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Autonomous wheelchair under a predefined environment

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ABSTRACT

This research work proposes a prototype of low-cost smart wheelchair design. The significance of this model of the wheelchair is to move autonomously around a known environment, following a definite path. Existing systems include control action using a joystick, voice recognition, head movements, and eye motion. However, these systems include limitations in terms of operating complexity, the environment in which it is used and cost. Most importantly, the limitation of the existing system is the need for the continuous effort of the user in controlling the wheelchair. Hence, this work targets to aid the physically challenged persons to have improved mobility without much of human effort. An automatic wheelchair model is proposed that empowers navigation without continuous steering of a wheelchair by the user in a known environment. The model includes a set of sensors, infrared, ultrasonic, RFID reader and tags. The other significant components are the compass module, ATmega microcontroller, and motors. This system was designed and developed to enable low cost, reduced time and effort of the user. This paper provides a comprehensive overview of the design and validation of the autonomous wheelchair system. Further, the sophistication towards the GPS enabled autonomous system could be extended, which works well in different new environments.

1. Introduction

This paper is conceived as an idea to ease the lives of those among us who are unfortunate enough to have lost the ability to move their legs due to a significant amount of paralysis, accident or due to old age. In order to provide assistance to this population, robotic and intelligent system technologies have been used to design an autonomous wheelchair. The existing electric wheelchairs are mostly based on joystick control. There are electric wheelchairs based on finger movement tracking in which flex sensors are used, voice recognition based system for end users who have lost control of upper body parts, eye movement based and EMG based wheelchair. These have limitations in terms of operating complexity, noisy environment and cost. The steering of the wheelchair is controlled by the user and the user always needs to be vigilant. Thereby, the proposed system mitigates the existing limitations by creating an automatic wheelchair that can move in a known environment with less human effort.

The rest of this paper is organized as follows; a brief discussion of related work is presented in section 2. The proposed system design is detailed in section 3. The approach of robotics planning and control is described in section 4. The implementation of the proposed system is presented in section 5.

2. Related works

The objective of this research work is to equip the present wheelchair control system with a keypad command system at low-price and friendly operation with proper safety measures. With these features, differently abled people especially with a severe disability will be able to move independently. Prototypes of several smart wheelchairs have been developed, based on advanced technology. The navigation problem of mobile robots has been treated in Nara and Takahashi (2006), such that obstacles are avoided using vision information. In the method used, obstacles were detected (which were present in front of a mobile robot) by calculating the optical flow, after which the optimal trajectory for a robot was decided based on the area of detection. Here, data from the sensors was used to support a vision system. In order to find the optimal

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trajectory, the distance between a mobile robot and obstacle was computed using a function.

In order to realize the autonomic movement of the mobile robot, obstacle detection and obstacle avoidance were proposed. As for the obstacle detection, the image of the detected obstacle with the distance information was formed by the fusion of information from the camera and ultrasonic sensors. As for the obstacle avoidance, trajectory generation (positive and negative trajectories were generated whose curvatures were calculated and subsequently minimized) and trajectory tracking were used.

Smart driving assistance algorithms were used to support the operator of an automated wheelchair in complex navigational situations in Rofer et al. (2009). On the basis of an empirical study in which eight untrained subjects performed a given course using a conventional joystick and a proportional head-joystick respectively, the benefits resulting from the application of a newly developed driving assistance module were proved. Altering the translational and rotational velocities in situations where an obstacle blocks the user-commanded way, the driving assistance module significantly improved driver-performance by preventing all collisions along the way.

The first important issue in this paper was that almost all subjects were able to navigate the wheelchair quite well after a minimal training phase of no more than five minutes. Even if the average time of travel and the driven distance increased for test runs incorporating driving assistance, the number of collisions dropped to zero. The increase in travel time and driven distance is only significant in tight navigation situations. In situations without obstacles, both measures were not impeded by the assistance module.

