CHAPTER 11
UTAH STATE UNIVERSITY

College of Education
Center for Persons with Disabilities
Logan, Utah

Principal Investigators:

Frank Redd, Ph.D. (801) 797-1981
redd@cc.usu.edu
Marvin G. Fifield, Ph.D. (801) 797-1981

Short-Range Autonomous Wheelchair Controller

Design Team: Steven J. Smith
Client Coordinators: Dr. Richard Baer, Center for Persons with Disabilities
Dr. Marvin Fifield, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson, Center for Self Organizing and Intelligence Systems, Department of Electrical Engineering
Dr. Frank Redd, Department of Mechanical and Aerospace Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

Most power wheelchair users can safely and accurately control their chairs in most situations. With practice, control devices, including joysticks, sip-and-puff straws, and mouthsticks are effective input devices for wheelchair control. However, a variety of environmental barriers, such as poorly designed bathroom stalls, restrictive office cubicle areas, narrow doorways, and uneven terrain, present difficulties that are further compounded by inexperience and/or specific disabilities of the user.

In focus group discussions with power chair users, a need repeatedly expressed was for an autonomous system that would take control of the wheelchair until a difficult obstacle(s) is avoided.

To address this need, the Center for Self-Organizing and Intelligence Systems (CSOIS) engaged in an investigation of the application of virtual reality and associated technologies as a means of assisting consumers to steer and control power wheelchairs. During the past two years, several solutions have been investigated and projects to design and fabricate prototypes have been undertaken. Engineering students and consumers have collaborated individually and as team members in the investigation of fabrication and field testing of various autonomous power chair controllers.

SUMMARY OF IMPACT

This short-range, autonomous wheelchair controller is designed to allow a power chair user to safely and quickly navigate in difficult situations. It is activated by simple on/off and desired-direction command input into the existing interface (joystick, mouthstick, sip-and-puff straw). The system can be engaged and disengaged instantaneously. Once engaged, it will map the immediate environment using sonar image data and plot a course in the direction indicated by the user. While moving toward the desired direction under autonomous control, the user can regain manual control at any time.

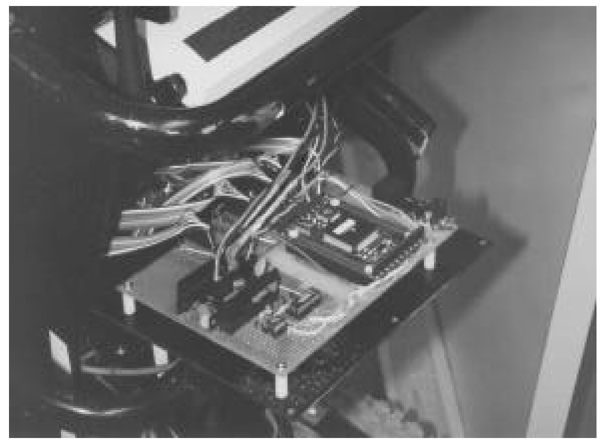

Figure 11.1. Wheelchair Control System.

TECHNICAL DESCRIPTION

For short-range autonomous power chair control, an obstacle-detection/obstacle-avoidance system is implemented using sonar for range detection and image data from a laser/CCD camera for obstacle identification. Input from these components is used to construct a path plan control file. An onboard computer system uses this file to guide the wheelchair from the point of activation to the desired destination. Optical encoders on the two rear wheels, and a digital compass mounted near the center of gravity of the chair, provide positional feedback and minimize error. The interface between the computer and the chair consists of the existing control device (i.e., joystick, mouthstick, or sip-and-puff straw). Figure 11.1 provides a systems block diagram of the wheelchair control system on board. Figure 11.2 provides a diagram of the remote power chair control system.

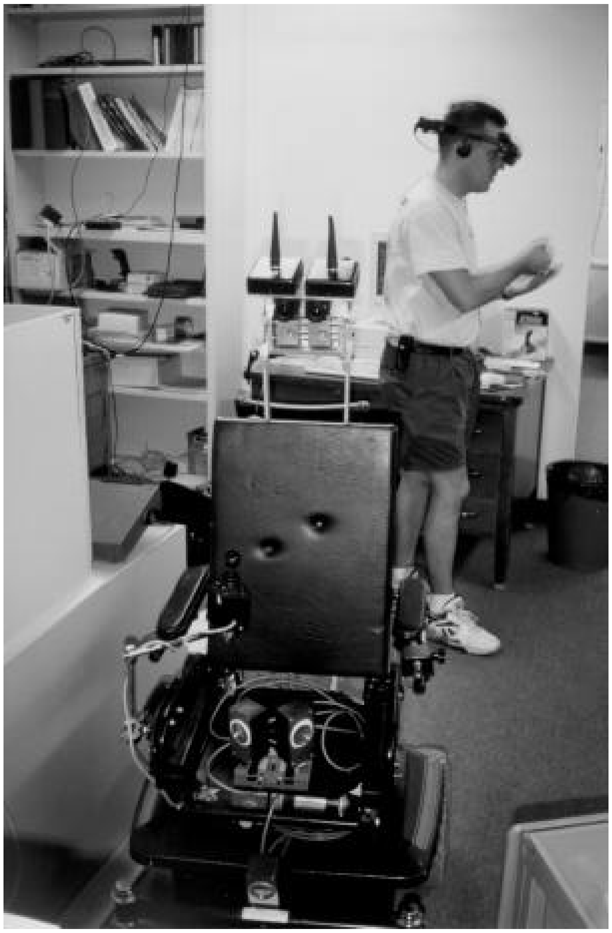

Figure 11.2. Short-Range Autonomous Wheelchair.

