# Applications of virtual reality technology to wheelchair remote steering systems

Robert W. Gundersen[1], Stephen J. Smith[2], and Ben A. Abbott[3]

Center for Self-Organizing Intelligent Systems,
College of Engineering, Utah State University
UMC 4120, Logan, UT 84322-4120, USA

[1]*snowvax@cc.usu.edu*, [2]*slngp@cc.usu.edu,* [3]*abbott@sol.ece.usu.edu*

## ABSTRACT

The Center for Self-Organizing and Intelligent Systems at Utah State University has been engaged in a two year project to investigate the application of virtual reality and associated technologies as a means for assisting the disabled to steer and control motorized wheelchairs. There have already been several interesting  investigations aimed at steering virtual wheelchairs in virtual, computer generated, environments.  This paper, however, reports on how this technology may be used to assist, or even completely take over, the task of steering and navigating a real wheel chair in real environments.  The basic objective is to arrive at affordable and effective systems that can be used to improve the independence and quality of life of the disabled.

**Keywords**: wheelchair control, path planning, fuzzy logic, ultrasonic sonar, obstacle avoidance

## 1.  INTRODUCTION

There has recently been an encouraging increase in attention directed toward uses of virtual reality (VR) technology for applications other than commercial video-games and similar forms of self-entertainment.  Among  the more promising are applications to the fields of medical technology, architectural design, telecommunications and, significantly, products and services designed to help and improve the quality of life for the severely disabled.  As examples of the latter, researchers for several organizations have  successfully demonstrated the use of VR as a tool for training new users to safely and efficiently operate  wheelchairs (for example, Inman et al., 1994) while others have focused on the application of VR as a unique opportunity for architectural designers to experience first hand the problems and difficulties facing the disabled in poorly designed homes and other buildings (Swan et al., 1994).

The Center for Self-Organizing and Intelligent Systems (CSOIS) at Utah State University has been involved since the Spring of 1994 in a project designed to enhance the wheelchair mobility of the severely disabled and the aged. Prior to that time, CSOIS had been actively involved with NASA and other international space agencies, working to develop telepresence and fully autonomous intelligent micro-robotic vehicle navigation and control systems for planned Mars exploration missions (McJunkin et al., 1994).  The wheelchair project originated with a suggestion by Dr. Bruce Murray, ex-director of NASA's Jet Propulsion Laboratory, to investigate the transfer of this technology to useful non-space applications.

The sections to follow will describe the technology, results, and possible uses of the CSOIS wheelchair research project.

## 2.  VIRTUAL PRESENCE WHEELCHAIR CONTROL

### 2.1 Background.

Stereo telepresence control plays an important fall-back role in navigating both the Russian Marsokhod and the NASA-JPL Rocky Rover micro-robotic planetary exploration vehicles.  In the event that the vehicles encounter an obstacle or some other terrain feature which baffles the primary autonomous navigation and control systems, dual on-board CCD cameras can be used to send stereo images back to earth-based remote operators, who are then expected to send return

signals and manually steer the vehicles around the difficulty. Since CSOIS engineers had participated in the development of this technology, it was natural to select telepresence as the first approach to remote wheelchair control. The idea was simply to provide a remote operator with a joystick, or some other appropriate hand controller, with which to drive a motorized wheelchair from a stereo telepresence image. The image was to be sensed by cameras on-board the wheelchair and transmitted to a computer monitor for display at the operator's work station.

It rapidly becomes obvious, however, that steering a wheelchair by telepresence presents a number of challenges over and above those of steering a small, stable, and relatively slow moving planetary exploration vehicle. Not the least of these problems is the need to take into consideration that the operator of a wheelchair will likely not be as highly trained and practiced as a space scientist or engineer. As a result, the approach was broadened to include a more general sensory environment. Stereo sight and sound, for example, allows an operator to instantly determine not only that the wheelchair is located on a sidewalk, but possibly out in the street and in the path of oncoming traffic. Speakers on the wheelchair permit the operator to ask questions of the occupant or bystanders. On-board electronic inclinometers can be slaved to a gimbaled operator platform to duplicate the orientation of a wheelchair in imminent danger of tipping. In general, the CSOIS idea was to immerse the remote operator in a sensory environment so close to the true environment that the operator could be considered *virtually* present in the wheelchair. To distinguish this approach from the purely visual concept of telepresence control, and to acknowledge the contribution of virtual reality (VR) technology, the investigators agreed that the new technology should be called *virtual presence* (VP) wheelchair control.

