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Human Robot Interaction: Application to Smart Wheelchairs

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Abstract

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Keywords

handicapped aids, intelligent control, mobile robots, motion control, user interfaces, assistive devices, control algorithms, human robot interaction, sensors suite, smart wheelchairs, software architecture, vision-based human interaction interface

Comments

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Human Robot Interaction: Application to Smart Wheelchairs

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Abstract

This paper addresses the problem of human robot interaction with application to the design of assistive devices. We describe the design and development of a prototype of a smart wheelchair that can be commanded by a rider. Specifically, we focus on (a) the vision-based human interaction interface; (b) the suite of sensors on the chair; and (c) the software architecture and the control algorithms used to control the chair.

1 Introduction

There are numerous examples of partially autonomous systems that are controlled at some level by a human operator or user. Generally control at the lowest levels is autonomous while the human user is primarily responsible for decision making at the highest levels. Examples of such systems include passenger automobiles, HVAC systems in buildings, CNC machines in job shops, and security systems. An important class of systems are mobile agents with embedded computers that are directly controlled by a human pilot or navigator in the loop. This paper addresses the design of interfaces between the human user and the computer-controlled system. The performance of such human-in-the-loop systems is very sensitive to the persons ability to interact with the embedded computer and sensors [6].

Our main focus in this article is on smart wheelchairs (Figure 1), devices that can potentially benefit over 15 million individuals in the U.S. alone. Current systems have very little computer control, except at the lowest levels of motor control. Interfaces are similar to those found in passenger cars. The rider has to continuously specify the direction, and in some cases, the velocity of the chair using a joystick like device. In cases where the level of neuromuscular control is poor, joysticks are used to specify directions while the choice of speed is limited to either zero or a safe constant value.

There is extensive research on computer-controlled chairs where sensors and intelligent control algorithms have been used to minimize the level of human intervention ([4],[5],[7],[9]). Many efforts have used sensors and low-level controllers to guarantee safety by monitoring human commands that may cause chairs to approach risky states. Attempts to build autonomous chairs have faced many challenges, most of which stem from the lack of robustness of motion planning, perception, and control algorithms [3].

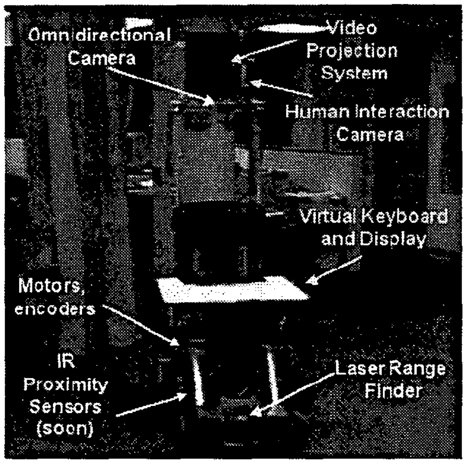

Figure 1: A view of the system showing the different components- the projector, the cameras, the motors and the laser.

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Our research goal is to design and develop a system that allows the user to robustly interact with the robot at different levels of the control and sensing hierarchy. At the lowest level, the user can drive the chair through a conventional joystick-like interfaces. At a higher level, the user can select from a range of behaviors such as hallway navigation, or moving forward while avoiding obstacles. At an even higher level, the user should be able to specify goal positions while the system automatically selects behaviors and plans paths to guide the chair to the goal. In intelligent buildings, where maps are available through wireless networks, the user should be able to specify destinations on the map and the chair should be able to navigate to that location.

Our smart wheelchair consists of a *vision-based human robot interface*, a suite of sensors, and a set of intelligent control algorithms that allow for *computer-mediated motion control*. The bulk of the paper addresses the interface, the control algorithms, and the design of the prototype.

The paper is organized as follows: We first discuss our prototype of the *SmartChair* in Section 2. The next section, Section 3 presents the vision-based human robot interface, while Section 4 discusses the computer-mediated motion control algorithms. Section 5 describes the performance of the system under different conditions . Some future directions for research and development are presented in (Section 6).

2 The *SmartChair* System

Figure 1 is a view of the system showing some of the components, including a video projector, two cameras, a laptop tray and a laser rangefinder. The main components of augmentative software and hardware system are shown in Figure 2.

