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Development of an Autonomous Wheelchair: A Progress Report

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Abstract: An autonomous wheelchair is developed with the aim of alleviating the handicap faced by those with impaired mobility. The wheelchair will seek the correct position of a patient holding a key card inside a specified room or a control environment and navigate its way to the said patient autonomously. The wheelchair will consist of two DC motors, a transmitter-receiver pair, and four proximity sensors that will be operated by a central Raspberry Pi 3, possibly in combination with an Arduino. The motors used are 24VDC 250W brushed DC motors, which will be independently controlled based on input provided by the proximity sensors and onboard receivers. Taken into account in performance testing were factors such as time taken to complete operation of initiation of Zigbee reception to arrival at within 30cm of the patient, detection of sudden changes in terrain height such as stairs, variation in sizes of the obstacles in the environment, motor rotation in collision detection, the effect of increasing the surface inclination and treading material on motor performance and traction.

Key Words: Autonomous; Wheelchair; Impaired Mobility; Navigation

1. INTRODUCTION

Wheelchair, as its name states, is a chair with wheels. It is an instrument/tool used by people who has difficulty in walking or due to illness, injury or disability, can no longer walk. The basic wheelchair being sold in the market today incorporates a seat, footrest and four wheels; which is usually being operated manually, either by an external/another person pushing the wheelchair or the wheels being moved by the person sitting on the wheelchair itself. There is also another variation of the wheelchair which is powered and moved by means of an electric motors and a navigational control which is usually a joystick that can be found in the armrest; known as Electric or Motorized wheelchair. These motorized wheelchair are useful for those unable to move the wheelchair on their own or have access to external help.

Mobile robotics is a branch of robotics that deals with robots that has the capability to move around their surroundings which can either be autonomous, semi-autonomous or manually controlled via remote controlled. Mobile robotics has been applied in many industrial and commercial use and has made moving heavy materials more efficiently. Autonomous mobile robotics is a control system having a programmed microcontroller as its controller. The robot will function depending on the program assigned to the microcontroller.

The thesis proposed in this paper is about incorporating a control system into a secondhand manual wheelchair. The prototype is to detect a person when he/she is in range using Zigbee, then the chair will maneuver towards that person at the same time avoiding obstacles along the the path in the process making use of its distance and proximity sensors

The general objective of this project is to create a wheelchair that will move autonomously from a non-predesignated starting position towards a particular patient; maneuvering its way past any obstacles that may appear in its path. The specific objectives are:

1. To design a prototype of a chair equipped with a microcontroller, motors, wheels and sensors.

2. To fabricate the designed prototype.
3. To test the prototype based on response time, restrictions in and range of in functionality, sensitivity in movement, accuracy of destination, and consistency of results and data.

1.1 Scope And Limitations

The purpose of the prototype will be to propose a system that will bring a wheelchair (of any kind), to the patient, alleviating the workload on existing hospitals' limited working staff by automating some of the work done by nurses and support staff. The focus of the study and objectives will be completely met once the prototype has reached its intended destination without any human intervention. While this technology in itself is in essence only doing half the job, the expectation is that it may be applied to existing technology by retrofitting an electric wheelchair or chairs of the like that do not require manual labor and require minimal user guidance.

1.2 Literature Review

Anti-collision systems have been developed and attached to powered wheelchairs to aid disabled people with physical impairments to safely maneuver along paths while riding the wheelchair. The capability of anti-collision systems to detect objects depends on the object's size, shape, specularity, reflectivity and sound absorption characteristics (How 2010). The sensors are tested to sense different objects typically seen in a room. The result with using a single sensor is that small objects can be easily detected by smaller cone of detection while larger objects can be easily detected by larger cone of detection. The result of testing with multiple sensors is that it can create larger cone of detection but it will incur disadvantages such as additional delay. From this article, the researchers can get ideas from the tests and trials on how to detect certain objects which will give findings on the limitation of the proposed sensors of the new study.

