NAVCHAIR: DESIGN OF AN ASSISTIVE NAVIGATION SYSTEM FOR WHEELCHAIRS

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ABSTRACT

The design of the NavChair system for assistive wheelchair navigation is described. The system utilizes a commercial powered wheelchair which has been enhanced to sense its environment so that it can assist the chair user in safe navigation. Enhancements include an array of Polaroid ultrasonic sensors to detect obstacles, a portable IBM-PC compatible computer, interface circuitry to monitor and control the wheelchair itself and software. This design provides the basic capabilities for a *shared control* system which can augment the limited capabilities of a wheelchair user to permit functional mobility and increased independence.

BACKGROUND

The development of mobility aids for persons with disabilities has followed a logical progression mirroring the pace of technology. In particular, the powered wheelchair has evolved into a range of products which offer a wide variety of interfaces and control features. Nevertheless, persons with a variety of motor, sensory, and/or cognitive impairments find it difficult or impossible to drive a wheelchair.

Many potential users would benefit from a wheelchair control system which assists in making control decisions related to avoiding obstacles, following a straight path, or safely approaching objects. An assistive navigation system for wheelchair control called NavChair is being developed to meet these objectives (3).

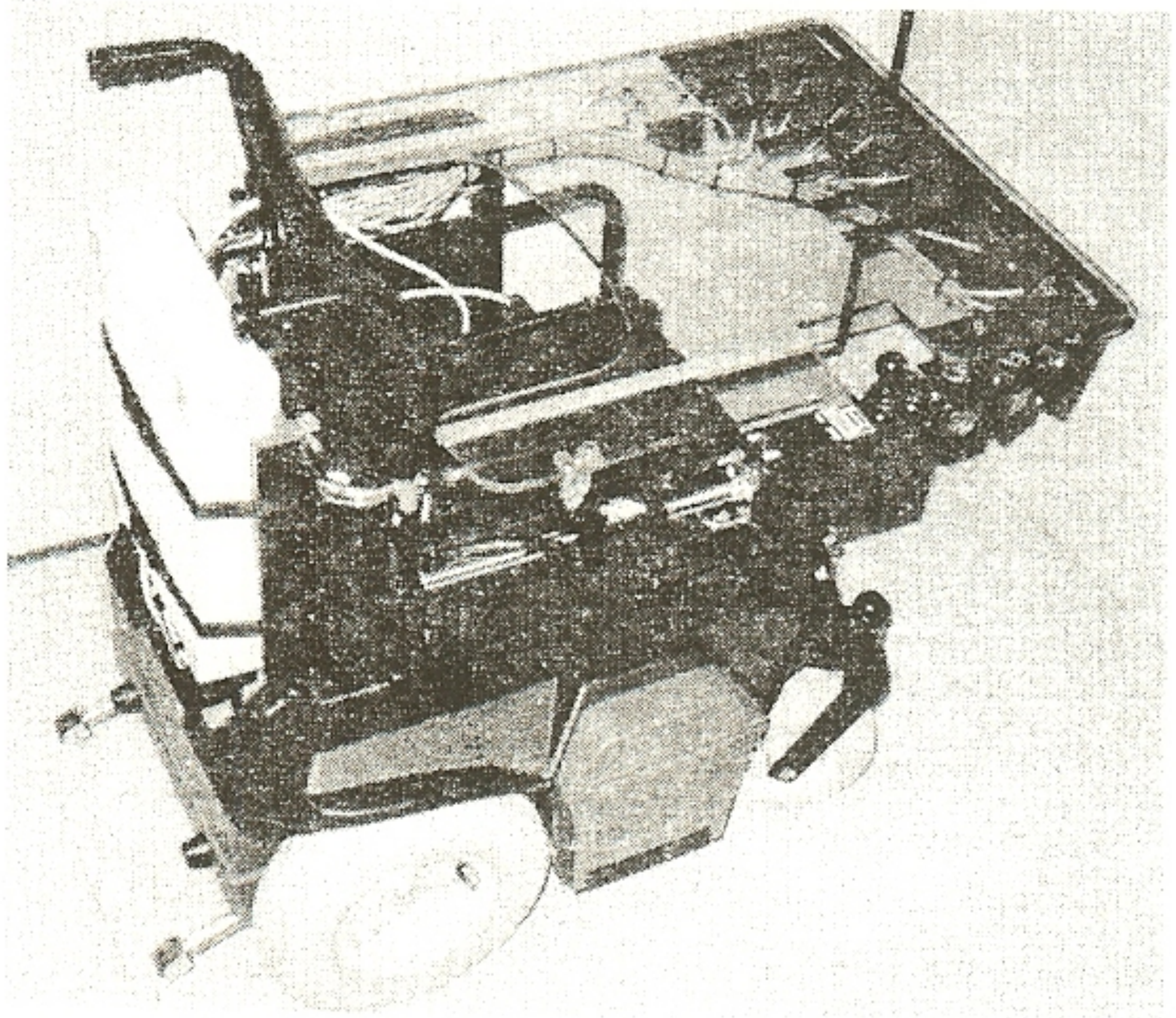

Figure 1. NavChair Prototype

STATEMENT OF THE PROBLEM

The ultimate goal of the NavChair project is to create a wheelchair control system which reduces the motor coordination and cognitive effort required from the user. There are a number of ways to decrease the control demands on the driver. The most important of these methods is automatic obstacle avoidance, which provides the central design goal of the NavChair system. Other features of the NavChair include a wall following mode and a close approach mode. NavChair is based on an ultrasonic mapping and navigation system developed for autonomous mobile robots (2). This technology allows a robot to move smoothly through an environment filled with both moving and stationary obstacles. Avoidance maneuvers are automatic, and occur in real time, without significant slowing of the robot.

NavChair employs these navigation techniques to assist the wheelchair operator. The user indicates desired direction and velocity of travel using the joystick in the normal way. NavChair monitors the joystick and also obstacles in the wheelchair's immediate environment. As long as the user's commands move the chair through clear space, the joystick commands are merely echoed to the power module. When an obstacle appears in the desired path, the NavChair computer will alter the joystick command enough to miss the obstacle, whether this requires a slight steering change for small obstacles, or a full stop when a dead end is encountered.