A standard PC mounted on the chair handles all of the required processing. The motion control system consists of a 2 axis controller driving two 150W Maxon servomotors. These are coupled to the rear wheels via a 15:1 planetary gear head and a 7:1 belt drive. A digital encoder on each motor provides the feedback in the control loop. The power for the motors is currently obtained from two PWM brush type servo amplifiers.

3 Interfaces for Human Robot Interaction

User input on the *SmartChair* is accomplished by projecting an image of the interface onto the laptray which is monitored by an overhead video camera. Figure 3 shows a view of this interface as seen from the perspective of the user. By analyzing the images acquired from the video camera, the system is able to determine what the user is pointing to on the interface and to respond appropriately. Effectively, the projector and camera systems acting in concert form a feedback system where user interaction is effected by occluding various parts of the projected image.

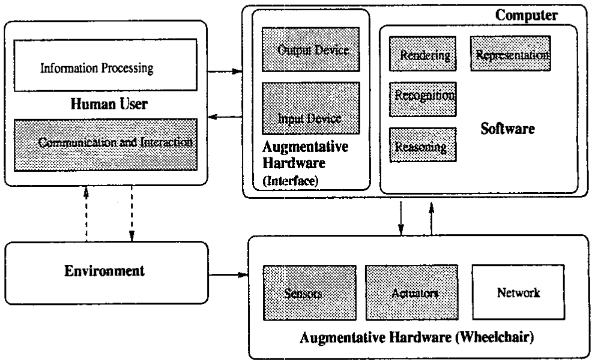

Figure 2: The main components and the architecture for the proposed interfaces. Shaded boxes show hardware and software components of interest, while solid arrows show information flow of interest.

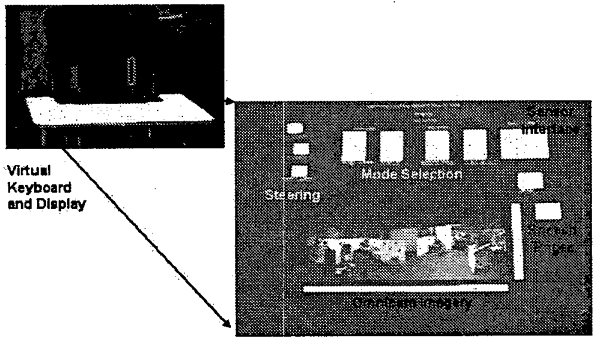

Figure 3: A view of the interface as seen by the user.

The scheme hinges on the observation that the relationship between the three surfaces of interest, the work surface, the virtual interface and the image obtained by the camera, can be characterized by projective transformations of $\mathbb{RP}^2$ (Figure 4). By definition the coordinates of a point in the frame buffer, (x_f, y_f), and the coordinates of its image on the screen, (x_s, y_s), are related by a projective transformation. This relationship can be expressed algebraically as follows: $(x_s \ \ y_s \ \ 1)^T \propto H_{sf}(x_f \ \ y_f \ \ 1)^T$ where $H_{sf} \in GL(3)$. Similarly, another projective transformation relates the positions of points on the screen to the coordinates of their projections on the video image, (x_i, y_i). We can, therefore, conclude that the relationship between points in the frame buffer and their correspondents in the image buffer can be expressed as follows: $(\ x_i \ \ y_i \ \ 1\ )^T \propto H_{if}(\ x_f \ \ y_f \ \ 1\ )^T$ where $H_{if} \propto H_{is}H_{sf}$.

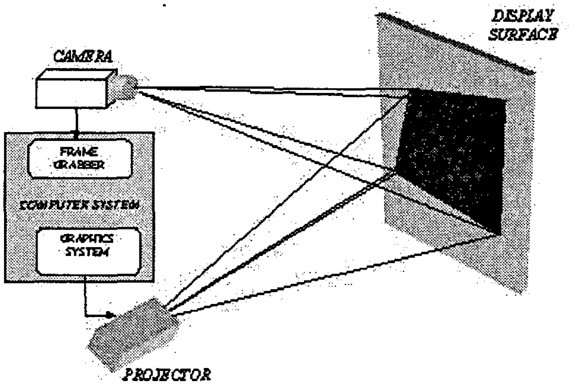

Figure 4: The transformation of points from the world frame to the camera frame.

