Design, Manufacture, and Test a ROS Operated Smart Obstacle Avoidance Wheelchair

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***Abstract*— In this paper, the designing, manufacturing, and testing of a smart obstacle avoidance wheelchair will be discussed. The wheelchair is designed to be light weighted, maintainable, able to maneuver easily across obstacles along the user path with minimum commands from the user. The design payload for this smart wheelchair is 120 kg. In order to minimize the weight, the chassis is made of steel hollow pipes. The user can drive the wheelchair either using a joystick or voice commands. Ultra-Sonic sensors are used to detect obstacles along the wheelchair path. The motion and steering action of the wheelchair are controlled using the Robot Operating System (ROS). The testing of the wheelchair has shown that it is capable of avoiding obstacles and can easily reach the destination with minimum commands from the user.**

***Index Terms*—smart wheelchair, obstacle avoidance, ROS, voice recognition, joystick**

I. Introduction

The number of elderly and people with disability who require a wheelchair are increasing worldwide. The World Health Organization estimated that around 70 million people worldwide who require wheelchair [1]. A wheelchair for them is a device with paramount importance as it assists them in their mobility and improves their quality of life. Wheelchair can be a traditional or a powered one. Fehr et al. has mentioned that 40% of powered wheelchair users experience serious difficulties with the standard operation of their wheelchair [2]. Some of these difficulties are with steering and maneuvering tasks. The lack of steering capabilities can cause dangerous situations such as collisions with obstacles, or people, and falling off ramps. Moreover, depending on the user medical condition, some users can have difficulty driving an electric powered wheelchair. Kairy et al. had performed a study on powered wheelchair users inquiring about their problems and challenges with using their wheelchairs and what feature of the smart wheelchair would address their challenges [3]. Their main challenges were negotiating small spaces, negotiating elevator, navigating in narrow aisles, driving over long distances, navigating crowded places, and uneven/changing driving surfaces [3]. They had noted that obstacle avoidance, and path following would be the main features in smart wheelchair that would address their difficulties [3]. Therefore, Smart Obstacle avoidance wheelchair is one of the appropriate solutions to solve these problems as it can provide extra safety and easiness for the user.

A Smart Obstacle avoidance wheelchair is a wheelchair with the ability to detect obstacles along its motion path and control the motion of the wheelchair accordingly to avoid collisions or accidents with minimum or no user input command. Technological advances had made it possible to create a smart obstacle avoidance wheelchair by incorporating several input devices, sensors and controllers to the wheelchair design. Most of the smart wheelchair designs used multiple input mode. Joystick was one of the most common manual input device by the user in several designs [4]–[9]. Rabhi et al. used a camera fixed on the wheelchair to recognize the hand gestures to control the wheelchair motion [10]. Voice commands were also used in several designs as the user input device [8], [10]–[12]. In addition, eye tracking [5], [8], [13], Head gestures [12], [14], [15], facial gestures [16], Brain Computer interface (BCI) [13],tongue movement [17], [18], and touch screens [9] had also been used as an user input device or interpretation of required motion direction. The most common sensors that were used for obstacle avoidance were Ultra-sonic (sonar) and Infrared sensors[4], [5], [11], [15], [16], [19]. Laser range finder was used in several designs for obstacle detection [5], [8]. Some designs made use of the camera to detect obstacle or to path mapping [6], [8], [9]. Several control algorithms were used to interpret the sensors and input devices data and convert them to motion instruction commands to the motors such as artificial neural network, machine learning, fuzzy logic[7], [10], [11], [16].

The presented wheelchair in this research work targets users with physical disability such as paraplegic patients who are having difficulty with operating powered or manual wheelchairs. In order to tackle the different challenges faced by wheelchair users, the presented design will have the ability to avoid obstacles without the need for extra user commands. This will release the burden on the users, assist in their mobility and thus improves their quality of life. The novelty of this design lies in the fact that it concentrated on both the mechanical and electrical design of the smart wheelchair to provide safe operation to the users with minimum commands from them and at an affordable price. The mechanical design is easy to maintain, and assemble. It also can accommodate users up to 120 kg. For the electrical design it uses the ROS

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operating system to enhance the fast response to different motion scenarios as well as the integration of the different sensors input to provide action to the drive motors.