## 2.2 *User Input and Cost Considerations.*

In an investigation of this type, it is easy for engineers to get carried away with the technological developments and to forget the real objectives of the research - i.e., to enhance the quality of life for the disabled. Fortunately, CSOIS has had the significant advantage of being co-located at Utah State University with the National Center for Persons with Disabilities (CPD), which has provided regular access to the real customers for this project, the disabled users themselves. The investigators have also made a point of regular attendance and presentation of results at several Conferences on Technology for Persons with Disabilities, sponsored and organized by Dr. Harry Murphy and his California State University, Northridge, Center on Disabilities (Powell et al, 1994; Smith and Gundersen, 1995; Smith et al, 1995). Feedback obtained in this manner directly from the disabled users of wheelchairs has been instrumental in shaping the goals and objectives of the project.

Cost has been a constant concern throughout the project. Obviously, the objective of improving the wheelchair users quality of life will not have been achieved if the end result is unaffordable. For this reason the center has set the goal of limiting the cost of retrofitting a motorized wheelchair with a remote steering system to no more than twenty percent of the wheelchair cost.

## 2.3 *Systems Description.*

The CSOIS virtual presence wheelchair system consists of two functional subsystems, the on-board subsystem and the (remote) control station subsystem, shown as Figures 1 and 2 respectively. Each subsystem is controlled by its own processor, with communication between processors provided via an RS-232 serial radio frequency (RF) link. The central processor for the onboard system is an Onset TT8™ micro-controller. The TT8 has a Motorola 68332 processor and peripheral devices such as A/D, UART, Timers/Counters, and digital I/O ports, all on a single 2"x3" board. The primary function of the on-board controller is to receive control commands from the remote control system and convert them to digital signals which drive the wheelchair motor control system. For the current CSOIS design, remote system control commands are received by a Proxlink™ RF modem transceiver, with a range of 1000 ft. (Modems with ranges in excess of this distance are readily available, but, in the USA, must be operated under a license issued by the Federal Communications Commission (FCC).) A program running on the TT8 converts this data to numerical drive commands. The numerical drive commands are then fed to a MAXIM MAX500 D/A converter to generate analog voltages that drive the wheelchair motor controller. One of the design goals of the CSOIS system has been to arrive at a configuration which can be readily added on, or retrofitted, to existing commercially available motorized wheelchairs. CSOIS has been using an ARROW-XT™ wheelchair as a prototype. With the design described above, it has not been necessary to make any modifications to the ARROW motor microcontroller.
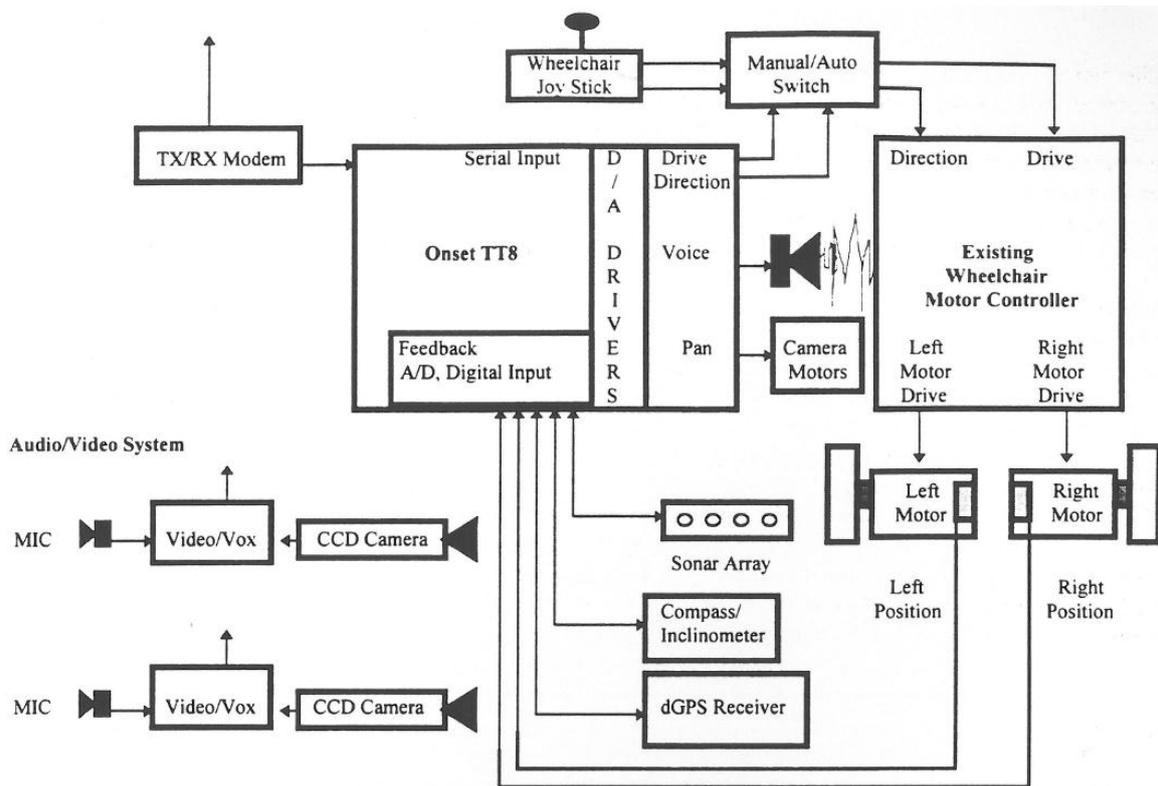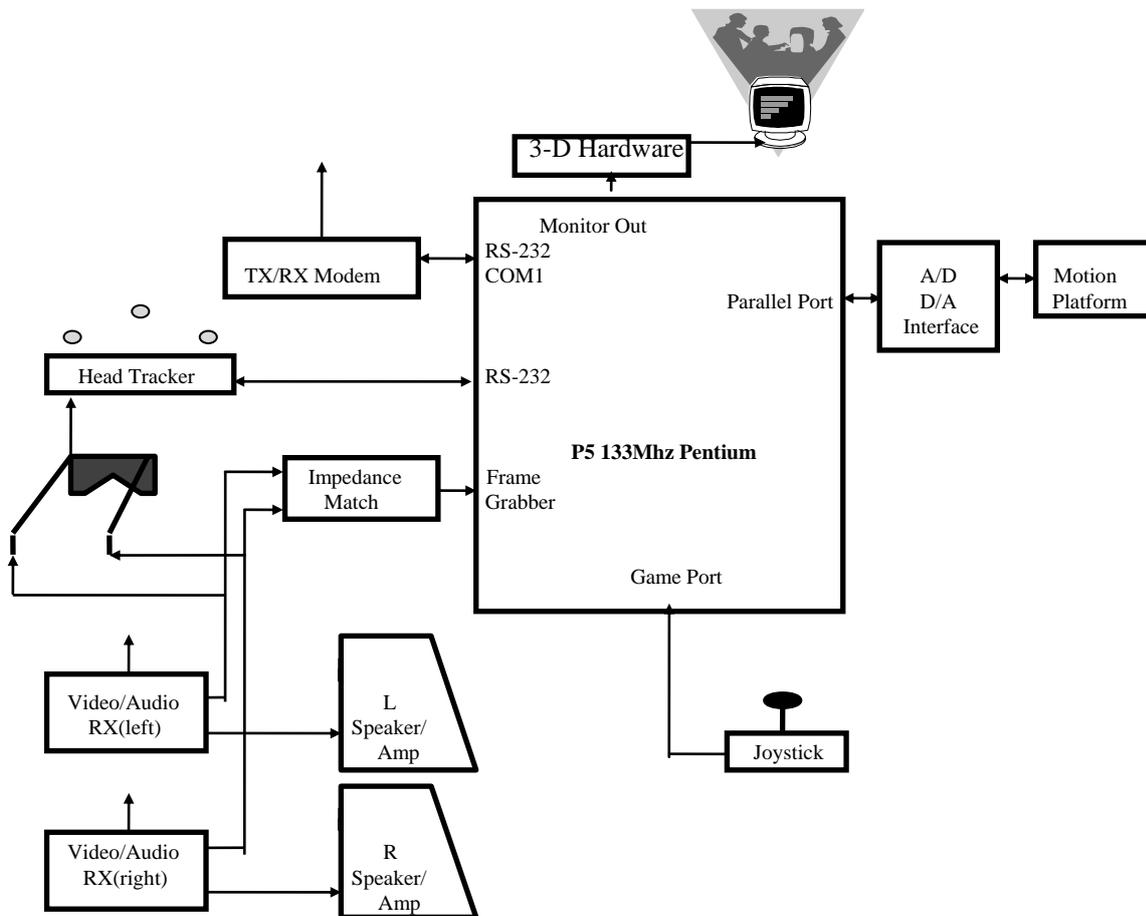
**Figure 1.** *Onboard System Diagram.*