It is well known that a projective transformation is completely specified if its operation on a set of points which constitute a projective basis for the relevant projective space (in this case the real projective plane $\mathbb{RP}^2$) is known. This suggests a straightforward calibration scheme for determining the mapping between the frame and image buffers. Simply choose four distinguished points in the frame buffer such that no three are colinear, and then locate their correspondents in the image buffer. The projective transformation H_{if} can then be computed from these four point correspondences in a straightforward manner using standard techniques ([2], [8]).

The basic advantage of this vision based interaction technique is that it does not involve mechanical input devices such as keyboards, mice and touch screens. There are no moving parts and no wires to connect to the interface surface. By avoiding a physical instantiation of the interface we gain a level of abstraction which can be exploited in a number of ways. Firstly the system designer is allowed to specify the layout and action of the user interface entirely in software without being constrained by a fixed mechanical interface. This flexibility can be used to customize interfaces to the requirements and capabilities of individual users. Secondly the interface can be switched off when not in use, freeing the laptray for other uses.

4 Computer-Mediated Motion Control Interface

4.1 Architecture and Design

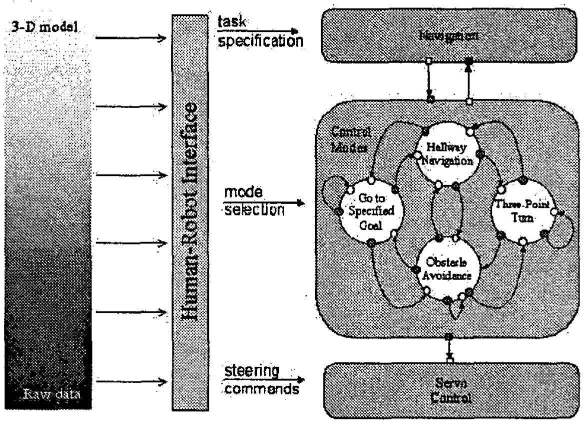

Figure 5: The Computer-Mediated Control Architecture for the System

Figure 5 shows the architecture of the computer mediated motion control system. The system is organized into a three level hierarchy and the user interface allows the occupant to interact with the sensors and actuators at various levels. The lowest level of interaction corresponds to direct control of the servo motors and direct access to the sensor data. The second level corresponds to a set of control behaviors that the user can invoke selectively while the highest level of the hierarchy, the navigation level, corresponds to sequences of operations that ultimately guide the chair to a desired location.

Figure 6 shows the user interacting with a joystick like interface that allows for direct control of the wheelchairs motion. The system determines the extent to which the user is occluding various regions of the display and sets the wheel velocities accordingly. This provides smooth, continuous control of the motion of the chair. The interface also presents the imagery obtained from the omnidirectional camera and the measurements provided by the laser range finder on the display. This provides the user with an enhanced awareness of obstacles and features all around the chair. The presence of a conspicuous **SHUT OFF** button on the interface gives the user an opportunity to override all other functions and shut off the system in any emergency.

At a higher level, the user can choose one of many con-

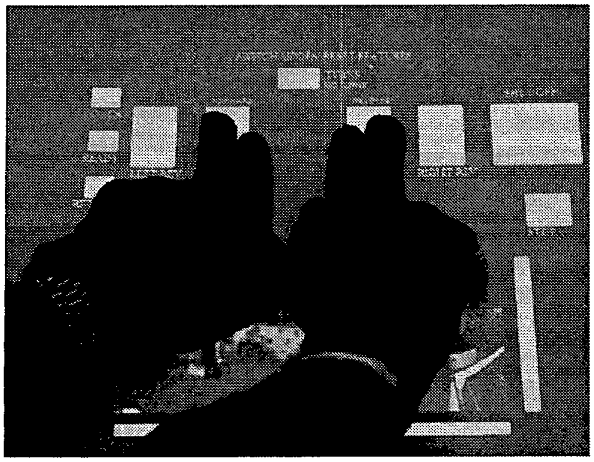

Figure 6: A user interacting with the virtual interface during manual steering

trol modes or behaviors (Figure 5). Modes are closely-coupled perception-action loops with associated controllers and estimators. The control modes or behaviors that we have implemented on our *SmartChair* include:

1. Go to relative postion and orientation;
2. Go forward while avoiding obstacles;
3. Three-point turn (backing up and turning to avoid an obstacle in the front);
4. Go down the hallway following wall(s);
5. Navigate through a doorway and
6. Make turns while avoiding obstacles.