II. Mechanical Design

The design guidelines for the presented wheelchair focus on being a light weight structure, easy to maintain, and simple to manufacture. The design should also accommodate users up to 120 kg.

The mechanical design methodology involves designing a light weight chassis which is structurally simulated on SOLIDWORKS to assess its resulted stresses and deflections under the maximum load. Actuator sizing is performed to select the proper motors for this design. A comfortable office chair is used and assembled to the chassis. The steering mechanism is differential steering based on two front drive wheels and two free back wheels.

Several chassis design iterations are simulated using SOLIDWORKS academic version 2018 to assess their structure feasibility. The chassis drawing of steel hollow pipes on SOLIDWORKS is shown in Fig. 1. The chassis is simulated with the maximum loading condition using a 1.5 factor of safety including the maximum payload as well as the weights of the different components. It is found that the resulted stresses and displacement are safe. As such using steel hollow pipes is determined to be suitable choice in-terms of weight as well as mechanical rigidity. A full design of the wheelchair on SOILDWORKS is shown in Fig. 2 where it shows the different components of the design.

The assembly of the chassis is divided into two parts, the first is to cut the hollow steel pipes (26 mm outer diameter with 1 mm thickness) into desired dimensions and the second part is to connect them using steel joints as shown in Fig. 3. Both the pipes and the joints have a plastic outer layer which can protect them from corrosion and also gives a good look to the chassis. Two front drive motors are fixed to the lower pipe of the chassis and directly to the front drive wheels. The encoders are connected to the rear motor shaft using a coupler. Two free rear wheels are fixed on the back pipe as shown in Fig. 3. For the chair seat, it is an office chair seat and it is attached on the upper pipes using pipe clamps as shown in Fig. 4.

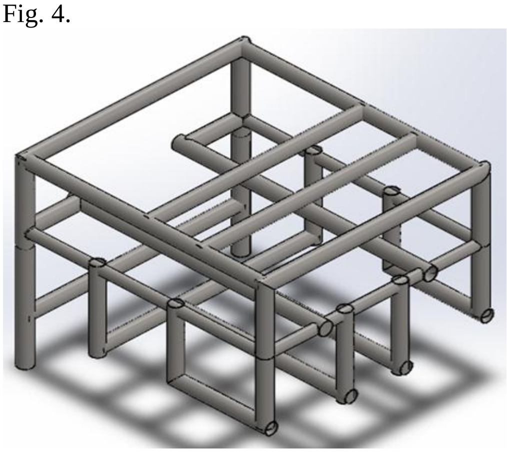

Figure 1. The designed chassis on SOLIDWORKS.

Figure 2. The wheelchair design assembly on SOLIDWORKS

Figure 3. Chassis assembly with drive motors, front and rear wheels

Figure 4. The wheelchair design with all the assembled components

In addition, a sensors' arm is manufactured where the joystick and microphone are attached and the sensors are inserted inside it. The arm material was chosen to be as light weighted as possible and also it should be electrically insulated as it will hold the sensors. It is fabricated from three aluminum hollow rectangle sections with 4x8 cm cross section and it is painted as well as there are several packing foam inserted into it to be electrically insulated. There are nine ultrasonic sensors attached around the chair as shown in Fig. 4, so eight cuts are performed in the arm in order to insert the sensors in and one ultrasonic sensor is attached in the back of the wheelchair seat, while the wires of the sensors are routed inside the rectangle pipe.

III. Electrical Design and Control

The design guidelines for the presented wheelchair is to provide a safe motion for the user with minimum physical commands. As such two modes of operation is advised which are manual analog joystick as well as voice commands via a microphone attached to the wheelchair. On the other hand, to provide a safe motion, ultrasonic sensors are used to detect obstacles along the user path. A proportional–integral– derivative controller (PID) controller is used to overcome the effect of friction and load weight on the velocity and to ensure that the wheelchair moves in straight line. An Arduino mega is used to connect all the ultrasonic sensors, encoders and dual channel motor driver, so it is the responsible for sending and receiving data to and from these components.