**Figure 2.** *Remote Control System Diagram.*

The other half of the onboard system is the visual feedback system, which consists of two CCD cameras mounted on a rigid, vernier adjustable, stereo mounting system. This mounting system allows for precise adjustment of the spacing of the cameras and their angle with respect to each other. Both BC-710 color and Pulnix TM-7CN black and white CCD cameras have been used by CSOIS. Two Pelco WLV video transmitters transmit the NTSC signal from the cameras to the remote control system. The range of these transmitters is 1000 ft. In earlier experiments, only one transmitter was used and a video switching system was employed to allow each camera to transmit alternately. To achieve stereo vision, the video signal then had to be de-multiplexed at the remote control system before viewing. While this approach lowered the cost of the system by one video transmitter, the received picture suffered from jitter, sync problems, and a slower frame rate of 15 frames per second. The two transmitter design gives jitter free video at 30 frames per second. The video transmitters include an audio transmission channel. By connecting an amplified microphone to this input, stereo audio signals can be sent to the remote control system.

*2.4 The Remote Control System.*

Processing at the remote control system end is accomplished using a 133 Mhz Multimedia equipped Pentium workstation. VIRTUAL i-O i-glasses!™ are used for stereo presentation of visual and audio feedback. The remote wheelchair driver currently uses a joystick type controller to input driving commands, with a program running on the Pentium computer converting the output commands to a digital signal for transmission by a RS-232 RF modem to the wheelchair on-board system. Video and audio signals from the wheelchair are received by Pelco WLV receivers and either passed directly to the i-glasses!, or to a frame grabber inside the Pentium if display on a computer monitor, rather than the i-glasses!, is desired. In the latter case, CSOIS has been using a Crystal EYES™ viewing system for stereo visual presentation. The audio signal can be fed to the computer's stereo speaker system.

Figure 3 shows a remote operator, wearing a VIRTUAL i-O headset, and controlling the wheelchair in Figure 4, which is equipped with the on-board system described in section *2.3*. Note that the headset is supplied with a head-tracking unit, which can be slaved to a gimbaled camera mounting system. Thus, the operator is not constrained to "see" only in the forward direction of the wheelchair, but can look around at will.



**Figure 3.** *VP operator wearing VIRTUAL i-O i-glasses! ™.*  **Figure 4.** *Arrow-XT™ configured for VP Control.*

*2.5  Uses of Virtual Presence Control.*

Perhaps the most likely use of virtual presence wheelchair control is provided by the example of an individual confined to a wheelchair and showing symptoms of the relatively early stages of Alzheimer's disease. This individual may normally be perfectly able to go for a lone outing around the block or down the street and back, without an attendant. However, there is always the risk that the individual may become confused one day, and unable to remember the way home. If the wheelchair is equipped with virtual presence steering, it would only be necessary for the occupant, or

possibly a passerby, to press an alarm button to obtain the attention of a remote operator at the base station. Immediately upon donning the virtual reality glasses, the operator will be able to see, hear, and look around in order to determine the location of the wheelchair and take action to either steer it out of harm's way, or possibly all the way back to the operator's station.

Another use suggested for virtual presence control would be as a "helper" system for either the severely disabled, or for new or unskilled users. Such users may, for example, be able to move around a hospital, retirement, or nursing home by themselves for the most part, but could experience difficulties and frustrations if required to enter a room through a narrow door, or enter a crowded elevator. If the wheelchair were equipped with a virtual presence control system, it would only be necessary for the occupant to signal a remote operator to take over, who could then return control back to the occupant once the difficulty was negotiated.

# 3. FULLY AUTONOMOUS NAVIGATION AND CONTROL

## 3.1 Background.

Stereo telepresence control has one serious shortcoming with regard to its use on planetary exploration vehicles - transmission time. For example, an estimated forty minutes would have to go by in order to transmit one stereo image from Mars back to Earth, and then relay the operators steering command back to the vehicle. At that rate, an entire mission could be spent trying to get around one rock. Consequently, stereo telepresence is planned for use only as an emergency backup, while primary control is usually left to navigation using an on-board fully autonomous system. CSOIS was actively involved in the development of autonomous systems for use on the NASA-JPL Rocky Rover series of micro-robotic planetary exploration vehicles (McJunkin et al., 1994; Madsen and Gundersen, 1994; Gundersen et al., 1995), so it was natural to look into the question of whether this, or a slightly modified technology could be usefully transferred to the wheelchair steering and navigation problem.

Two possible approaches to fully autonomous wheelchair systems are described in this part of the paper, both based upon the concept of global steering by path programming and local steering via an autonomous obstacle detection and avoidance scheme. The two approaches differ only in the methodology used for path programming - operator-based planning from computer imaging on the one hand, versus a strictly computer-based optimal dynamic programming scheme on the other.

## 3.2 Operator-Based Path Programming.

Both approaches to global path planning assume the availability of prior maps, floor plans, or reasonably accurate architectural information from which a two or three-dimensional computer model of a building's interior can be constructed. These approaches are more intended for moving about inside a home, a building, or relatively small outdoor area such as a garden, since it is more likely that the necessary prior map information will be available, or easily generated, for the more limited regions. Also, it will shortly be seen that the second, optimal dynamic programming scheme has some very desirable features. However, these features require that the position or location of the wheelchair must be accurately tracked while the chair is en route to its goal. This type of information can be easily obtained using differential global satellite positioning system (dGPS) technology. Unfortunately, dGPS would be prohibitively expensive for this application, and only useful out of doors anyway. An alternate approach is required and will be described in section 3.4.1 below.

