THE NAVCHAIR CONTROL SYSTEM FOR AUTOMATIC ASSISTIVE WHEELCHAIR NAVIGATION

Simon P. Levine, Johann Borenstein, Yoram Koren

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation
Mobile Robot Laboratory, Department of Mechanical Engineering
University of Michigan

INTRODUCTION

There are a variety of control systems which permit severely handicapped people to operate a power wheelchair. However, there are still many people who could benefit from powered mobility that are unable to safely and effectively operate any of these systems. Impaired motor, sensory, or perceptual functions which can make it difficult or impossible to operate a power wheelchair include spasticity, tremor, paralysis, weakness, poor vision, visual field neglect, etc. Even wheelchair users with good capabilities for operating a power wheelchair experience collisions with objects in their operating environments (walls, people, etc.).

This paper presents the operational characteristics of an assistive navigation system for wheelchair control named *NavChair*. The NavChair system provides for automatic obstacle avoidance to greatly reduce or eliminate the possibility of collisions for a wheelchair user and wall following capabilities for improved tracking. The goal of this system is to provide improved mobility and safety for people who have impairments which limit their ability to operate a power wheelchair.

METHODS

The NavChair system is based on new mobile robot navigation technology (1). A key advance incorporated into this technology is that the robot does not stop in the autonomous process of avoiding obstacles. Furthermore, speed is only marginally diminished during most avoidance maneuvers.

Obstacle avoidance methods are based on a newly developed technique entitled the "vector field histogram" (VFH) algorithm (1). The VFH method uses a two dimensional Cartesian *histogram grid* for representation of obstacles. Each grid cell contains a time dependent probability that the cell is occupied. These probabilities are continually updated based on range data obtained from ultrasonic sensors. Data from the histogram grid is reduced in two stages. First, the grid is reduced to a one dimensional polar obstacle density histogram centered at the robot's current location. Then, a suitable direction with low obstacle density is chosen in order to move as close as possible to the prescribed direction.

The VFH method allows simultaneous sensing of the environment and control of robot motion, with each newly acquired data point from the sensors immediately affecting robot steering and speed. The VFH method has been found to be effective in compensating for the shortcomings of ultrasonic sensors especially when used in combination with custom developed sampling routines which help eliminate sensor cross talk problems.

A new type of mobile robot operation which has been developed and is the direct basis for the NavChair system is *Tele-autonomous* control. With this method, the mobile robot assumes responsibility for its own protection from collisions (using the algorithms described above), while concurrently following a remote operator's instructions. This approach combines the two traditional modes of control for mobile robots, namely: (a) tele-operated mode, in which an operator has full control over the robot's motions and (b) fully autonomous mode, without direct human interference. Tele-autonomous control was originally designed to operate with robot sensor feedback provided to a remote operator. However, feedback is not required for applications such as the NavChair system where the operator is actually riding on or in direct visual contact with the vehicle under control.

OPERATION

NavChair is an "assistive" control system which combines with an operator's control inputs to improve tracking and provide automatic obstacle avoidance. It can be integrated with standard power wheelchair controls such as a joystick or switch inputs as well as any other type of control scheme (head positioning, voice command, etc.). The NavChair system integrates sensor data into the control scheme and includes algorithms for both obstacle avoidance and wall following. It utilizes a set of ultrasonic transducers placed around a wheelchair in order to sense obstacles in its environment while simultaneously providing input to the motion control algorithms.

Under the standard mode of NavChair operation, a wheelchair (or other vehicle) follows the general direction prescribed by the operator. However, if the wheelchair/vehicle encounters an obstacle, it autonomously avoids collision with that obstacle, trying to match the prescribed direction as well as possible. As soon as the path is clear again, the wheelchair/vehicle resumes motion in the prescribed direction. With this integral self-protection mechanism, wheelchairs or other vehicles can be steered at high speeds and in cluttered environments without fear of collisions.