In order to provide a high level of safety for the user, the controller must be robust in dealing with the different sensors data and in parallel be able to generate the commands to the different actuators. So, to execute this great number of data at the same time, we need intelligent software which is Robot Operating System (ROS). It is a BSD (Berkley Source Distribution) licensed system for controlling robotic components from a PC. ROS is a collection of tools, libraries, and conventions that aim to simplify the task of creating complex and robust robot behavior across a wide variety of robotic platforms. A ROS architecture is comprised of a number of independent nodes, which represents sensors, input devices and motors, each of which communicates with the other nodes using publish/subscribe messaging model. ROS software is interfaced with raspberry pi 3 which act as a PC to synchronize data between the Arduino and the software. As shown in Fig. 5, the input devices, which are joystick and microphone, are connected to the raspberry pi 3 using USB cables. It also illustrates the connection of the different components.

Fig. 6 illustrates the data transfer between the hardware components and ROS software. The main nodes (I/O devices) are ultrasonic sensors, Microphone, joystick and the motors which are the hardware components of the wheelchair. The nodes which are sending data (publishers) directly to the ROS are the microphone, and the joystick while the ultrasonic sensors send their data to the ROS via the Arduino mega serial connection. The motors as an actuator receives (subscriber) velocity commands from the ROS software via the Arduino serial connection to the motor drivers.

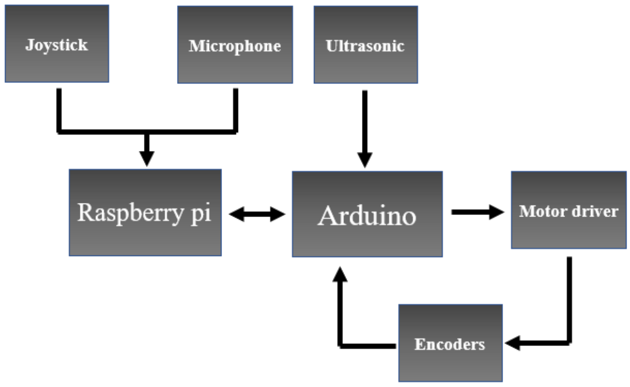

Figure 5. Connection block diagram

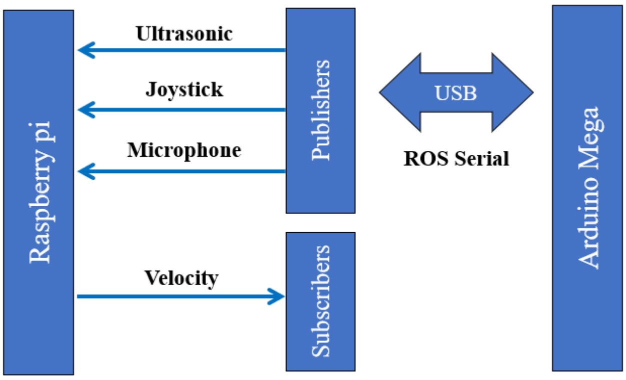

Figure 6. Data transfer diagram between the input/output devices and the ROS software installed on the Rasperry pi.

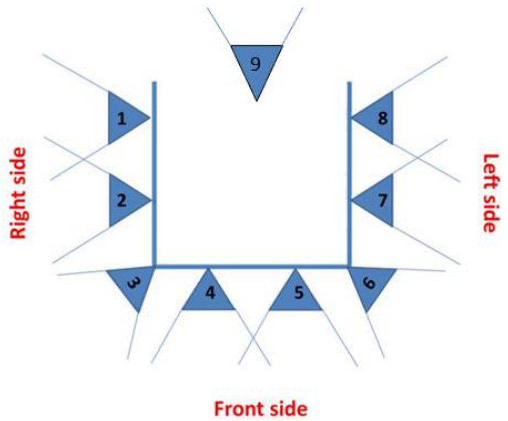

Figure 7. Ultrasonic sensors distribution on the sensors' arm

The ROS software receives the user motion commands via either the Joystick or the microphone. The motion command to the motors is complemented with the information from the ultrasonic sensors which are located in the sensors' arm around the wheelchair as shown in Fig. 4. The nine sensors are distributed to cover the area around the wheelchair as shown in Fig. 7. The ultrasonic sensor can detect an obstacle up to 100 cm away. The incorporation of the sensors information and the motion required by the user is governed by the motion scenarios presented in Table I. The motion scenarios cover all the combination of the conflict sensors data with the respective Joystick/voice command (user input). Some of the combinations are inapplicable that is why they are not listed in the motion scenarios for example if the user want