Feasibility

A prototype of the short-range, autonomous wheelchair controller was developed and tested. The need was identified for a more sophisticated on-board processor to provide additional speed and reliability. The Tattletale 8 was designed to provide security and fault protection when control is taken from the user for a period of time. In addition, a sonar location system was added for obstacle detection. The primary purpose of this project was to integrate these elements into a system and implement the autonomous system in software.

The cost of equipment and materials for this project include the following:

ITEM	QUANTITY	TOTAL COST
Laser Suite--Lasiris ULG-519	1	$995
Digital Compass--PCITCM2	1	$795
Sonar Kit--Polaroid OEM Kit	1	$99
Total Cost		**$1,889**

Autonomous Wheelchair Positioning Feedback System

Designer: Collin Lewis
Client Coordinators: Dr. Richard Baer and Dr. Marvin Fifield, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson, Center for Self Organizing and Intelligence Systems
Department of Electrical Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

Students at the Center for Self-Organizing Intelligent Systems (CSOIS) at Utah State University have been working on a number of projects to make powered wheelchairs more functional and consumer friendly. CSOIS currently has a functional power chair that can be remotely operated by virtual presence control. Future plans include constructing a "virtual" map of buildings, using construction blueprints, and then using that map to program the power chair to navigate to any destination in the building on command, following the most efficient route. A prerequisite to accomplishing this is for the autonomous power chair to know its own location. The purpose of this project was to provide a means of sensing the movement of the chair and to deliver that information to participants in other phases of the project in efforts to complete the information loop and allow the chair to drive itself.

SUMMARY OF IMPACT

Many users of power chairs lack the capacity to adequately control the guidance system on their own in an efficient manner that will facilitate independence and not damage the chair or the environment in which it operates. An autonomous power chair that can travel to remote locations upon command, circumvent obstacles, and provide additional safety, will be of tremendous benefit to those consumers who have not been able to operate control systems independently. An essential component of an autonomous power chair is a system whereby positional feedback is provided.

TECHNICAL DESCRIPTION

The drive system of the autonomous power chair consists of a motor running through gear reductions to drive each of the rear wheels. The front wheels are castor style. Thus, steering is accomplished by driving one of the rear motors faster than the other.

Driving straight requires both motors drive at the same speed. Each drive motor has an auxiliary shaft to which a wheel of an operating encoder was attached. The encoder was attached to the housing of the drive motor; it contains an infrared emitter detector that counts the slots in the encoder wheel as it rotates with the armature of the drive motor. The output of these sensors is a digital signal that is fed into a processor that counts the pulses and determines distance and direction traveled by the chair. A Hewlett Packard Model #HEDS-6310 encoder assembly was fit into the motor housing; it generates 500 pulses per revolution of the drive motor. The Onset Computer Corp. (Pocasset, MA) makes an embedded system called the Tattletale Model 8, which is equipped with the I/O lines to efficiently monitor the signals from each wheel and process the data. This will obtain positional feedback from the wheels of the power chair and represents the first step in an intelligence control system. This project lays the foundation for other projects that will enhance the independence of people using power chairs.

The hardware required to implement the positional feedback system includes:

ITEM	QUANTITY	TOTAL COST
Encoders HP #HEDS-6310	2	$131
Onset TT8 Processor	1	$500
Other costs: wiring, machining, miscellaneous hardware		$250
Total Cost		**$1,281**