The idea of operator-based path programming is straight forward enough provided some form of information is available, such as builder's plans or blueprints, which can be used to build either a two or three-dimensional computer imaging model of the relevant area. For example, Utah State University has computerized most of its buildings and grounds blueprints, which can in turn be used with a commercial program such as AutoCAD☺ to build a two-dimensional computer image of the area, with monitor pixel locations registered one-to-one with the dimensions of the blueprint. Similarly, the blueprints furnish sufficient information to allow a program such as Performer☺ to create a three-dimensional model suitable for viewing by two-dimensional projection techniques, or through virtual reality optical viewing devices such as i-glasses! or Crystal EYES. A computer operator then simply traces the desired path from the wheelchairs present position to the desired location. This data is stored in the form of a sequence of path commands for execution by the wheelchair computer station, and transmitted to the wheelchair on command of the occupant. In reality, little seems to be gained by going to the extra software and hardware expense of three-dimensional rendering of blueprint data, unless the terrain is outdoors where one path might be chosen over another

because of steepness or some other terrain feature. Of course, there may be similar indoor features, such as narrow doorways and difficult corners to negotiate which could affect path selection, in which case the expense may be justifiable.

*3.3 Computer-Based Path Programming*

The objective of the path planning could be as simple as proceeding from the present location of the wheelchair to the desired location in the shortest possible time, or it could be complicated by requiring the chair to travel a route which avoids use of certain congested hallways or wheelchair unfriendly architectural features, such as too narrow doorways or sharp turns. These criteria and preferences can be selected by the occupant on a pull-down menu residing on a small computer monitor on-board the vehicle. Path planning works backward from the specified goal to find paths satisfying the selected path criteria from *all* relevant starting points, including the present position of the wheelchair, to the goal. These paths are optimal, relative to the selected path criteria, and obtained using the method of incremental dynamic programming (Dietterich and Flann, 1995).

If there are no unexpected obstacles to completing the computed path, the wheel chair will start from the present position and follow that particular computed route to the goal. If this is the case, one could say that there has been a lot of wasted computation; i.e., in order to obtain alternate paths from all of the other possible starting points to the goal. However, if someone has blocked off a hallway with furniture, and the computed route fails, then the other computations have not been wasted. The wheelchair obstacle detection system, or possibly the occupant, now tells the computer that it has a *new* starting point, it's current location, and off they go.

What is nice about this scheme, is that once an unexpected obstacle to wheelchair movement is discovered, it is no longer unknown. Indeed, that information can now be added to the building and grounds model used by all of the wheelchairs equipped with the system. The next time any wheelchair path is planned, that obstacle will automatically be taken into consideration. If all of the wheelchairs are able to communicate with each other, say by radio frequency modems, these corrections could even be made while the chairs were *en route* to their respective goals.

One problem with implementing this scheme would appear to be the computational load it adds to the TT8 on-board computer. A similar, but even more computationally intensive scheme, is already being used by CSOIS on another project, however, and has been programmed for and is operating on the TT8. The real problem with implementing the scheme arises from its demands on knowing the instantaneous position of the wheelchair.

*3.4 Systems Description.*

At present, the path planning systems have been implemented with the master controller located at a remote computing center, using the same communication system as described earlier to relay on-board measurements to the control station, and control commands back to the wheelchair wheel controllers. Future plans call for simply downloading the path plan to the on-board TT8, so that the wheelchair will operate autonomously until a new route or path plan is required. There are some major differences in on-board sensors and instrumentation, however. The next two sections discuss these modifications and their functions.

*3.4.1 Position Tracking.* Regardless of whether the computer-based or operator-based method is used, the path, once planned, consists of a locus of points on a map of the area, with the coordinates of each point given relative to a convenient coordinate system. Given that the present position and angular orientation of the wheelchair is known in that coordinate system, a vector command can be computed and sent to the controller on-board the wheelchair, which instructs it to precede at a certain angle for a certain distance in order to arrive at its next programmed position. By using this one-step-ahead protocol, it is possible to minimize the cumulative effect of position error. Nevertheless, a reasonably accurate method for tracking the present position of the wheelchair is required. For example, it may be necessary to make a turn and enter a room through a narrow door. The positioning system must be accurate enough to avoid the obvious consequences of missing the doorway. In terms of planning itself, knowing the expected position error allows the path planner to accept or reject various available paths.

As mentioned earlier, dGPS systems offer one way of tracking position. Currently available dGPS systems can track within a few centimeters. Unfortunately, systems with this kind of accuracy are still prohibitively expensive, and are generally suitable only for outdoor applications. Consequently, it is necessary to rely upon some form of improved dead reckoning. In the case of a wheelchair traveling on a level surface, this can usually be accomplished with satisfactory accuracy by counting wheel revolutions, together with the use of an electronic compass to obtain instantaneous heading information. Center investigators have interfaced two Hewlett Packard (HP) HEDS-6310 optical encoders to the Onset TT8 for relative angular measurements, mounting one encoder on the left and one on the right

wheel drive motors. Assuming the heading command is executed first so that travel is in a straight line, the average of these two counts provides an accurate distance measurement, once again assuming a level and reasonably smooth surface. True heading information is obtained from a Precision Navigation Vector-2x electronic compass that has been interfaced with the TT8. If even greater accuracy is required, it is possible, at the expense of some additional instrumentation, to update the absolute position of the wheelchair at a few way sites common to most of the possible route choices. For example, infra-red checkpoints could be established at each end of a hallway.