Rechy-Ramirez et al. (2012) presented a user-friendly Human Machine Interface (HMI) for hands-free control of an Electric Powered Wheelchair (EPW). Its two operation modes were based on head movements: Mode 1 uses only one head movement to give the commands, and Mode 2 employs four head movements. In both control modes, the user does not have to maintain the head movement during the control command. An EEG device, namely Emotiv EPOC, had been deployed in this HMI to obtain the head movement information of users without the need of a camera.

Ruíz-Serrano et al. (2014) proposed a real-time obstacle avoidance embedded system adapted to work with a multimodal navigation interface. 26 Ultrasonic sensors (Sonars) were used to provide feedback of the distance between the wheelchair and the obstacles. Interfaces that allow a more natural interaction with a wheelchair were created. The proposed multimodal interface integrated four control methods: a voice control interface using a microphone, a magnetic control system using a magnet, a joystick and a control pad that it can perform a simple command control with the basic moves to drive the wheelchair. Ultrasonic sensors were used to prevent accidents and stop the wheelchair if this was directed against an obstacle by mistake. Moreover a speaker was programmed to beep with certain proximity to avoid a collision.

Simpson and Levine (2002) proposed a solution to utilize voice control in combination with the navigation assistance provided by "smart wheelchairs," which use sensors to identify and avoid obstacles in the wheelchair's path. This paper describes an experiment that compares the performance of able-bodied subjects using voice control to operate a power wheelchair both with and without navigation assistance. The voice control system described in this paper was implemented within the NavChair Assistive Wheelchair Navigation System. The NavChair was being developed to provide mobility to those individuals who would otherwise find it difficult or impossible to operate a power wheelchair. The NavChair was chosen for this project because the navigation assistance it provides to the user makes it possible to ensure the user's safety while limiting the amount of interaction required between the user and the wheelchair.

3. Proposed system

Undoubtedly, industrial automation application is one of the key issues in developing RFID technology. The utilization of RFID technology is novel and might enhance the existed automation system. A RFID and Line follower based autonomous wheelchair is designed and implemented in this paper for more extensively application of RFID systems. The Arduino based Microcontroller of Microchip ATmega 2560 is used to control the proposed autonomous mobile robot and to communicate with RFID reader. Due to the uniqueness of RFID tag, the moving control commands such as turn right, turn left, speed up and speed down etc. The autonomous mobile robot can read the moving control commands from the tags and accomplish the proper actions. It also has IR sensors attached which makes used of line follower concept. The novel localization system for a mobile robot through RFID tags and line follower is proposed to improve the efficiency of the system.

4. System architecture

In this work, Arduino ATmega microprocessor is chosen as an intelligent controller.

Fig. 1 shows the major components of the proposed system design. For the sensor part, ultrasonic sensors will be attached to measure the distance from any obstacle within the detectable range.

Fig. 2 shows the hardware pin connections of the set of components with the controller. Wheel encoder and compass are included to keep track of direction and movements. RFID for efficient maneuver at turns and steep corners it is also used for localization and directional control.

IR sensors send a HIGH output when it senses white and a LOW output when it senses black, to the controller. The row and column pins of the matrix keypad are connected to the digital pins of the Arduino. RFID reader transmits the tag value via serial communication of the controller. Then the controller generates a trigger signal and sends to the ultrasonic sensor. Based on the presence of an obstacle, the controller receives an echo signal within a timeout. Compass module uses I2C to communicate with the controller. Based on the inputs obtained from IR sensors, ultrasonic sensors, RFID Reader, compass module and keypad, the controller sends command to the motor driver, which controls the direction of movement of the motors.