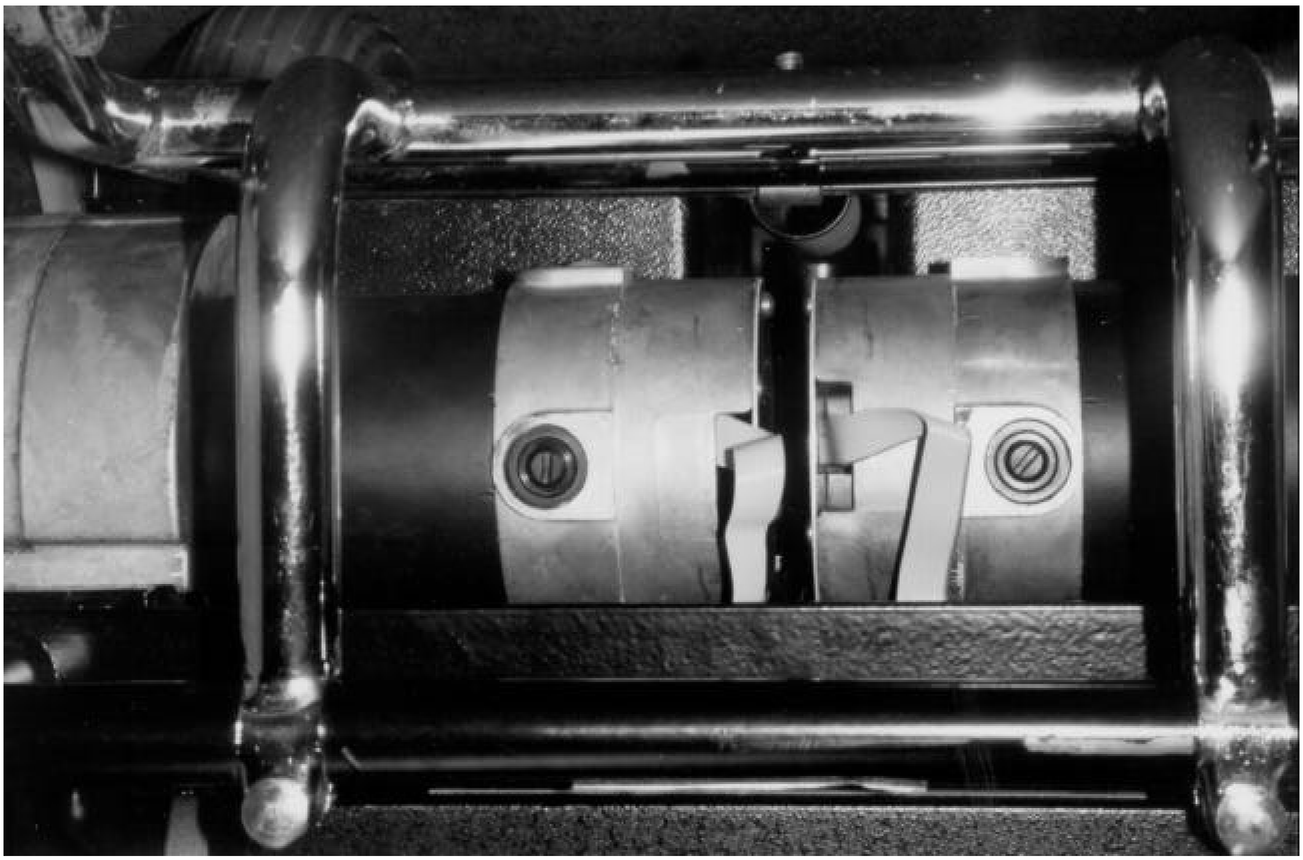

Figure 11.3. Photograph of the Autonomous Wheelchair Positioning Feedback System.

Path Navigation Program for a Power Wheelchair

Designer: Monica Joshi
Client Coordinators: Dr. Marvin Fifield and
Dr. Richard Baer, Center for Persons with Disabilities
Supervising Professor: Dr. Ben Abbott
Department of Computer Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

An essential characteristic of an autonomous power chair includes its ability to navigate a predetermined path. This project constitutes one component of the efforts of the Center for Self-Organizing Intelligent Systems (CSOIS) at Utah State University to develop innovative approaches in the control of power chairs for persons with disabilities utilizing a "test bed" vehicle. The aim of this project was to develop a program using AutoCAD to prompt the user to draw a path. The program provides information about the path. Traced on the map, this information is then used to remotely navigate the power chair. The program will enable the power chair to follow the path drawn on the map, and to generate the coordinates of the path and other information needed for navigation.

SUMMARY OF IMPACT

Successful path navigation for a power chair will provide a variety of benefits to power chair users. Such a program will: 1) permit the user to travel from one location to another without assistance of another person; 2) prevent the chair from bumping into obstacles, thus, protecting both the environment and the chair; and 3) aid in training the user to successfully utilize manual control systems. As path navigation becomes more sophisticated and as such designs are implemented in conjunction with other sensory systems, paths of increasing length and complexity will be made possible. Also, safety will increase and user fatigue will be reduced.

TECHNICAL DESCRIPTION

The product was an AutoCAD program designed: 1) to prompt the user to draw the path the power chair would traverse on the map; and then 2) to allow the user to remotely navigate the power chair. Maps of the entire Utah State University campus were loaded into AutoCAD. A utility was developed to prompt the user to draw the path and then traverse it. The components include a "test bed" vehicle developed by CSOIS. The "test bed" vehicle is designed to be remotely controlled. The CADCAM component permits the mapping and storage of information on desired paths to be followed and generates the coordinates of the path and other information needed to navigate the power chair.

Proper attention to safety and interaction with other sensory systems of the "test bed" vehicle were accommodated through field-testing and systematic improvement in the program and the interfacing of the components.

In addition to the utilization of the "test bed" vehicle, the cost of materials included AutoCAD software costing approximately $1,200.