*3.4.2 Obstacle Detection and Avoidance.* Because the planned path is obtained from "historical" data, such as maps etc., it is always possible to encounter unexpected obstacles in the way of the wheelchair. Thus, an effective path planning system has to include some method for detecting and reacting to their presence. Since the method is to be autonomous, coping with the obstacles has to be done automatically. This is not a new problem. Obstacle detection and avoidance is also a system design requirement for planetary exploration vehicles and an area where CSOIS has concentrated a considerable amount of time and interest (Madsen and Gundersen, 1994; McJunkin et al., 1994; Gundersen et al., 1995). It may not be necessary to transfer all of this technology to the wheelchair application, however, since both the type of obstacles and the conditions are likely to be quite different.

For example, it has already been assumed that the autonomous path planning approaches of this paper are most feasible for moving occupied wheelchairs around buildings or limited outdoor areas. Thus the wheelchair will be spending a lot of its time in hallways or sidewalks, where an unexpected object will more than likely be in the form of another wheelchair, a person, or some similar dynamic object. In such cases, all that should be necessary is to detect the presence of the obstacle, stop, and wait for the obstacle to move, or be moved. Just in case, the TT8 can be used to time the duration of the wait, and if excessive, a call for assistance and the present position of the wheelchair could be issued via the central computer. CSOIS investigators have found that mounting a single inexpensive Polaroid Ultrasonic Sonar sensor with a 30 degree cone of ultrasound searching directly in front of the wheelchair, works quite well. Students walking down the hallways are usually out of the path before the wheelchair even comes to a stop. Some of the more preoccupied faculty, on the other hand, appear to need obstacle detection and avoidance devices more than the wheelchair.

*3.4.3 Fuzzy Obstacle Detection and Avoidance.* Of course it is possible to imagine applications where the simple obstacle detection and avoidance scheme of the preceding section is insufficient. For example, it may be necessary for the wheelchair to pass through a lobby with furniture and decorative plants. These obstacles would not show up in building blueprints, and could be moved around regularly. This possibility and similar situations could alone justify the extra expense of an autonomous obstacle avoidance system. However, there is another use for such a system which may be of even more value. That is, it could be used to reduce path planning accuracy requirements. For example, even with careful and conservative planning to take in possible position and orientation errors, it is still possible that the chair could arrive at a narrow doorway too far off its mark. Sensing that a collision was imminent, an obstacle detection system could take over and successfully steer through the door.

Two approaches to obstacle detection and avoidance have been investigated by CSOIS. In this section we shall describe a fuzzy logic scheme, which is based on a similar system developed by CSOIS (with the encouragement of NASA-JPL) for possible secondary mission uses of the JPL Rocky Rover class of micro-robotic planetary exploration vehicles (McJunkin et al., 1994). The objective of that project was to use the intelligent systems technologies of neural networks and/or fuzzy inference machines to arrive at a fully autonomous navigation and control scheme, without making any changes whatsoever in the already established Rocky Rover sensor, computer, or electronic hardware systems. Sensors available on the Rocky Rover include an array of five striping (planar) lasers and two CCD cameras, all mounted at suitable angles to provide a "view" of the scene in front of the vehicle. On a perfectly flat surface, the light appears as a straight line. However, any object interrupting the flat surface causes a discontinuity, or a jump, to occur at a point representative of the distance to that object. By aiming the cameras at known non-coincident angles, elementary trigonometry can be used to determine the approximate height of the object, using the distance from where the pixel should have been to where the interrupting object had displaced it.

The CSOIS approach was to use only the pixels corresponding to the intersection of *three* scan lines of the CCD image with each of the five laser lines appearing in the image, *a total of only 15 active data points*. Figure 5 illustrates how this minimal information can be translated into an approximate, or *fuzzy*, map of the terrain immediately in front of the vehicle. For the wheelchair application, the three lines were chosen to correspond to distances of one, two, and three chair lengths in front of the sensors. As shown, each intersection point serves as the center of an ellipsoid. A fuzzy membership function is then used to color the ellipsoid so as to provide a measure of the "hazard" presented by an obstacle, with a null membership value indicating the absence of an obstacle altogether and a membership of unity indicating a certainly impassable object. Using the traffic light analogy, these membership values have been mapped into a color continuum ranging from green ("0") to amber ( "0.5") to red ("1"). It will be noted that the rectangular figure in the center of the approximate image is surrounded by ellipsoids, twenty six in all. As the vehicle moves