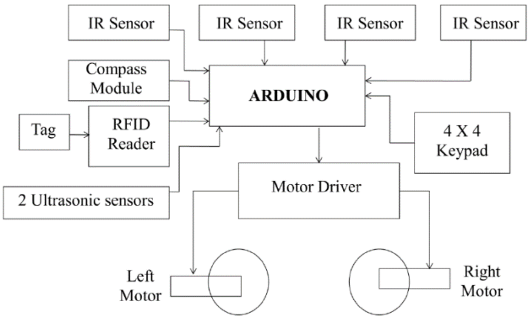

Fig. 1: Proposed system design

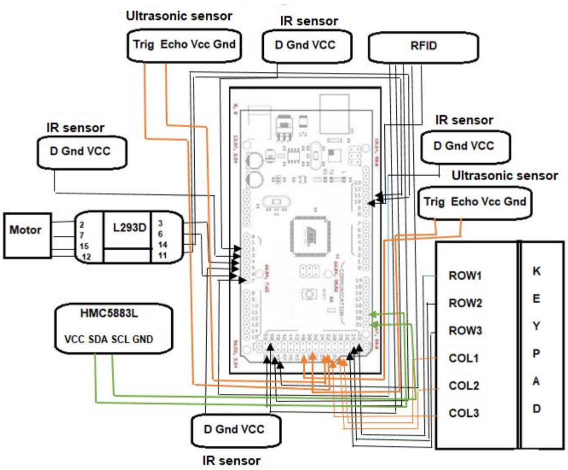

Fig. 2: PIN out connection

The sequences of action taken by the controller are as follows:

- Interpret sensor data.
- Plan a path to its goal destination.
- Localize itself in the world.
- Plan a local path to reach the next waypoint in the defined route.
- Execute local path.
- Avoid hitting obstacles of any kind.

4.1. System components

It is used to power up the tag. It established Bidirectional data link. It can communicate with network server. Inventory tags and filter results. It can read 100 to 300 tags per tag. These readers can be fixed or mobile type. A typical reader generally includes Digital Signal Processor, Network Processor and Radio modules (915 MHz, 13.56 MHz and 125 KHz). The PCB mounted diagram of typical RFID reader consists of two processors these are DSP and N/W processors. DSP deals with the radio frequency signals.

The other circuitry is also shown in the Fig. 3. There is a coil antenna which is quit big in size with other components. This antenna is used for radio wave transmission.

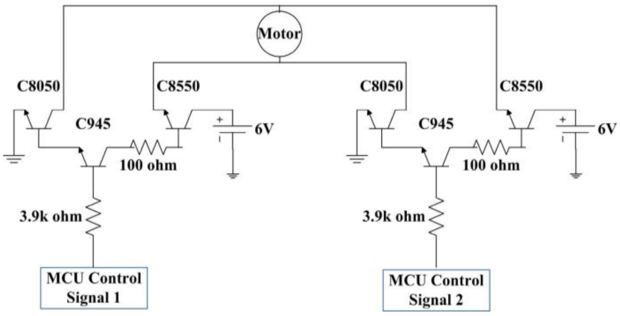

Fig. 3: Concepts of RFID-based autonomous wheelchair

There are many different versions of RFID that operate at different radio frequencies. Three primary frequency bands have been allocated for RFID:

1. Low Frequency (125/134 KHz) – Most commonly used for access control and asset tracking.
2. Mid-Frequency (13.56 MHz) – Used where medium data rate and read ranges are required.
3. Ultra-High Frequency (850 MHz to 950 MHz and 2.4 GHz to 2.5 GHz) – offer the longest read range.

For a case, with the Fig. 4, while the robot moves to tag 1 and receives the commands of turn left and speed up, then the controller will make some control actions to let the robot conform the commands. While the robot moves to tag 2, the commands to go straight and slow down were received, the controller will once again make some control actions to let the robot conform the commands. Therefore, the robot will then move in moving path 1 automatically. Of course, the robot can also move in the other paths according to the commands received from tags.

The system consists of a microchip and an antenna. Attached to an object to be tracked (vary in size) Stores information about the object Read/Write or Read Only. Contact less, line of sight not required. Read Range: few inches if passive to hundreds of feet if active.

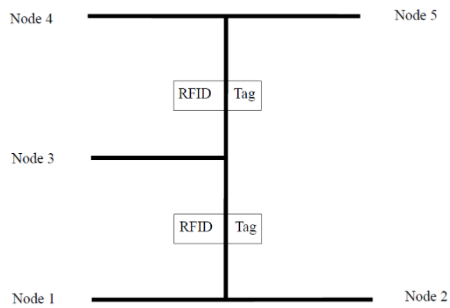

Fig. 4: Driving environment with RF tags and line follower

The ATmega 2560 is a low power CMOS 8-bit microcontroller based on AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle ATmega 2560 achieves a throughput of 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed.