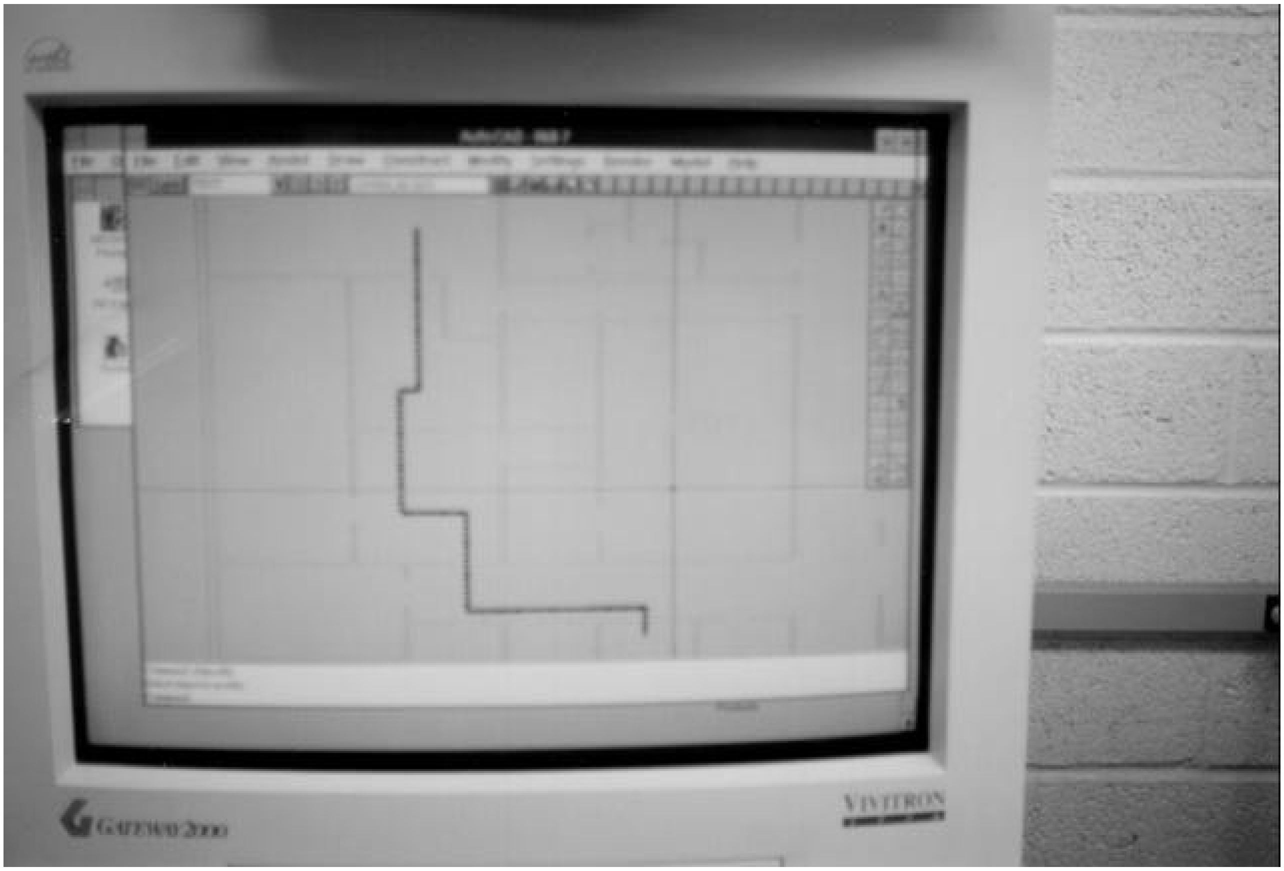

Figure 11.4. Path Navigation Program for Power Chair.

Autonomous Wheelchair Tracking System

Designer: Eric Poulson
Client Coordinators: Dr. Marvin Fifield, Dr. Richard Baer, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson, Center for Self Organizing Intelligent Systems, Department of Electrical Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

To navigate around known obstacles, such as walls and furniture, and to arrive at a specific location, a functional autonomous wheelchair must have information about its position. Typically, when a command is sent to the drive system to move ahead or turn, the control system assumes these commands reflect exactly the new position and orientation of the vehicle. In real life, wheels slip as the chair starts, moves, and stops; this slippage must be accounted for. The autonomous wheelchair tracking system will allow a control system to use information about the rotation of the wheels and the force applied to the wheels to estimate the amount of slippage and to arrive at a better estimate of the new vehicle position.

SUMMARY OF IMPACT

The product consists of a program that collects data from seven controlled computer modules recording information on wheel position, velocity, drive current, and force. When used with a wheelchair (or, in the future, with a scooter or other motorized personal vehicle) it will provide a much improved guidance system that can move people with disabilities autonomously to specific locations. The system will better avoid obstacles, be able to navigate in more confined spaces, and arrive closer to desired positions.

TECHNICAL DESCRIPTION

The sensors, computer modules, and program for this project are designed to work on a "test bed" vehicle. The modules use and record information on wheel position, velocity, drive current, and force.

The relative velocity between a wheel and the surface on which it rests is a function of many parameters. The composition of the surface has a significant effect on slippage, which is sensitive to the force or torque applied to the wheels and the velocity. This project will develop means to estimate that slippage without knowledge of the surface composition. It will incorporate information about the position of the wheel, the torque applied to the wheel, and how these values change with time. Slippage estimates can then be improved by comparing information from all the wheels on a vehicle.

Figure 11.5. Photograph of the Autonomous Wheelchair Tracking System.

Feasibility

This project is one part of an ongoing development of autonomous wheelchairs and other vehicles by the Center for Self-Organizing Intelligent Systems (CSOIS). A “test bed” vehicle for the development of the control algorithms is available. The seven computers used to record information on wheel position are provided by the CSOIS. Thus, support and commitment to the project was available.

Estimated costs of materials include seven control computers at $500 each, plus the cost of the “test bed” vehicle, and labor for connecting, programming, and field testing the program.