The interface allows the user to select the desired mode of operation by pointing to buttons on the interface. These modes can also be combined in natural ways, for example the system can be made to avoid obstacles in its path while following hallways or corridors by invoking the obstacle avoidance and hallway following modes simultaneously.

One convenient feature of the interface is that it allows the user to select target locations in the scene by pointing to regions in the unwarped omnidirectional image. For instance the user can specify a target for the doorway navigation algorithm by selecting two vertical lines in the image. The user can also select arbitrary destinations in the scene for the Go To mode by pointing to locations in the image. This image based human robot interaction provides a powerful, intuitive and convenient mechanism for registering the users intention with the systems sensory devices (cameras and range finders).

There is also a natural "undo" action that is reminiscent of the undo operation in human computer interfaces [1]. Sometimes a user might find himself in a corner, without enough room for the system to execute a turn. With this situation in mind, a *Retrace* mode has been added. In this mode the wheelchair returns to its starting point along the same path that it took to get to the current position. Of course, the user has the option to take over control of the system in any emergency or at any point during the retrace maneuver.

4.2 Computer Mediated Communication

The *SmartChair* also allows the occupant to communicate with others through a speech board interface. Figure 7 shows the interface that has been developed. The interface is divided into a set of pages each of which contains a collection of interactive icons that have been mapped to common phrases used in daily conversation. The occupant communicates by pointing to appropriate icons on the interface which causes the computer to generate the phrase through a speech synthesizer. It is envisioned that such an interface would be useful to persons who have impaired speech but reasonable motor control abilities.

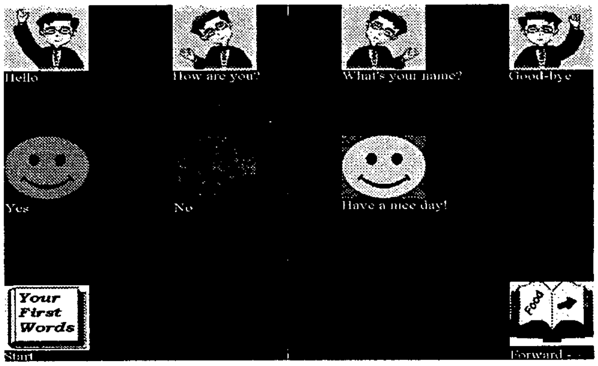

Figure 7: The speech interface displaying the different icons seen by the user

5 System Performance

Some experimental tests were conducted indoors to assess the performance of the system that has been described and built. These runs were performed with the intention of assessing (i) the controllers' performance, and (ii) the performance of the human robot interface. The performance of the system will be affected by several factors. As a benchmark, we would like to list the resolutions and accuracy of some components as follows- the odometry (± 0.05m in about 4.5m of travel), the laser range finder (resolution of 0.5^o and an accuracy of 0.05m), the omnidirectional camera ($0.1^o - 0.3^o$ for azimuth angles), the human robot interface (allows the user to choose features as close as 0.15m to each other on a plane that was 3.3m away, thereby yielding a resolution of about 3^o).

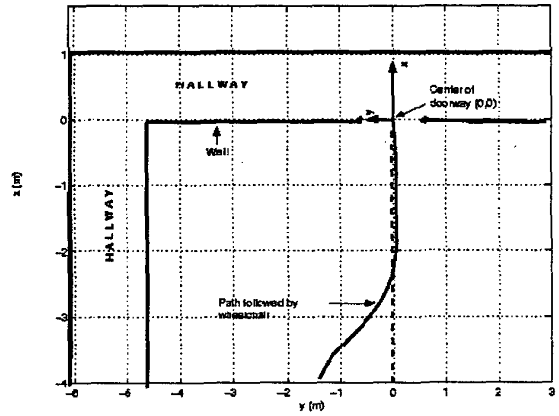

Figure 8: The trajectory followed by the wheelchair towards a desired destination

Figure 8 shows the simplest case- the virtual interface was used to choose a destination (in this case, a doorway) and the controllers then guided the wheelchair towards it. It must be noted that in this case, the objective of the controller was not to get the wheelchair to a target point, but to use the azimuth angles as obtained from the camera images and the distance feedback from the laser to guide the wheelchair through the doorway along the line $y = 0$.