Arduino Mega 2560 is based on the microcontroller ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It can be connected to a computer with a USB cable or can be powered using an AC-to-DC adapter or battery.

This serves as a useful human interface component. Matrix keypads are used as it reduces the number of pins required to interface the keypad buttons with a microcontroller. For example – In a 4X4 matrix keypad only 8 pins are needed to read 16 digital outputs. Similarly for 10X10 matrix keypad only 20 pins are required to read 100 digital outputs.

It is an electronic device that emits infrared rays in order to the surroundings. The emitter is an IR LED and the detector is an IR Photodiode which is sensitive to IR light of the same wavelength as that emitted by the IR LED. When IR light falls on the photodiode, the resistances and output voltages, change in proportion to the magnitude of the IR light received.

The transmitter transmits IR rays continuously. The output terminal of the receiver varies depending on the magnitude of IR light received. Since this variation cannot be analyzed as such, this output is fed to a comparator circuit.

The comparator used is LM358, shown in Fig. 5. When the receiver does not receive any signal, the potential at the inverting input goes higher than the non-inverting input of the comparator IC. Thus the output of the comparator goes low, hence the indicator LED does not glow. When the receiver receives signal, the potential at the inverting input goes low. Thus the output of the comparator goes high and the LED glows. Resistors are used to ensure that a minimum of 10 mA current passes through the LED and photodiode.

This evaluates the attributes of a target by interpreting the echoes which are above the audible frequency range of human beings and operates at 40 KHz, shown in Fig. 6. The transmitter emits a high frequency pulse for a short duration of time. After receiving the signal, the properties of the signal are evaluated.

In reflection mode (also known as "echo ranging"), an ultrasonic transmitter emits a short burst of sound in a particular direction, as shown in Fig. 7.

The pulse bounces off a target and returns to the receiver after a time interval t. The receiver records the length of this time interval, and calculates the distance travelled r based on the speed of sound c as

$$r = c^{*}t/2. \quad (1)$$

Digital compass module combines 2-axis magneto-resistive sensors with the required analog and digital support circuits, and algorithms for heading computation. It helps in providing directions (N, S, E, W) for navigation.

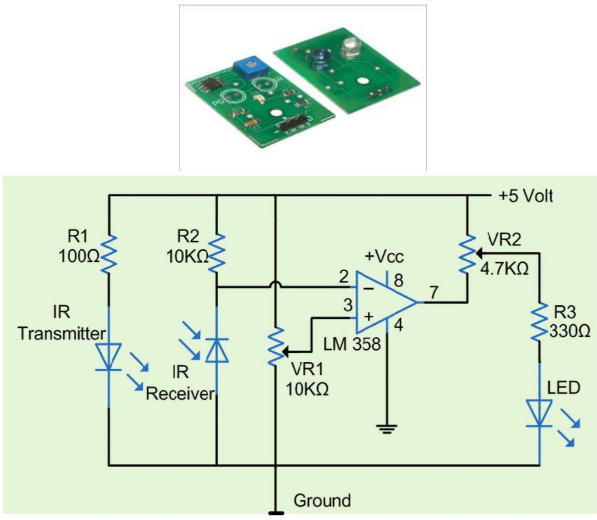

Fig. 5: Infrared sensor module and internal circuit

Fig. 6: HCSR04 ultrasonic sensor

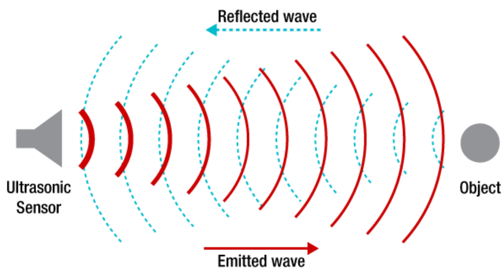

Fig. 7: Time of flight measurement of Ultrasonic Sensor

Fig. 8 shows HMC5883L, digital compass which includes state-of-theart, high-resolution HMC118X series magneto-resistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. I^2C serial bus allows for easy interface.