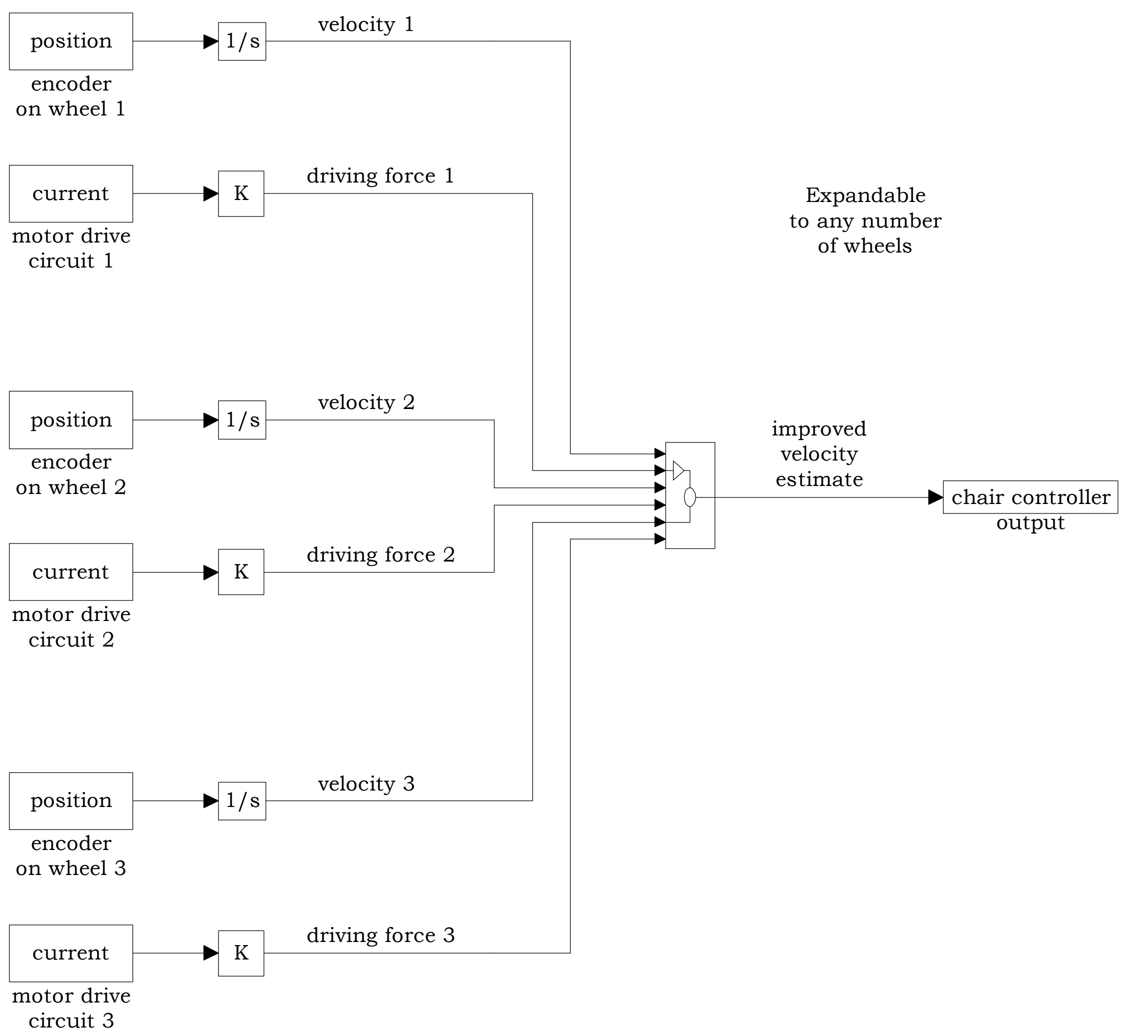

Figure 11.6. Control System Design.

Virtual Reality Representation of Autonomous Wheelchair Training

Designer: Yan Lin
Client Coordinators: Dr. Marvin Fifield, Dr. Richard Baer, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson, Center for Self Organizing and Intelligence Systems, Department of Electrical Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

Users of power wheelchairs have repeatedly identified the need for more sophisticated guidance, training, and sensory systems to facilitate movement in the environment and avoidance of many barriers common in the house or workplace. The purpose of the project was to develop a wheelchair capable of sensing and mapping its immediate environment, making navigational decisions based on this mapping, and then taking full or partial control of the chair to help the user move to desired locations in a safe and effective manner. A teleoperable test-bed vehicle was produced for designing various control algorithms and a "training" system. It was the purpose of this project to develop a virtual reality environment for the training of the autonomous wheelchair controller and the training of electrical power chair drivers.

SUMMARY OF IMPACT

This project is a software system designed to create a virtual reality representation of the real world using real- world data. The system involves "immersion" of the operator and the objects in a new, virtual space in which the virtual operator can interact directly with the virtual object in sensing environmental data.

The system is designed to be used for training people who need to use an electronic wheelchair. It often takes a year or more to obtain a power wheelchair because of delays associated with third-party approval and reimbursement. By utilizing a virtual reality environment system, persons with disabilities could learn to drive the chair before obtaining a real one. This would permit first-time users to be trained to drive in a more efficient and safe manner.

This system is also designed to train an autonomous wheelchair controller. In some situations, people with severe disabilities cannot personally control their power chair and must rely on a family member or therapist to move the chair from one location to another. In the virtual representation of the training area, the trainer can drive the power chair along a desired path and download the data into the chair's on-board computer. Utilizing this data, at the user's command, the chair can determine its starting point and then move to a desired location under the control of the self-navigating system. The on-board autonomous obstacle-avoidance system keeps the chair moving in the desired direction while avoiding obstacles along the way.

TECHNICAL DESCRIPTION

The interactive components of the training software were programmed in C. The components used for the system included a blueprint of the training area and the wheelchair, including: 1) a three-dimensional rendering of the training area, constructed from an AutoCAD blueprint file; and 2) an accurate model of the wheelchair in the three-dimensional domain. The program was designed to control, with constant velocity, a three-wheeled power chair with variable slip steering from the rear pair of wheels.

Feasibility

With current hardware and software, it is feasible to develop a program to be used to train consumers in the operation of a power chair controller and to train an autonomous wheelchair controller to drive a powered chair along a desired path at the user's command to a desired location, under the control of the self-navigating system.

This technology was determined to be potentially useful in family care, emergency situations, training of first-time wheelchair users, and the training of autonomous power chair controllers. The application is both practical and cost effective. With appropriate graphical user interface, the program will be easily accepted by users.

Costs of the program for software and hardware include the following:

ITEM	QUANTITY	TOTAL COST
IRIS's Fomers V1.2	1	$1,200
Programmer's Manual	1	$200
TOTAL COST		**$1,400**

Autonomous Wheelchair Cameras and Mounts

Designer: David Koch
Client Coordinators: Dr. Marvin Fifield, Dr. Richard Baer, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson
Center for Self-Organizing Intelligent Systems
Department of Electrical and Computer Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

Essential components of an autonomous power chair are cameras mounted for obstacle recognition and detection. Virtual reality training requires visual feedback through cameras that are stable so that clear images are produced. Stability is dependent upon the rigidity and precision of the camera mounts.

SUMMARY OF IMPACT

Visual feedback via CCD cameras is a necessary function of an autonomous power chair system. This feedback serves to allow close range, intermittent autonomous control and obstacle avoidance, virtual-reality training for long-range path following, and virtual presence control. These design requirements are derived from the different functions that the power chair should provide. Power chair cameras and mounts are an important addition to the autonomous wheelchair project with the potential of helping numerous people with disabilities learn to appropriately navigate their chairs. The cameras will facilitate remote operator control, thus freeing users from dependency on personal attendants, while adding flexibility of movement within the environment.