Most obstacle avoidance methods usually bring a wheelchair/vehicle to a stop when obstacles or potential collisions are identified and then rely totally on the operator to steer around the obstacle. Even in the most sophisticated systems obstacle avoidance requires substantial slowing of a vehicle. In contrast, the NavChair has the ability to automatically steer around obstacles with only a marginal decrease of speed in most situations.

A second mode of operation under development for the NavChair system is "wall following". In this mode the wheelchair travels parallel to a wall as long as some degree of forward motion is signaled from the user. Control commands to steer the wheelchair away from or towards the wall are ignored even if they can be safely performed without the possibility of a collision. Obstacle avoidance remains active during wall following. Manual methods under consideration for switching between normal mode and wall following mode include a separate switch or a coded sequence of wheelchair control inputs (i.e. directing the chair at greater than 90° away from the wall in order to leave wall following mode). Automatic switching between modes is also under consideration.

A third potential mode of operation is possible for training prospective wheelchair operators using the obstacle avoidance algorithms of the NavChair control system. In this mode the NavChair routines would not exhibit any active control over the wheelchair drive system but rather selectively filter out any wheelchair control signals from the user which would lead to a collision. Thus, in a training environment, a user could safely attempt to operate a wheelchair but would not be able to move in the indicated direction unless it was safe to do so. This type of feedback system provides an ideal environment for training individuals with marginal capabilities for wheelchair control.

PROGRESS TO DATE

The NavChair control system has been prototyped using a Cybermation K2A mobile robot platform which has a maximum travel speed of 0.78 m/sec and weighs approximately 125 kg in its current configuration. A 3-wheel synchro-drive permits omni-directional steering under the control of an on board Z-80 controller. Custom hardware developed for this system includes a ring of 24 ultrasonic sensors interfaced with a dedicated controller. An 80386 based computer has also been added on board to run the navigation software and direct the motion of the robot.

Initial testing of this system is being performed with a remote operator in direct view of the prototype using a joystick control to drive the robot. Successful trials have been performed in the laboratory through relatively cluttered environments including chairs, desks, tables, and even vertical dowel rods as narrow as 3/4 inch in diameter. The system's ability to avoid moving obstacles has also been demonstrated in preliminarily trials. Trials with an operator riding on the robot are planned in the near future.

The NavChair control system and the user can be viewed as co-dependent components of the wheelchair navigation system. Engineering analysis of this "shared control" aspect of the NavChair system is being performed to further understand and improve its performance (2).

DISCUSSION

The NavChair control system potentially permits individuals with a wide range of motor, sensory, and perceptual difficulties who would normally be unable to operate a power wheelchair to do so. It also can increase the safety of power wheelchair operation for more capable users.

The NavChair system provides the capability to automatically steer around any stationary or moving obstacle occurring in a wheelchair's path while following the user's general direction and speed input to the greatest extent possible. This includes the elimination of the case where a user "cuts a corner" too close and runs into it — a problem even for wheelchair users with good motor control and sensory perception. It also provides the capacity for an operator to travel through narrow passageways, doorways, and tight spaces by the general indication of a forward control command, since the obstacle avoidance routines will keep the wheelchair centered in such situations. Additionally, the wall following mode allows a wheelchair operator to follow a straight path parallel to a wall even though they could not maintain a straight path on their own.

Planned development for the NavChair system calls for the integration of wall following mode including mechanisms for turning this feature on and off. A second NavChair prototype based on a commercial wheelchair base is the next anticipated step, prior to testing in a wide range of environments. Design criteria to be determined during testing include the minimum number and mounting positions of ultrasonic sensors required for acceptable performance.

An extension of the NavChair technology is also under development to allow people with severe visual impairment to operate a power wheelchair in unstructured environments (2). This system incorporates audio feedback to the operator for navigation in combination with the other NavChair system features.

REFERENCES

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ADDRESS

Simon P. Levine, Ph.D.
1C335 University of Michigan Hospital
Ann Arbor, MI 48109-0032