320*240 image) when the system is run on a PC (Pentium 200 Pro processor) [6].

3.3 INTELLIGENT TELEOPERATION

The problem with traditional teleoperation is that it depends too heavily on the user's skill. By intelligent teleoperation, we mean that the reactive controlling system is part of it. The intelligent component takes over if the user is likely to make a mistake, such as cause the robot to collide with an object. We let the user overrule the control architecture, but she must do it purposefully.

We have developed a control architecture for a mobile robot operating in a dynamic environment. The early version of the control system, PEMM, was applied to control an intelligent and skilled paper roll manipulator [7,8]. The research resulted in a practical implementation of a full-size paper roll manipulator capable of handling paper rolls in warehouses and harbors. A key characteristic of the more recent version of the control architecture, Samba, is its capability to both reason out actions based on task constraints and to react quickly to unexpected events in the environment [9,10]. In other words, the architecture is goal-oriented and context-aware.

Samba produces continuously reactions to all the important objects in the environment. The reactions are represented as action maps. An action map describes, for each possible action, how preferable that action is from the perspective of reacting to the object in a certain way (e.g. avoiding or chasing). The preferences are show by assigning a weight to each action. By combining action maps, an action producing a satisfactory reaction to several objects simultaneously can be found. Figure 6 shows two robots and an action map enabling the robot closer to the viewer to catch the ball. The ridge represents the actions by which the robot reaches the ball. Actions resulting in a collision with the other robot before the ball is reached are inhibited.

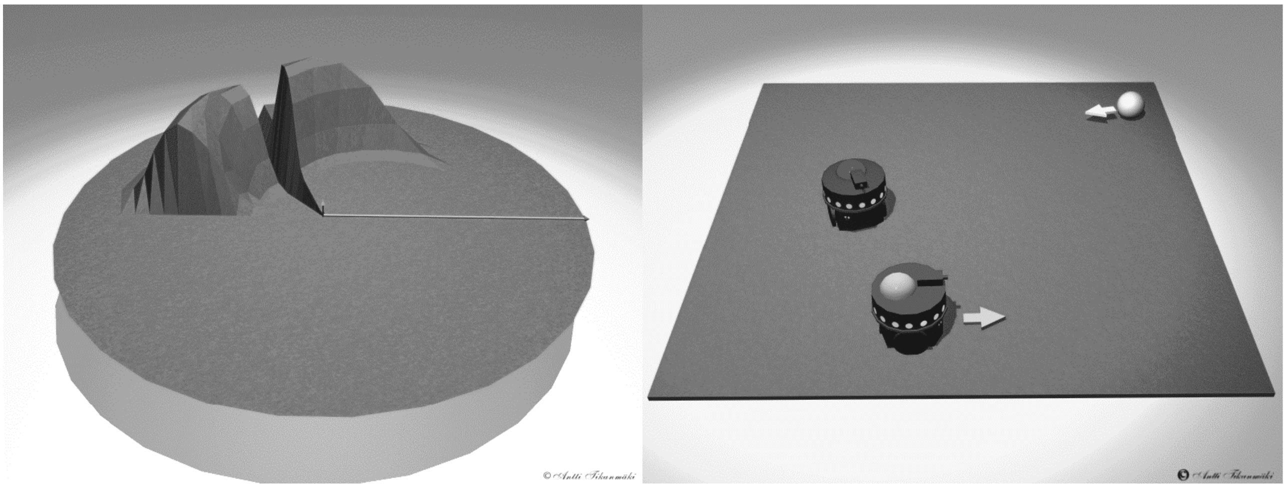

Fig. 6. An action map and two robots catching the ball.

We have applied the control architecture to playing simulated soccer. Our group participated the first world championships of robotic soccer, RoboCup, held in Nagoya in 1997 and the second championship games held in Paris in 1998 [11,12]. We have also demonstrated the use of intelligent teleoperation in guiding a mobile robot for domestic help.