The HMC5883L is a 3.0x3.0x0.9mm surface mount 16-pin leadless chip carrier (LCC). Applications for the HMC5883L include Mobile Phones, Netbooks, Consumer Electronics, Auto Navigation Systems, and Personal Navigation Device.

In any electric motor, operation is based on simple electromagnetism. A current-carrying conductor generates a magnetic field; when this is then placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field. As you are well aware of from playing with magnets as a kid, opposite (North and South) polarities attract while like polarities (North and North, South and South) repel.

Fig. 8: Digital Compass (HMCS5883L)

The internal configuration of a DC motor is designed to harness the magnetic interaction between a current-carrying conductor and an external magnetic field to generate rotational motion. Let's start by looking at a simple 2-pole DC electric motor (here red represents a magnet or winding with a "North" polarization, while green represents a magnet or winding with a "South" polarization).

5. Implementation

Map of a known environment is drawn by using black lines and each destination is assigned a number. Two RFID tags are fixed on the path. For line detection logic, IR Sensors are used, which consists of IR LED and Photodiode. They are placed in a reflective way i.e., side–by–side so that whenever they come in to proximity of a reflective surface, the light emitted by IR LED will be detected by Photo diode. As the reflectance of the light colored surface is high, the infrared light emitted by IR LED will be maximum reflected and will be detected by the Photodiode. In case of black surface, which has a low reflectance, the light gets completely absorbed by the black surface and doesn't reach the photodiode. When the robot moves forward, both the sensors wait for the line to be detected. For example, if the IR Sensor 1 in the above image detects the black line, it means that there is a right curve (or turn) ahead. Arduino UNO detects this change and sends signal to motor driver accordingly. In order to turn right, the motor on the right side of the robot is slowed down using PWM, while the motor on the left side is run at normal speed. RFID tag are placed on the line so that it can keep track of the wheelchair and provide suitable information. Tag of RFID also acts as waypoints which help in navigation through the defined environment. Based on the source and destination selection, a path is selected within the defined environment with RFID's mark along the path containing required directional control for the bot. The identified vital components of the proposed systems are integrated to develop a complete model. Fig. 9 shows the front view of the complete prototype developed, depicting the position of the sensor units and their connectivity.

Similarly Fig. 10 shows the rear view of the prototype developed.

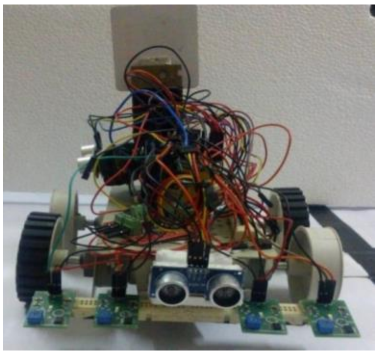

Fig. 9: IR sensors and ultrasonic sensor placed in front of wheelchair model

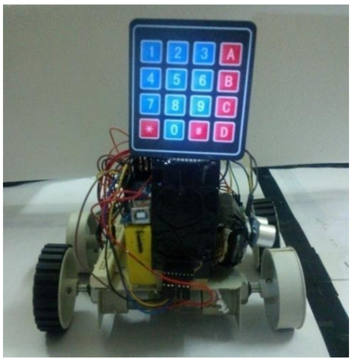

Fig. 10: Wheelchair model with the keypad

6. Conclusion

The wheelchair model that has been built, can move from one node to another based on inputs given from a keypad, avoid stationary obstacles and follow a line. The line following concept has been used purely for achieving straight movement. The limitation of constant vigilance on the part of the user has been mitigated in the proposed model. Furthermore, PID controller along with a feedback loop can be used to control speeds of the motors such that the motors run at equal speeds.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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