An intelligent wheelchair system (IWS) can also make use of stereovision camera for detection. The IWS uses a Focus Robotics stereovision camera as a forward sensor. It has the ability to calculate depths in real-time speeds. The data is then analyzed to calculate the depth of the obstacle and the navigation system will calculate a different direction of greatest freedom in front of the wheelchair. The user won't be able to move the joystick to the direction of the blocked zone (Dutta 2005). Unlike the IWS that uses stereovision camera as the primary tool for detection, the group will use proximity sensors. Proximity sensors are more simple and less expensive. Stereo vision calculates the depth of objects, however, the researchers only needs to identify that an object is nearby for the wheelchair to avoid it, which can be done by a proximity sensor. Another intelligent wheelchair is the "TAO Aicle" which is a wheelchair robot that has autonomous traveling capability. It has internal sensors that use Global Positioning System (GPS) and Radio Frequency Identification (RFID) to map out the environment unlike other wheelchairs that uses sensors such as infrared and ultrasound (Matsumoto 2008). "TAO Aicle" uses GPS whenever it is outside of a building, on the other hand, it uses RFID whenever it is inside. The wheelchair in this study is located in a closed room, therefore, it will only require RFID.

A different wheelchair is invented to be controlled by a disabled person. It caters to different types of disabilities. For persons with only lower body injuries, joysticks are provided for control. For more severe disabilities, voice recognition and finger movement tracking is available and for the worst case, eye tracking is also given. To help in navigating, this wheelchair also features obstacle avoidance using ultrasonic and infrared sensors (Asgar 2013). This is similar to the study in terms of navigating through obstacles. Same principle is used which is making use of sensors for detection, however, as stated above, the researchers will be using proximity sensors and not ultrasonic and infrared that are used in the previous study.

There are a number of intelligent wheelchair that are now created and developed. A previous study was conducted that centers on how these intelligent wheelchairs work or how it come up with decisions on its own in certain situations (Boucher 2013). The study tackles mostly on the control systems of the intelligent wheelchairs which this project also has. The researchers will also develop a control system similar to other wheelchairs however, some intelligent wheelchairs covered by this previous study needs human interaction, not fully autonomous.

2. METHODOLOGY

The researchers will modify a secondhand manual wheelchair. DC motors will be attached to its wheels, proximity sensors placed in appropriate locations of the chair, and both will be connected to a Raspberry Pi 3 microcontroller, which will be placed in a chamber under the seat of the wheelchair. Zigbee receiver modules will be placed in the same locations as the sensors, and the transmitter will be placed in a key-card held by the user. An additional proximity sensor will be placed under the seat to avoid staircases and similar sudden drops or jumps in the surface.

Performance testing will be carried out in multiple stages, the first of which will verify the ability of the system to detect signals from the sensors and receivers and being able to react desirably. Next, the environment will be varied to test the performance limits of the model such as the minimum size of detectable obstacles, effect of surface inclination, treading surface, and sizes of the changes in surface level and the corresponding motor response.

2.1 Control System

The flow of the code will begin at the detection of the transmitter from which the receivers around the wheelchair will receive a specific signal. The signal received by the receivers will be different from one another, and the chair will face in the direction of the strongest signal. After the chair has rotated it will start moving towards the direction of the strongest signal, while the proximity sensors detect if there are any obstacles in its path. The chair will find a different route to take if there are obstacles in its original path. The code will keep on repeating until the chair is about 30 centimeter from the transmitter which will terminate the program.

2.2 Small Scale Basic Implementation

The authors designed a simple preliminary model using a 5V DC Motor, an ultrasonic sensor, and an Arduino with a motor driver shield, programmed using C++. The idea was to implement a basic collision detection system where the motor function is dictated by the signals actuated by the sensor to the controller. While the implementation was successful, several further issues are expected to be encountered in a full scale model and changes will be administered to accommodate a more powerful (24V 250W) motor, and a heavy power source. Moreover, Raspberry Pi 3 will replace the Arduino for increased flexibility in performance and power capabilities.