TECHNICAL DESCRIPTION

The components of the project are driven by design requirements that include:

(1) Precise linear or rotary adjustment. The cameras are used to create a three-dimensional virtual-presence environment. Thus, they must be adjustable to concurrently focus on objects and provide a three-dimensional image. The cameras need to be at a width proportional to the width of the distance between the user's eyes. So, the cameras must be adjusted each time a new driver uses the chair.

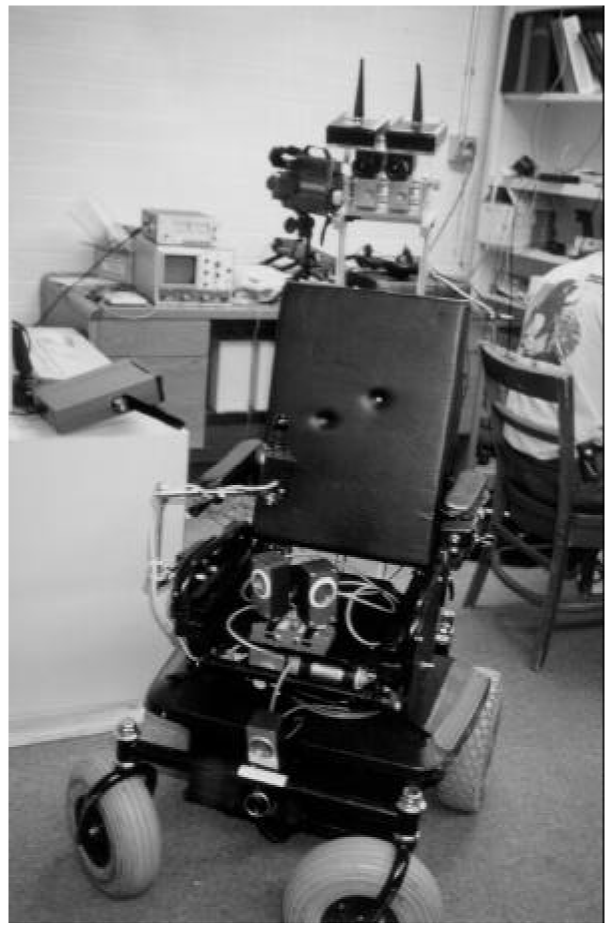

Figure 11.7. Autonomous Wheelchair Cameras and Mounts.

(2) Rigid mounting to facilitate object recognition and detection. The cameras must be stable to create a clear image. Stability is dependent upon the rigidity and precision of the camera mounts.

This project consisted of building mounts and then securing them to the cameras used for the power chair guidance system. It was necessary that the system be flexible enough to accommodate various chair users.

The linear motion of the camera was provided by using pillow blocks mounted on shafts. Two of the shafts were precision Rockwell 60, case-hardened, ½-inch-diameter shafts. The pillow blocks were appropriately drilled; two were fitted with Teflon bushings that ride on the shafts and constrain the motion of the pillow blocks laterally. One other shaft was drilled and threaded, providing the conversion from rotary motion to the shaft of linear motion. The pillow block of the fourth shaft was drilled with an oversized hole that allowed the threaded shaft of the other pillow blocks to pass through. This permitted the pillow blocks to move independently of one another while riding on the same two support shafts. The pillow blocks were machined so that a set of worm gears could be placed in the block that transfers and reduces rotary motion from a screw shaft on the mount to rotary motion of the shaft on which the camera is mounted. The worm gear is supported by bushings and removable locator screws. The complete assembly was then mounted to a frame that was attached to the body of the autonomous wheelchair

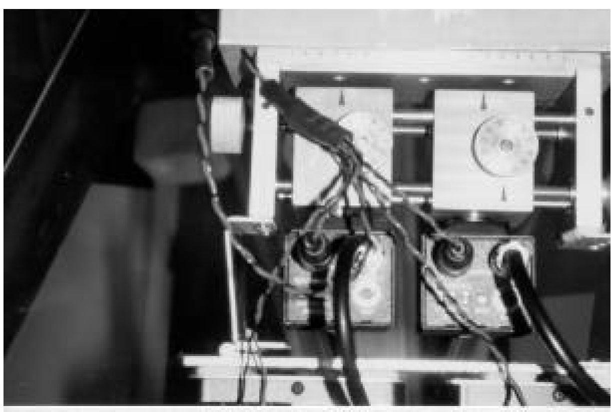

Figure 11.8. Close-Up Photograph of the Autonomous Wheelchair Cameras and Mounts.

"test bed" vehicle. A quick-release clamp was used to allow pivotal motion of the entire mount, thus allowing the cameras to be pointed at different angles relative to the horizon.

The cost associated with this system includes the cameras, machining time for the original parts, and the cost of the parts. Components include mounting blocks and frame, pillow blocks, vertical mounting shaft, extension arms, rotary-motion drive shaft, adjustment knobs, and shared connections. The fabrication of these components constitute the bulk of the cost of the mounts. The components that were purchased off the shelf include: cameras, hardened shafting, threaded shafting, bearings, screws, etc., and a quick-release clamp.

Costs associated with the project include:

ITEM	QUANTITY	TOTAL COST
Color cameras	2 @$850 each	$1,700
Machine time	20 hrs. @$30/hr.	$600
Materials Costs		$120
Total Cost		**$2,425**

Motion Feedback Platform for Virtual Presence Control of the Power Chair

Designer: Don Cripps
Client Coordinators: Dr. Marvin Fifield, Dr. Richard Baer, Center for Persons with Disabilities
Supervising Professors: Dr. Robert W. Gunderson
Center for Self Organizing Intelligent Systems
Department of Electrical and Computer Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

A virtual-presence system that allows a care provider to remotely operate a wheelchair has been developed by the Center for Self-Organizing Intelligent Systems (CSOIS) at Utah State University. However, the current system provides only visual feedback to the remote operator. This information does not always give an accurate indication of the motion orientation of the chair.

