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A Robotic Wheelchair

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p. 5

Abstract

Many people who are mobility impaired are incapable, for a variety of reasons, of using an ordinary wheelchair. These people must rely on either a power wheelchair, which they control, or another person to push and guide them while they are in an ordinary or power wheelchair. Power wheelchairs can be difficult to operate. If a person has additional disabilities, either in perception or fine motor control of their hands, a power chair can be difficult or impossible for them to use safely. Having one person push and guide a person who is mobility impaired is very expensive, and if the disabled person is otherwise independent, very inefficient and frustrating. This paper describes a low-cost robotic addition to a power wheelchair that assists the rider of the chair in avoiding obstacles, going to pre-designated places, and maneuvering through doorways and other narrow or crowded areas. This system can be interfaced to a variety of input devices, and can give the operator as much or as little moment by moment control of the chair as they wish.

1 Introduction

The powered wheelchair as an assistive device for the mobility impaired is a direct outgrowth of the basic metal tube parallel frame design philosophy that originated just before W.W.II. It was developed by adding DC drive motors to the manual design and an analog differential joy stick for direction control. In many cases, speed control as an on-off-coast function with little or no progressivity. Late in the 1970's, the advent of computer miniaturization led several designers to investigate the potential applications of digital control as means of expanding range of capability, user features and environmental compatibility. While the fruits of these previous efforts are just now beginning to enter the marketplace, all are flawed in that they lack the sort of "intuitive" directional capability commonly exercised by the able bodied when proceeding from point A to B. Although this is not necessarily a major problem for the mobility impaired individual who retains adequate upper body and extremity motor control, for those with more profound loss and/or multiple disabilities, it can result in near or total removal of personal options for independence.

1.1 Current State of the Art:

Microprocessor-controllers are now available with varying degrees of capability and programmability. Much of the effort, to date, has focused on providing clinicians the ability to "program" performance parameters, improve the linearity of control/speed response and develop chair to "external" environmental interfaces. The rate of acceleration and turning are tuned to a particular user's capabilities and environment.

Quest technologies provided a degree of automation for its *access* chair that related to edge and drop-off recognition, which is probably the only FDA "approved" use of automation in wheelchair applications. Those that would benefit from the application of more automation in chair control include:

- Upper level spinal cord injured incapable of operating joy stick controllers. Such individuals currently use either a chin adapted joy stick, head controller, or a "sip" and "puff" actuator.
- Neurologically impaired (stroke, cerebral palsy, ALS, MD, MS, etc.,).
- People with low and eccentric vision.
- Individuals with multiple handicaps.
- Geriatric populations with declining physical abilities.

Despite the advances in robotics and AI research in other fields, little practical work has been done in adapting power wheelchair control to be more usable by the class of potential users outlined above. What work has been done (e.g., [3]) uses customized platforms and electronics and is prohibitively expensive.

1.2 An "Autonomous/Intuitive" Controller:

An autonomous controller should embody the capabilities necessary to safely and efficiently operate a powered wheelchair for a wide variety of individuals with profound motor and neurological control functions. It should be able to track a given course from A to B while avoiding intervening obstacles as part of its decision making process, rather than that of the operator. The ability to perceive unsafe environments should be incorporated as some of the target user population is so positioned or otherwise limited that their range or degree of effective vision is severely circumscribed. Essentially, it should be possible for its user to operate the system using various control interfaces that range from a joystick through chin and "sip" and "puff" to voice and eyegaze. All operating parameters (speed, turn rate, access to options, etc.,) must be readily prescribable and programmable by the clinical "intervention" team of doctors and therapists to assure professional acceptability.

The remainder of this paper describes Tin Man, a *Vector* brand power wheelchair which has an enhanced controller and sensor array. Tin Man allows the user to operate the chair in a variety of modes ranging from normal power chair operation through simply designating a heading which the chair will follow while automatically skirting obstacles. But perhaps the most significant accomplishment of Tin Man is that it involves virtually no custom electronics or mechanics. All components are consumer off the shelf, and the component cost of the modifications to the standard power chair are less than $500, and take less than a day to put together and install on the chair. The initial design of the controller and construction of the software took appreciably longer.

2 System Design

This section describes the hardware and software of *Tin Man* the robotic wheelchair.

2.1 Hardware Configuration

Tin Man is built on top of a commercial pediatric wheelchair from Vector Wheelchair Corporation. In its current instantiation, Tin Man has no electrical interface between the chair's controls and the robot's computer. Instead, there is a mechanical interface. The control computer controls two servomotors which are mechanically linked to the standard joystick that comes with the chair. The user enters their commands through an input device (usually another joystick). The commands and sensory data are processed by a commercial micro-controller based around the Motorola 68HC11 processor. The micro-controller then commands the servo motors which move the main joystick on the chair. The joystick position is read by a standard wheelchair analog controller which generates PWM signals to the two drive motors.