To provide these navigation capabilities, several features must be added to a standard wheelchair. First, significant computational power is necessary, in the form of one or more computers. The system must have an interface which allows it to read the user joystick and send its own commands to the wheelchair motors. It must have sensors which can detect obstacles around the chair, and finally, it must be able to measure the actual movement of the chair.

This last requirement presents a challenge to wheelchair implementation. In order to maintain a map of the environment, the robot or wheelchair must know when it has moved, so that its internal map can be altered to reflect that change. Mobile robot drive systems are designed with close attention to this requirement. Wheelchairs are quite different. Most make no provision for feedback about wheel movement, as this is normally unnecessary. While pneumatic tires cushion the ride for the user, they slide across the ground easily and move differently at different internal pressures.

DESIGN

The NavChair prototype is constructed on an standard Everest & Jennings Lancer[a] powered wheelchair. Modifications made to the chair, itself, are minor and are described below. The Lancer (Figure 1) is a robust, powerful base with an accurate and responsive control system. It is functionally divided into a joystick module which produces the proportional control signals and a power module which converts these controls into appropriate motor current (Figure 2). This separation of functions allows the NavChair module to intercept control signals from the joystick, modify them and then pass them on the power module.

In standard operation, the joystick module translates the position of the joystick into two output voltages, one for the right wheel and one for the left wheel. The transfer function employed by the joystick module can be customized by the user. A series of 9 potentiometers allow the user to specify individual characteristics such as maximum forward velocity and maximum turning velocity.

The Lancer has one unusual feature which benefits the NavChair project: closed-loop velocity feedback control. This chair is designed to monitor the actual motion of the wheels. This allows it to compensate automatically for unusual terrain such as inclines. To provide this capability, wheel rotation sensors are built in to the motors. These sensors are used by the NavChair system, as explained below.

The components of the NavChair module are mounted on the Lancer and powered by the chair batteries, making the system completely mobile. The NavChair module consists of three subsystems (Figure 2):

Onboard *Master Control* Computer This is a 33 MHz PC-compatible 80486-based computer manufactured by Ergo Computing. Designed as a portable computer, it is small and rugged. It has an aluminum case, internal space for two expansion circuit boards and takes DC power from an external source. The computer reads joystick voltages and produces output control voltages through an internal analog interface board made by Real Time Devices[c]. The computer is visible as the light-colored box behind the chair back in Figure 1.