4. CASE EXAMPLES

We are applying a mobile robot to support independent living by the elderly and disabled. We call this user-centered approach for developing robotic aids for the elderly “gerobotics” [13]. A personal robot could be part of an intelligent home assistant supporting communication and social life of the elderly. It can also be used as a technical helper providing a remote eye or an intelligent moving aid. The motivation for this research stems from the aging of the population of Finland. It has been predicted that the number of elderly people (over 65 years) will grow from 0.743 million (14.5%) to 1.36 million (26%) in 1996-2030. Furthermore, the ratio of working-aged to elderly people will decrease from 5.2 to 2.5. Thus, it is clear that even the maintenance of the current quality of life of the elderly will require much more efficient utilization of resources. This trend of aging population is not unique to Finland but common to all industrialized countries.

4.1 INTELLIGENT HOME ASSISTANTS AND REMOTE EYE OF THE AGED

In the multimedia Home Aid Communication System (mmHACS) project, the main objective is to create new product and service concepts for the home environment and service providers and also to develop a complete system that includes social, health care and other services for aged end-users. With the new services and products, the project aims to improve their ability to live independently and safely in their own homes.

The core of the mmHACS system consists of a telecommunication network, servers of the service providers and various easy-to-operate fixed or mobile terminals. The videotelephone set comprises the basic PC technology with a touchscreen User Interface (UI) and a codec card providing a rapid video and voice connection via, for instance, ISDN or ADSL. The mobile GSM terminals are tools for the people taking care of home-dwelling clients (nurses, doctors, cleaners, etc). So far, two prototypes have been developed, SMS-based and WAP-based software.

A communication system including the fixed and mobile terminals has been demonstrated. An easy-to-use interface has been developed for a multimedia terminal consisting of a PC, a touch screen, and video telephony equipment. The user interface was designed based on the needs of the elderly. Nearly ten such terminals have been installed in the Oulu region and connected by a fast network. This communication system has been tested extensively together with potential users [14].

The use of a mobile robot for domestic help also has been studied. A preliminary study of the acceptance of robots was done by user interviews. They revealed that the elderly seem to have a positive attitude towards all robotic aids that they believe will support them in their independent coping [15]. As a first step to utilize a context-aware robot, a teleoperated robot was used as a remote eye for the elderly and the care providers.

In the usability studies, a Nomad Super Scout was controlled remotely via Internet. The user interface was implemented as a Web page. The user observed real-time video captured by the robot's camera and sent motion commands back to the robot (Figure 7). The setup of the experiments was arranged so that the robot was running in our laboratory but the users (mainly nurses) were located elsewhere. The system was found intuitive and easy to use. The next step is to continue the usability studies at a local residential home.

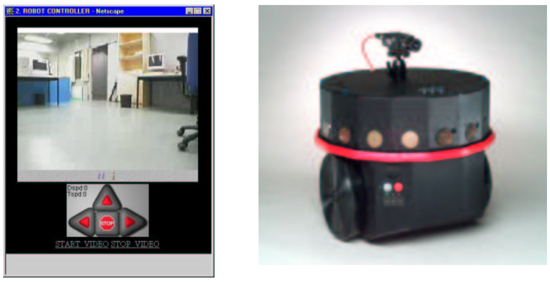

Fig. 7. A web page user interface and a teleoperated robot.

4. CONCLUSIONS

In the future, interaction between humans and mobile robots and other devices in smart environments will become increasingly important, as these devices will operate as assistants in our everyday life. Because of this, there is a need for a general-purpose technique that we can use to interact with robots and other embedded systems in smart environments.

In this paper, we proposed context-aware mobile systems for supporting the user to manage and use the services and resources that will be around us. The Genie of the Net architecture can ultimately be thought of as an ever-expanding system providing helpful information and guidance when our own capabilities are exceeded. It is also a technique to handle several individual robots so that they can co-operate with each other and human beings. The interaction with robots and other appliances in the environment should be made as natural as possible for the human being. Vision is good and powerful sense to be used.

In developing a mobile robot capable of executing complex tasks in a dynamic environment, we selected the approach of first building a teleoperated robot and then gradually shifting tasks from the human to the robot. This approach enables complex tasks to be performed as soon as teleoperation is operational.

A user-centred research approach is being applied in our work on context-aware personal robots. The needs of the users will be further investigated in user studies and prototypes tested in usability studies. The aging of the population motivates strongly our choice of application. A personal robot or even a simpler mobility aid with some robot-like capabilities would increase the functional capacity of the aged and possibly even improve their state of health. The aged could hence avoid institutional care and manage to go on living at home.

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