Tin Man has five types of sensors:

- Drive motor encoders;
- Contact sensors;
- IR proximity sensors;
- Sonar rangefinders;
- Fluxgate compass;

Tin Man is equipped with encoders on each of its drive motors. The drive motor encoders, after gearing, deliver a resolution of 6.725 tics per inch. With the encoder resolution and the robot's wheel separation, theoretically the robot's orientation can be known to a resolution better than 0.01 radians. Unfortunately, because of the width of the drive wheels, slippage, wheel distortion, etc., it appears that the robot is only able to turn within $\pm 10\%$ of the commanded amount. As a result, dead reckoning errors can grow quickly.

There are eight contact sensors on the robot. Each sensor is made from a resistive strip approximately ten centimeters in length. As the strip is bent, its resistance changes, and the degree of the bend can be calculated from the current flow through the strip. Two of the strips are mounted on each side of the robot, one in front of the wheel and the other in front of the armrest. The remaining four sensors are mounted on the front. These sensors are enclosed by a sheet of foam rubber. The foam fills the gaps between the sensors. If the foam contacts an obstacle, its shape is distorted causing the sensing strips to bend.

There are four IR proximity sensors distributed evenly along the front and sides of the robot. These sensors emit a coded beam of infrared light. If an object is nearby, the light is reflected back to the sensor. When a reflection is detected the sensor goes high. These sensors are very albedo sensitive.

There are six sonar rangfinders on Tin Man. Each sonar has a resolution of one centimeter, a minimum range of thirty-five centimeters and a maximum range of five meters. It takes each sensor approximately two-hundred milliseconds, from the time it is activated until it settles on a reading. Due to port limitations, all of the sonars are ported into the same timing port. They are sampled round robin. Each sonar can be activated or deactivated in software, and only the active sonars are polled. If all the sonars are active, it can take over one second between readings from a specific sonar.

The fluxgate compass is a standard compass meant to be used in an automobile. The coils that control the display are directly wired to two of the analog to digital ports on the micro-controller. The computer can distinguish changes in heading of approximately ten degrees. While not adequate for accurately traversing long, open distances, this is sufficient resolution for navigating along streets and in building corridors where the environment can help you keep on course.

2.2 Software Design

The software for Tin Man is written in IC, an interactive, multi-tasking dialect of the C language. Each sensor type has its own asynchronous process which monitors those sensors. With the exception of the sonars, every sensor is polled at at least 5Hz. The maximum safe speed of the chair is governed by this sensor refresh rate combined with the deceleration rate of the chair.

All the sonars are multiplexed through a single port and into a single timing register. It takes several ultrasonic pulses to ensure a reliable distance reading from the sonar, and from the time the first pulse starts, till the last echo returns, a single sonar owns the timing register. A single sonar can be read at 3-5Hz. Most modes of the robot use at least three active sonars leading to an update rate of approximately 1Hz.

In the manual operation mode, the operator gives their input through a joystick. The micro-controller reads the joystick and issues servo-motor commands to cause the chair's joystick to copy the movements of the operators joystick. There are three semi-automatic modes that Tin Man can run. They are:

- Human guided with obstacle override;
- Move forward along a heading;
- Move to X,Y.

In all three modes, the same priority scheme holds true:

1. If a contact sensor reads true, the chair moves away from the point of contact;
2. If a proximity sensor reads true (and contact sensors do not) then the chair turns away from the direction of the sensor reading true (if both front sensors read true then the chair will back up, if both side sensors read true then the chair will go straight, slowly);
3. If a sonar senses an obstacle less than 60cm away in front or behind then the chair will not move forward or backward. If a sonar senses an obstacle less than 1m away, then the chair will turn away from the direction of the obstacle;
4. The robot follows the designated heading or towards the designated waypoint, unless this conflicts with one of the sensor rules listed above;
5. The chair follows the commands from the user input device, unless the commands conflict with one of the rules above.

When operating in the obstacle override mode, the chair follows the user's instructions except when a nearby obstacle is detected. When an obstacle is detected, the chair will modify its heading, following the a safe heading that is as close as possible to the heading being input by the user. If the user puts in a stop, the chair will stop. This is probably the most common mode to run the chair. It is especially useful when training someone to use a power chair. It is also helpful when maneuvering in tight spaces or through narrow doorways. For an operator with slow reflexes or limited perception, this mode allows the chair to be operated at a speed much faster than would otherwise be safe. In all cases, it greatly reduces the risk of impact with an obstacle, and the severity of an impact should one occur.