It is the purpose of this senior design project to provide motion feedback to the system, allowing the remote operator to feel the same motions of the chair that the occupant is experiencing. Such a system would allow better remote operation and more appropriate and rapid response to chair motion.

SUMMARY OF IMPACT

It was the purpose of this project to collect and provide motion feedback to a remote operator of a power chair, providing additional information on the pitch, yaw, and roll experienced by the occupant of the chair. This information will allow better remote operation by allowing the remote operator to make subtle and rapid changes in the chair's motion, providing a motion platform capable of simulating the range of motion the chair user is experiencing. The remote operator, while sitting on this platform and experiencing the same motion feedback as the user of the chair, can increase the precision and accuracy of the control of the chair.

TECHNICAL DESCRIPTION

A motion platform was built to provide motion in three axes, commonly referred to as pitch, yaw, and roll. The actuators that move the platform in the axis were high-speed linear electronic activators available commercially. Power supply for driving actuators and control electronics for interfacing with the power chair controller were required.

This project used technology and components currently available and in use in a variety of settings. These components were applied to provide motion feedback for virtual presence of a power chair. The project included the integration of these systems, the application of them to a "test bed" vehicle, and a field test of the components to determine their utility in providing necessary motion feedback for a remote power chair operator.

The cost of materials include linear activators at approximately $1,000, the platform structure at $200, power supplies at approximately $500, and interface electronics at approximately $500. The total cost of materials was approximately $2,200. Most of the components were available and used by other projects in the CSOIS. The primary costs for this project involved the power supply and interface electronics, the development of the program, and interface electronics between components.

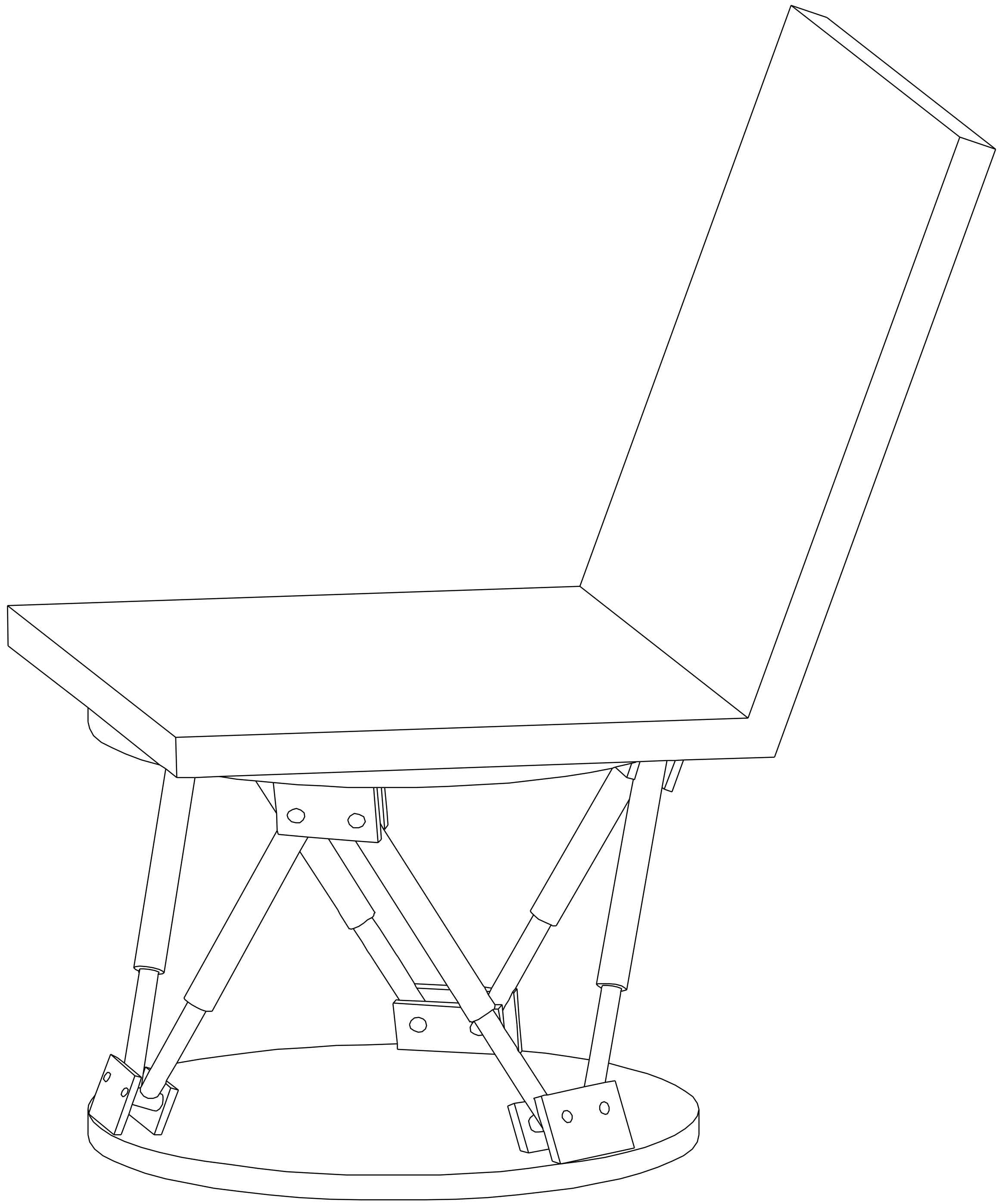

Figure 11.9. Diagram of the Motion Feedback Platform for Virtual Presence Control of the Power Chair.