forward, the three rows of ellipsoids in front of the vehicle are allowed to shift backward one length. In effect the fuzzy display "remembers" what was in front of the vehicle.
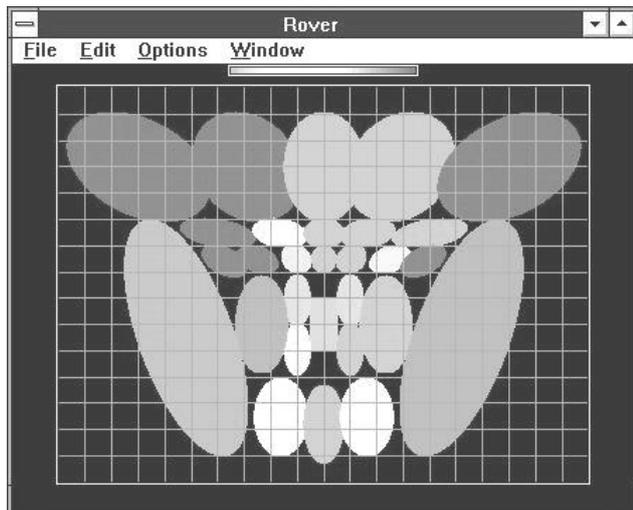


**Figure 5.** *A fuzzy approximate map.*          **Figure 6.** *Actual scene in front of chair.*

The fuzzy display is not directly used in the actual system. Instead, a human operator trains on the fuzzy display until expert in detecting and avoiding obstacles in the wheelchairs path. The expert operator then devises a set of rules of the form, " If the goal is straight ahead, and If all of the ellipsoids directly ahead are nearly green; Then steer straight ahead". In this manner, a rule-base was built with twenty six fuzzy input variables corresponding to the twenty six ellipsoids surrounding the vehicle, three fuzzy input variables corresponding to desired heading, and three fuzzy output steering commands; "steer to the left", "steer to the right", "straight ahead" and "straight back". The scheme has been used to successfully steer through many examples of cluttered and complex room arrangements. It is rather slow, but that seems not to be a problem, since it would only be needed when an unexpected obstacle is encountered. It is accurate, and is able to successfully negotiate its way through narrow doorways and around tight corners.

The laser system approach does have two problems associated with it. The first is obviously cost. The second problem arises from concerns that the laser array may be alarming to some individuals in the vicinity, or at least annoying. There is also a perceived safety factor, even though the power level of the lasers is within the safe region. For these reasons, CSOIS has been investigating a second approach, which uses ultrasonic sonar sensors instead of lasers.

*3.4.4 Ultrasonic Sonar Obstacle Detection and Avoidance.* Although development of an ultrasonic alternative to the laser sensing array has not been entirely finalized at the time of this writing, results to date suggest that it should serve as a more than satisfactory and significantly less expensive replacement for the laser system. The current concept calls for an array of five Polaroid 6500 series sonar ranging modules to be arranged in a pattern such as that shown in Figure 7 (a). Each sonar emits a 30° cone of ultrasonic 50 kHz sound, measuring distance to first objects in the cone with an error of less than 2 cm at distances from 0.26 to 10.7 meters away. The amount of energy return is proportional to the object surface area tangential to the sonic arc (Maslin, 1983). Figure 7 (b) shows one way to display the output of such an array for the scene of Figure 7 (c), as seen from a camera mounted and looking straight ahead of the wheelchair. Just as in the case of the fuzzy display of laser-sensed data, a human operator uses the sonar display to detect and avoid obstacles lying in the path of a wheelchair controlled by the operator. After becoming "expert", the operator then devises a set of rules for a fuzzy inference machine, which then is used to replace the operator.
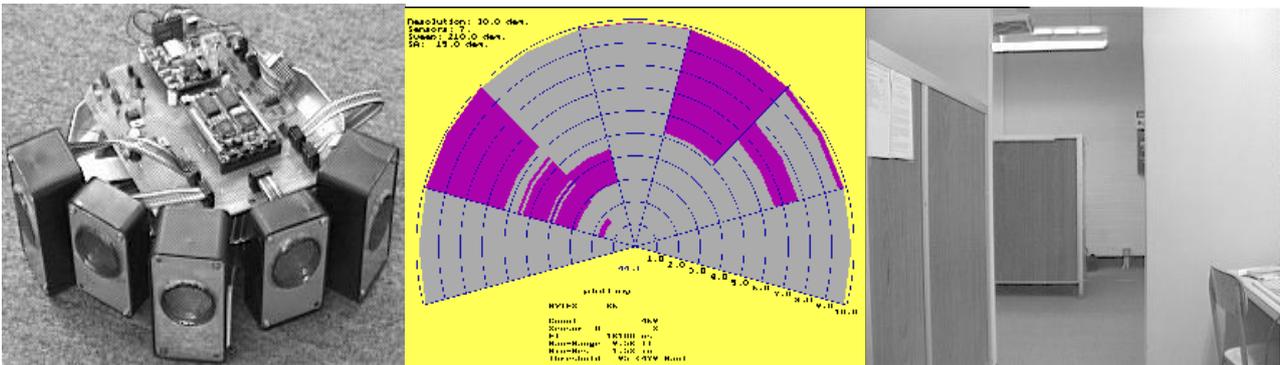
**Figure 7 (a).** *Sonar array*      **Figure 7 (b).** *Sonar map*      **Figure 7 (c).** *View from wheelchair*