The move forward along a heading is the mode that is most useful for someone who has a very limited amount of bandwidth for input to the chair. The chair can be spun until the desired heading is reached. When at the desired heading, the chair moves forward, avoiding or maneuvering about obstacles as needed. If the chair is pointed in the general direction of a doorway, it will autonomously maneuver through the doorway. If pointed down a hallway, the chair will continue down the hallway until blocked. The only control needed by the user is to: put the chair into this mode; designate the proper heading; tell the chair when to stop. Currently all three commands are executed by pressing a button at the desired time, but they could as easily be commanded by monitoring eye blinks or a sip/puff controller.

The move to X,Y position mode allows the user to specify a specific position in absolute coordinates for the chair to go to. A heading to the desired point is calculated, the chair turns to that heading and then moves forward much as in the previous mode. Obstacles are avoided, and after each deviation, the chair heads straight for the goal location. This mode is meant to be used only in situations where there is a mostly clear path towards the goal location. To go to locations that involve going around corners, down corridors, etc., it is best to input a series of locations representing waypoints for the robot to follow.

3 Future Work

Tin Man has two major shortcomings that prevent it from being a useful device for the mobility impaired: the current user interface and the current handling of raised obstacles such as tables and desks.

The current user interface is all run through a joystick and menu with two selector buttons on the micro-controller board. In order to switch between modes, or set specific X,Y positions, a level of dexterity, visual acuity, and flexibility is required that is inconsistent with the targeted user group. These problems can be easily overcome by repositioning the control panel on the chair's armrest, using larger buttons and a larger, backlit display.

A more serious shortcoming is that the vast majority of obstacle sensors are located near to the ground, where the vast majority of obstacles are to be found. However, common objects such as tables and desks, which may have clearance adequate for the chair, do not have adequate clearance for the user. We believe that an upward looking sonar would be able to detect when the chair is starting to go under an object without adequate clearance for the user. When this condition is detected, appropriate action could then be taken by the micro-controller. Stairwells and other dropoff could in principle be detected similarly by using a downward looking sonar or proximity sensor.

We plan to supplement the chair's current capabilities (obstacle avoidance while following user commands, following a heading, or going to a specific point) with the following:

Backtracking: the chair would retrace its previous movements up to some limit or till stopped by the user. This would allow the user to quickly and easily return to a previous location or room. This would be accomplished by recording waypoints every time the chair changed its heading significantly and then automatically performing a series of X,Y moves to the list of waypoints, in reverse order.

Wall Following: the chair would align itself to the wall (selected by the user) and move along that wall at a constant distance (while avoiding obstacles) until terminated by the user. This would be implemented by servoing (when no other obstacles were closer) to a preset distance on the side sonars.

Docking: the chair would approach an object in front, slow down and stop at first contact. If the object was a table or a desk, the chair would slow and then stop when it was a prespecified distance under the object.

Automated Safing: these functions would prevent the chair from moving too quickly over bumpy surfaces or going over terrain that might cause tipover. Both functions could be implemented using roll and pitch "3-position" sensors.

Path Planning: the Tin Man micro-controller can easily be connected to a general purpose computer for carrying out more complicated tasks. The capabilities currently implemented on the chair can act as the low-level reactive skills for an autonomous agent architecture that has been created [4, 2, 5, 1, 6]. Under this mode, the user would interface through a laptop or similar additional computer installed on the chair, hooked into the chair's micro-controller. The laptop might have a CAD model of the building. The user would specify where the chair currently is, and where the user wants to go. A topologic path planner would use the model of the building to generate waypoints for the controller. It could also monitor some of the sensors to update its position during the traverse (e.g., monitor the side looking sonars so that it would know when it had moved through doors). This way, dead reckoning errors could be kept to a minimum. If the chair should stray too far due to slippage, the user could update their position on the map. The laptop could be used to drive a host of more sophisticated interfaces (than the joystick and buttons) including an eye tracker, a speech interpreter, or a menu driven "sip/puff" controller.

4 Conclusions

We have constructed a robotic wheelchair that is capable of maneuvering through a wide variety of typical environments without collision. The chair takes direction from the human user in a variety of forms ranging from direct control to destination specification. This type of chair should prove useful to persons with mobility impairment and limited visual acuity, spasticity, diminished fine motor control or any condition that makes it difficult for them to independently operate a normal power wheelchair.

The most significant accomplishments of this project are: the equipment and parts are all readily available and off the shelf; the cost for the modifications represent only a 10% increase in cost over a normal power wheelchair. Tin Man is an existence proof that robotic aides for the mobility impaired do not have to be prohibitively expensive.

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