Ultrasonic Sensor Array A semi-circular array of 12 Polaroid ultrasonic transducers is mounted across the front of a standard-size lap tray. The sensors are aimed in a radial pattern with an interval of 15°. Each sensor can be fired individually, and provides information about the distance to the nearest obstacle in the direction the sensor is facing.

Interface Module All necessary interface circuits are combined in one box, located between the *Master Control* computer and the back of the chair. This box provides voltage conversion for computer power, a multiplexor to fire and read ultrasonic sensors and a set of wheel position pulse counters to track wheelchair movement.

When it is active, the NavChair module interrupts the direct connection of the joystick module to the power module. Joystick signals are read by the A/D board in the computer. In this way the computer can monitor what the user wants the chair to do. The joystick signals can then be modified by the computer (if necessary) before being passed on to the chair power module through the D/A converters in the computer.

Information used by the Master Computer to make decisions about editing the user's joystick commands comes from several sources. The most important of these is the ultrasonic obstacle detection system. The Master Computer can trigger individual sonar transducers to produce a short ultrasonic click (this is called *firing* a sensor). That burst of sound travels away from the sensor, bounces off the closest obstacle and returns. The sonar transducer functions as a microphone to detect this returning echo and the time from trigger to echo is directly proportional to the distance the sound waves have to travel. NavChair uses this method to assemble data about its immediate environment.

While the sonar sensor is attractive due to its simplicity and low cost, individual sonar distance readings are often erroneous. There are several sources for these errors. The sound wave travels out in a 30° cone, and can reflect off anything in that area. Sound from one sensor can reflect back to another sensor. A pulse can bounce off a series of object in a round-about path, before returning to the transducer. A smooth, hard surface oriented at an oblique angle to the sensor may reflect enough of the sound energy away so that not enough returns to trigger the transducer. To extract useful information, sonar readings must clearly be acquired and evaluated under carefully controlled conditions.

The sonar mapping method currently used with NavChair is the result of substantial research in