In addition to being less costly, the sonar system is also much faster than the laser system, since is not necessary to proacess the laser images obtained by the CCD cameras (which can be eliminated, along with the striping lasers). Finally, most humans will be completely unaware of the sonic energy emitted by the sensors. A higher frequency than 50kHz may have to be used, however, if pets or guide dogs are in the area.

*3.5 Uses of an Autonomous Wheelchair Controller.*

As discussed above, an autonomously controlled system of the type described in this section would serve quite a different purpose than the previously described "emergency" virtual presence system. It would allow severely disabled individuals a degree of independence and freedom not otherwise attainable, allowing them to move around the home, hospital, or care center without constant supervision.

An interesting possibility which has been suggested is to use an autonomously controlled wheelchair during the training process; for example, by providing frustration-free mobility during "off-training" hours, or by serving as a back-up takeover in case the trainee becomes overly tired. Further, demands on the human occupant could be reduced by designing the system to augment human control of the wheelchair. In this sense, it may be possible to design the autonomous system to gradually relinquish control in favor of the trainee, as the individuals skill and confidence increases.

It may be valuable to combine the skills of a human operator and an autonomous system. The occupant could assume responsibility for "steering" the chair by pointing it in the desired direction, relying on the autonomous system to keep it on the desired path and to avoid obstacles. With such a scheme, a wheelchair user could, for example, relax and enjoy window shopping in a mall, without having to be constantly on guard for other persons or objects getting in the way. In another scenario, the autonomous system might be used only to stay on lookout for dangerous situations such as curbs or stairways, automatically stopping the wheelchair or simply sounding a warning alarm to alert the occupant to the hazard.

## 4. CONCLUSIONS

In this paper we have reported on the results to date of a two year investigation at Utah State University into the uses of virtual reality and its associated technologies for assisting the disabled in steering and controlling wheelchairs. There have been several interesting investigations of the use of virtual reality for steering virtual wheelchairs through virtual, computer generated, environments. The purpose of the USU investigation has concentrated instead on using the technologies associated with virtual reality to operate a real wheelchair in real world environments. The results to date have been quite encouraging and satisfactory. In particular, it appears that systems can be realized that are both useful and cost effective.

## 6. REFERENCES

T G Dietterich and N S Flann (1995), Explanation-based learning and reinforcement learning: A unified view. *Proceedings of the International Machine Learning Conference*, Snowbird, UT.

R W Gundersen, G Olsen, and G Powell (1995), A fuzzy-inference scheme for fully autonomous control of Rover class planetary exploration vehicles, *Proceedings of the 46th International Astronautical Conf.*, Oslo, Norway.

D Inman, J Peaks, K Loge, and V Chen (1994), Teaching orthopedically impaired children to drive motorized wheelchairs in virtual reality, *Proceedings of the 2nd Annual International Conference on Virtual Reality and Persons with disabilities*, San Francisco, CA.

D Madsen and R W Gundersen (1994), An autonomous fuzzy logic Rover navigation scheme, *Proceedings of the 2nd Joint Conf. On Information Sciences*, Durham, N.C.

G D Maslin (1983), A simple ultrasonic ranging system, *Presented at the 102nd Convention of the Audio Engineering Society*, Cincinnati, Ohio.

T McJunkin, G Powell, and R W Gundersen (1994), A unique approach to advanced obstacle detection and avoidance, *2nd International Symp. On Missions, Technologies, and Design of planetary mobile vehicles*, Moscow-St. Petersburg, Russia.

G Powell, T McJunkin, and R W Gundersen (1994), Autonomous wheelchair control by an approximate virtual reality system, *Proceedings of the 2nd Annual International Conference on virtual reality and persons with disabilities*, San Francisco, CA.

S J Smith and R W Gundersen (1995), Telepresence wheelchair control for severely disabled persons, *Proceedings of the 10th Annual International Conference on Technology and Persons with Disabilities*, Los Angeles, CA.

S J Smith, R W Gundersen, and B A Abbott (1995), Virtual Presence and autonomous wheelchair control: An update, *Proceedings of the 3rd Annual International Conference on virtual reality and persons with disabilities*, San Francisco, CA.

J Swan, D Stredney, W Carlson, and B Blostein (1994), The determination of wheelchair user proficiency and environmental accessibility through virtual simulation, *Proceedings of the 2nd Annual International Conference on Virtual Reality and Persons with disabilities*, San Francisco, CA.