2.3 Motor Calculation

The required specification of the motor to be used is determined theoretically by a series of motor speed and torque analysis equations. The minimum performance characteristics desired from the motor was a minimum top speed, V_{max}, of 1 m/s and a maximum acceleration, $a_U = 0.2 m/s^2$ at a 10° surface inclination, α, and a gross tare weight, GTW, of 48 kg distributed such that the weight on the drive wheel, W_D, is 19.2 kg (40%) of the gross weight. Note: The subscript U will be used henceforth to denote calculations based on uphill requirements (α ≠ 0)

The wheelchair used has a radius, R_W of 40cm and the surface is assumed to be concrete with a coefficient of rolling resistance, C_{RR}=0.02 and coefficient of dynamic friction, μ_k with rubber tires at 0.8. The following calculations were made to determine the motor specification:

First the *wheel speed*, N_U of the motor is calculated using the formula:

$$N_U = 60s/min * V_{max}/(2\pi R_W) \quad \text{(Eq. 1)}$$
$$N_U = 23.87 \ rpm$$

Rolling Resistance, RR_U (Eq. 2)
$$RR_U = C_{RR} * GTW * g$$
$$RR_U = 9.418N$$

Grade Resistance, GR_U (Eq. 3)
$$GR_U = GTW * g * \sin\alpha$$
$$GR_U = 81.767N$$

Acceleration Force, FA_U (Eq. 4)
$$FA_U = GVW * a_U$$
$$FA_U = 9.60N$$

**Total Force, F_{UT}*
$$F_{UT} = RR_U + GR_U + FA_U \quad \text{(Eq. 5)}$$
$$F_{UT} = 100.785N$$

Power, P_U
$$P_U = F_{UT} * V_{max} \quad \text{(Eq. 6)}$$
$$\mathbf{P_U = 100.785W}$$

Drive Wheel Torque, T_{UW}
$$T_{UW} = F_{UT} * R_W \quad \text{(Eq. 7)}$$
$$T_{UW} = 40.314 \ Nm$$

Maximum tractive Torque, T_{UT}
$$T_{UT} = \mu_k * g * W_D * R_W \quad \text{(Eq. 8)}$$
$$T_{UT} = 60.273 \ Nm$$

The above calculations yield a minimum motor power of marginally over 100W. However, for flexibility and cautionary practice, a 250W motor will be installed in the initial prototype of the semi-autonomous wheelchair. Crucially, the sum of the drive wheel torques is predicted to be significantly below the tractive torque, and hence slippage is not expected.

**The effect of drag forces have been neglected since the wheelchair is expected to have too low a maximum velocity.*

The tare weight of the wheelchair has been overestimated for safety in performance, and to ensure prompt arrival at the destination. Since the technology is being designed with a view to future implementation into existing technology, where the passenger will add weight to the wheelchair, the traversing speed is expected to decrease, which is desirable for safety purposes of the patient. The overpowered motors will also ensure that the gross weight of the wheelchair does not overcome the maximum bearable load for the motors.

2.4 Performance Testing

While a small scale basic implementation of the model has been carried out using 5V DC motors, an ultrasonic sensor, and an Arduino board, the results were unremarkable and insufficient in detail to formally report. The purpose of the preliminary testing was for familiarization purposes only.

The testing process proper will commence with a wheelchair equipped with ultrasonic sensors, 250W motors, and a programmed microcontroller in an obstacle free plain terrain to test the functionality of the motors and response of the sensors programmed by Arduino/Raspberry Pi. The chair should be able to move from point to point, as well as orient itself as is desirable. Next, small obstacles will be placed around the chair to verify that the sensors register their presence. The top and bottom sensors will also be tested by operating the chair in environments with floating counters and small steps in the terrain.

Once the motors and sensors are known to function appropriately, the tracking and identifying of the subject holding the "key" (Zigbee Transmitter) by the chair will be tested. The subject will first be placed in close proximity to the chair, with no obstacle in between. The chair should be able to able to detect the subject, as well as be able to orient itself as to face in the direction of the subject and move towards him. Once that is established, the chair should be able to perform the above operation in an obstacle ridden terrain by maneuvering its way past them to reach the subject (come to within 30cm of the subject). Tests will also be carried out to evaluate the performance under environments with moving obstacles or persons, and also the effect of the change in terrain to performance indicators such as response to the signal, velocity of the chair and actual torque that can be achieved. Also to be analyzed is the consistency of results, whether the chair follows the same path and arrives at the same position under identical circumstances. Also measured will be the time taken by the chair in completing its operation, and steps will be taken to ensure the chair maintains a satisfactory time frame in its task completion. These tests will be repeated to test the functionality under different obstacle courses to ensure the chair operates successfully when faced with all types of obstacles within the aforementioned scope and limitations.