Figure 9 shows the path taken by the wheelchair in the presence of obstacles in its path. As indicated in the figure, the feedback obtained from the sensors enable the controllers to guide the wheelchair along an obstacle- free path. For clarity, the straight line path joining the starting point of the wheelchair and the centre of the doorway is also shown.

Finally, Figure 10 is a scatter plot that shows how well the system performed under different starting conditions. Again, it is emphasized that the final desired destination of the wheelchair was **not** the center of the doorway. Rather, the objective was to guide the wheelchair through the doorway along the line $y = 0$. Once the wheelchair got close to the doorway along the centre line and it was evident that it would go through, it was stopped and taken to a different starting location in the vicinity.

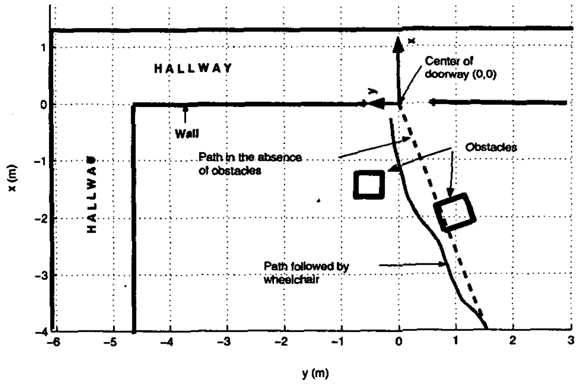

Figure 9: The trajectory followed by the wheelchair towards a desired destination in the presence of obstacles

6 Conclusions/ Future Work

We have described a smart wheelchair equipped with sensors and driven by intelligent control algorithms and a vision-based robot control interface that allows the rider to interact with and command the system at various levels of abstraction. The interface and the software can be adapted to the user and to the level of disability. We believe that the vision-based control interface and the paradigm of computer-mediated motion control are applicable to a large class of smart embedded systems and have the potential to increase the level of access to such systems. Although we are presently focusing on tasks involving control, our framework and the support tools that are developed will allow users with physical disabilities to program such devices to tailor them to their own individual needs. Also, while we will likely only be able to implement a few simple interfaces such as these in our experimental test bed, our goal will be to provide a computer software interface that is suitably extensible to the expanding technology of embedded computing and networked appliances.

Our future work is directed in two different directions. First we will integrate our system with databases that can be made availabe through a wireless network and access to the internet. The user can download maps describing buildings and streets, and the onboard sensors (cameras, laser range finders, GPS) must allow the user to designate destinations at the highest navigation level. Second, we are interested in pursuing feedback from potential users and working toward the next design with a view of developing a more practical, aesthetically appealing prototype.

We must note however that the scope of our work is limited in one sense. We address interfaces for legacy sys-

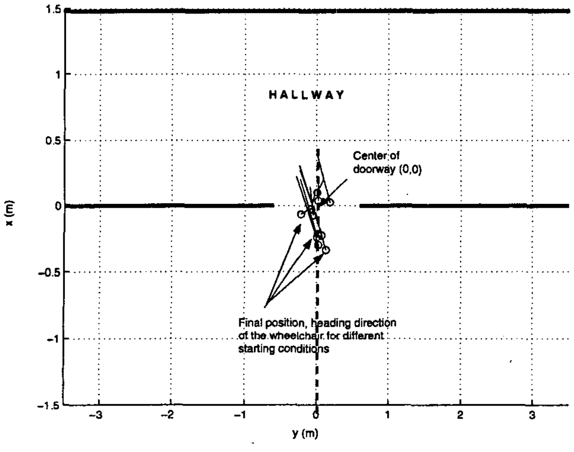

Figure 10: Final position of the wheelchair from different starting positions

tems, computer-controlled wheelchairs and typical human-made environments. Obviously if homes were redesigned to accomodate smart mobility systems and mobility systems could be designed to work in smart homes, some of these issues would be addressed very differently.

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