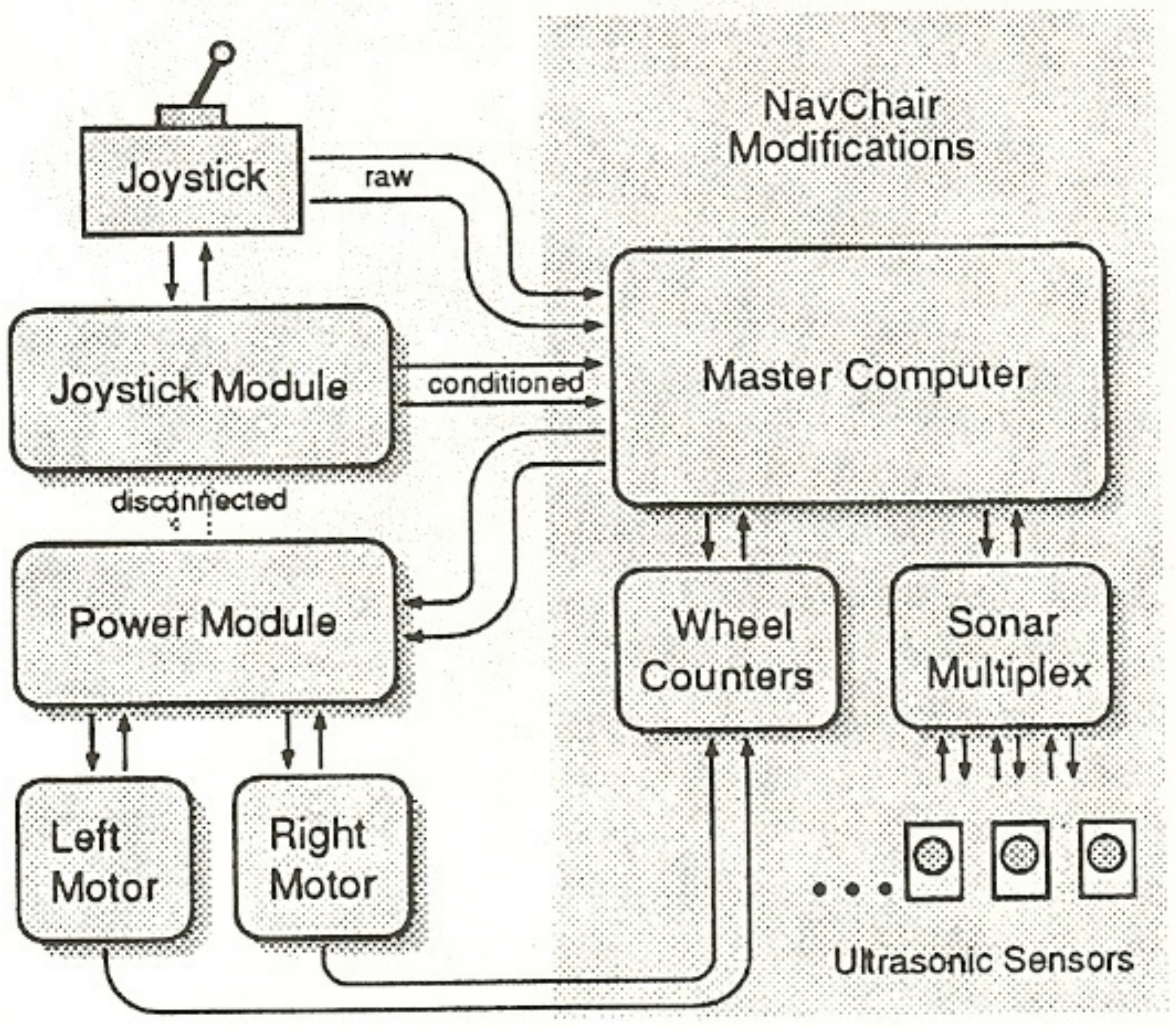

Figure 2. NavChair Block Diagram

controlling autonomous mobile robots. It is called the Error Eliminating Rapid Ultrasonic Firing (EERUF) method (2). The mapping process is performed by the Master Computer. The computer fires all the transducers in the array approximately 10 times each second. By varying the order and timing of individual sensor readings, the EERUF algorithm is able to detect and reject a large proportion of erroneous readings. This correction, combined with large numbers of separate readings, allows the computer to assemble an accurate two-dimensional grid map of obstacles around the wheelchair.

The Master Computer has one other important source of data about the environment. To keep the grid map of obstacles accurate, the computer tracks when and how far the chair moves. This is accomplished using binary counters to track the motion of the two driven wheels, right and left. The counters tally tach pulses produced by the rotation sensors on the wheelchair's motors. Each time a wheel moves one millimeter forward or backward, one tach pulse is produced. To complete the system, the motor circuits also provide a forward-backward signal which tells the counter whether tach pulses should be added (forward motion) or subtracted (backward motion). The Master Computer can read these two counters at any time to find out the current position of the chair.

DEVELOPMENT

During development, the joystick interface had to be redesigned. Initially, it was to use only the control signals coming out of the joystick module. These signals are already modified by the joystick module to limit velocity and acceleration (as dictated by the potentiometer settings). This signal conditioning causes an unacceptable delay between actual joystick motion by the user and output voltage change. The interface had to be altered to give the NavChair system access to both these conditioned signals and the raw position signal coming straight from the joystick.

Another area which had to be reworked was the motion control software. As noted above, the Lancer monitors the actual motion of its wheels and alters motor current automatically to maintain velocity. Thus, a given control voltage produces the same chair velocity whether the chair is going uphill or downhill. The initial NavChair plan was to rely on this built-in velocity control. Experimentation showed that this did not give the NavChair software accurate enough control. The software now monitors wheel motion and implements its own closed-loop feedback control.

DISCUSSION

The hardware of the basic NavChair system is complete. The functions of ultrasonic mapping, obstacle detection, path planning and motor control operate as planned. The software can be configured to make the wheelchair function much as the robot from which it is copied. In fact, one of the system tests used was to run the wheelchair as an autonomous robot, without a driver.

However, this represents the completion of only the first phase of the NavChair project. Current efforts are focused on refinement of navigation routines and optimizing performance. This includes the development of methods for a user to manually choose between various control modes (wall following, close approach, etc.). Next will come testing with users to investigate the functional effectiveness of the NavChair system as well as to establish optimal system configuration for varying user capabilities.

One offshoot of this research has been the use of the NavChair for investigating issues related to *shared control* systems (3). *Shared control* describes systems where both human and machine participate in the control process. Study includes the development of methods for automatic mode selection based on prediction of human intention.

ACKNOWLEDGEMENTS

This work is funded under a grant (Number B630-DA) from the Department of Veteran Affairs Rehabilitation Research and Development Service.

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