Below are some of the specific tests that will be carried out and the data that will be gathered:

-Test proximity sensors by placing small obstacles in the terrain

The system will be designed to turn in increments, and will try to detect obstacles after each increment. A test will be carried out, investigating the relationship between the minimum width of passage that is detected for any given increment setting. This will help determine the best increment setting that will not compromise either the functionality of the system or the time taken for operation. The best increment setting will be the largest increment that readily detects gaps the size of the width of the chair, so that the chair may move through the gap. This test will be modified to examine the implications of moving obstacles on the response time and corresponding performance concession, to simulate humans and other moving obstacles.

-Gauge sizes of obstacles that are readily detected, and which are not

The next set of tests will help determine the sizes of obstacles that are detected by the three proximity sensors on the sides of the wheelchair. Height and width of the obstacle will be tested independently (one changed while the other is kept constant), to check for detection.

-Effect of changes in terrain to signal response and motor function

These set of tests will determine the type and orientation of the treading surface under which the system will function. Various surfaces will be tested, and their inclination varied while the overall time taken for the prototype to move across the surface will be monitored

-Effect of changes in terrain height to signal response and motor function

These set of tests will determine the limitations of the prototype when traversing terrains with vertical changes in height. While the motors used are expected to overcome small changes in the height, a large vertical rise will block the path of the wheelchair, while a large vertical drop will cause the chair to topple; both scenarios would endanger the safety and functionality of the chair. To aid in the implementation of these limiting factors, an ultrasonic sensor would be incorporated in the chair facing downwards, which will be programmed to stop the motor function when these conditions are encountered.

4. CONCLUSIONS

In conclusion, the wheelchair system design will be designed by modifying a secondhand manual wheelchair to incorporate motors, sensors, a microcontroller, and a power source. Such a system could be used in hospitals to alleviate the workload of nurses and would be especially useful in hospitals with a shortage in staff. While basic implementation of the idea has been successful, difficulties are anticipated upon further progress. A flowchart for the code has been devised, but it will contain limitations and the program will need to be improved for better functionality. The proposed prototype is currently being developed as a standalone technology but it could further be complemented by a remote control or incorporated into an existing electric wheelchair technology to gain maximum efficacy

Culture and Technology have always been a part of one another, since the creation of new technology is often inspired by various human cultures, while technology plays a vital role in shaping modern technology. The proposed project intends to help shape the future in terms of mobility and ease of access, thus opening new paths that may lead to the creation of something that may eventually instigate a change of human culture in the future.

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6. REFERENCES

Asgar, M., Badra, M., Irshad, K., & Aftab, S. (2013). Automated Innovative Wheelchair. International Journal of Information Technology Convergence and Services, 3(6), 1-8. doi:10.5121/ijitcs.2013.3601

Boucher, P., Atrash, A., Kelouwani, S., Honoré, W., Nguyen, H., Villemure, J., … Pineau, J. (2013). Design and validation of an intelligent wheelchair towards a clinically-functional outcome. Journal of NeuroEngineering and Rehabilitation, 10(1), 58. doi:10.1186/1743-0003-10-58

Dutta, T., & Fernie, G. (2005). Utilization of Ultrasound Sensors for Anti-Collision Systems of Powered Wheelchairs. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 13(1), 24-32. doi:10.1109/tnsre.2004.842366

How, T., & Mihailidis, A. (2010). Anti-collision and navigation system for powered wheelchairs. Gerontechnology, 9(2). doi:10.4017/gt.2010.09.02.138.00

Matsumoto, O., Komoriya, K., Hatase, T., Yuki, T., & Goto, S. (2008). Intelligent Wheelchair Robot "TAO Aicle". Service Robot Applications. doi:10.5772/6064