Forward Motion Prone Scooter Board

Designer: Rick Escobar
Client Coordinators: Amy Henningsen, OT, Center for Persons with Disabilities
Supervising Professors: Dr. Frank Redd,
Department of Mechanical and Aerospace Engineering
Utah State University
Logan, UT 84322

INTRODUCTION

For children with severe disabilities, a prone scooter board is one of the few devices that can expand sensory experience, touch, and movement. Scooter boards are available, but most have to be customized to address the specific needs of clients. Given specific disabilities, combinations of disabilities, ranges of motion, and restrictions in movement, as well as a variety of other factors, many children need a customized scooter board to facilitate movement.

It was the purpose of this project to develop a scooter that would combine several adjustable features, allowing it to be modified to accommodate the needs of a variety of consumers with unique problems.

The client for whom the device was intended is unable to crawl or move on her own. This prevents her from exercising voluntary movement and limits touching and playing with objects. Consequently, interaction and learning from the environment were impaired. The client's leg and thigh movements were rhythmic; thus, with a regular prone scooter board, she moved back and forth, but not forward or backward, for significant distances. As a result, she could not proceed to destinations. To assist her, the project designed a scooter board that allowed only forward motion. Additionally, it was designed to accommodate a feeding tube, a foam pad that could be removed, and a hinged system allowing for height and slant adjustment.

SUMMARY OF IMPACT

Although this project was initiated with a specific child in mind and customized to her individual needs, special features were incorporated to permit it to be adjusted and used by a wide class of individuals with similar levels and types of impairments. The product was designed to be safe, to facilitate interaction with objects and increased sensory functioning, and to allow the user to expand touch, movement, and other kinesthetic experiences.

The product represents another step in a line of research to develop a more universal prone scooter board that can be adjusted easily to accommodate the needs of children with multiple and severe disabilities.

TECHNICAL DESCRIPTION

High-density foam material was utilized to give the user adequate body support. The foam padding was separated to accommodate the client's feeding tube. Gliding hand controls were designed into the scooter board with a mechanism that would enable only forward movement. With the use of hand controls, the scooter board facilitates more muscular involvement, enhancing muscular development. The gliding hand controls can easily be locked into place if this feature is not always needed. Features to prevent backward motion were also built near the rear castors of the scooter board.

The design and shape of the board allow the use of free arm and leg movement, and the board is sufficiently wide to prevent tipping either forward or to one side.

The base component is separated from the foam pad, and a hinge is installed to permit adjustment to the board's angle setting. This provides for greater stimulation and greater individual control by the user. Both the lower and upper boards are easily expandable, allowing for quick adjustment for a wide number of children with multiple and severe motor disabilities. Cost of materials is approximately $75.

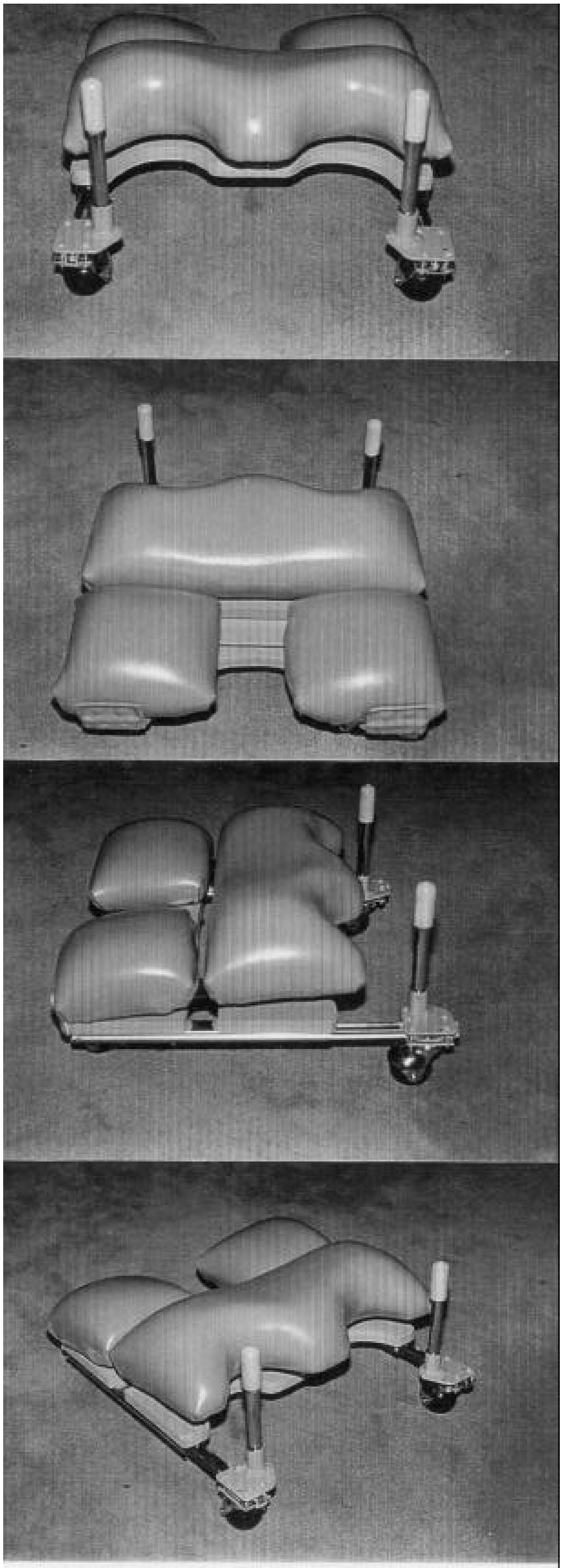

Figure 11.10. Forward Motion Prone Scooter Board.

Feasibility

This design will allow children with muscular problems new opportunities to independently move about, yielding a more normalized environment by providing increased exercise to their muscles and greater opportunity to interact with people and objects.