TABLE I. MOTION SCENARIOS OF CONFLICT JOYSTICK/ VOICE COMMANDS AND ULTRASONIC SENSORS READINGS

Joystick/ Voice	Ultrasonic sensors			Action
	Sensor 1	***Sensor 2***	***Sensor 3***	
Right	OFF	OFF	OFF	Go according to the joystick command
	OFF	OFF	ON	Go right by wide angle
	OFF	ON	OFF	Go sharply right
	OFF	ON	ON	Go right by wide angle
	ON	OFF	OFF	Rotate Right
	ON	OFF	ON	Not applicable
	ON	ON	OFF	Go through a corridor
	ON	ON	ON	Don't take the right action from the joystick
Forward-Right	OFF	OFF	ON	Go slightly left by a specific angular speed
Forward	***Sensor 4***		***Sensor 5***	STOP
	ON		ON	
	OFF		ON	
	ON		OFF	
Backward	***Sensor 9*** is ON			STOP
Left	***Sensor 6***	***Sensor 7***	***Sensor 8***	
	OFF	OFF	OFF	Go according to the joystick command
	OFF	OFF	ON	Go left by wide angle
	OFF	ON	OFF	Go sharply left
	OFF	ON	ON	Go left by wide angle
	ON	OFF	OFF	Rotate Left
	ON	OFF	ON	Not applicable
	ON	ON	OFF	Go through a corridor
	ON	ON	ON	Don't take the left action from the joystick
Forward-Left	OFF	OFF	ON	Go slightly right by a specific angular speed

to move right, the data of the left, front or back sensors are not relevant in this motion decision. Two motion scenarios are not listed which are backward right and backward left, as they required more sensors which resulted in difficulty in the resolution of the motion. So the decision is to opt these two motion scenarios, however this doesn't hinder the proper motion of the wheelchair as the user can move back and then either turn forward right or forward left to achieve the motion of backward right or backward left respectively. Some of the actions are descriptive to more motion commands such as going with a wide angle or sharp angle, and go through a corridor. All these actions are a combination of commands to the two motors to achieve this differential steering motion. As the wheelchair is moving for a certain action command, it acquires more data from the sensors and update its motion accordingly. Moreover, some of the combination of the sensors are not logically fit and that is why the action is to ignore these combinations. If there are no sensor readings, then the action would be follow the Joystick/voice command.

The wheelchair requires two 12 V DC/ 12 Ah batteries which are connected in series for a combined 24 V. They last for four- five hours. A step down circuitry is used to step down the 24 V to 5 V / 2.5 A for the controllers. The batteries, controllers, cooling fan and motor drivers are enclosed inside a plastic box in a specified compartment in the chassis underneath the chair as shown in Fig. 4.

IV. TESTING

The testing of the smart wheelchair involves mimicking the different motion scenarios and check if it will perform according to the algorithm and avoid the obstacle or not. For testing the forward direction, an obstacle is put in front of the wheelchair and a forward direction command is given using the joystick as shown in Fig.8, once sensors 4&5 or one of them receive a signal that there is an obstacle within 1 m, the controller send a command to the motors to stop. Similarly, the performance for the backward motion in case of backward obstacle is tested and it performed perfectly. As shown in Fig.9, the user gave a left command by the joystick while there is an obstacle on the left. The smart wheelchair turns right with a wide angle until it was safe to turn left. It avoided the obstacle and performed the required motion by the user with no extra commands from the user. As shown in Fig.10, if the user requested to move left while there is an obstacle on the left and in front of him. The smart wheelchair avoided the left obstacle as well as the forward obstacle until it is safe to turn left. The testing is performed for the different scenarios for both the joystick commands and the voice commands.

The wheelchair can avoid static and dynamic obstacles. For example, a moving person in front of the wheelchair will result in the wheelchair to stop if the motion from the user is to go forward. It will not try to move around the obstacle as the scenarios are designed such that the wheelchair will try to accomplish the user input safely.

All the motion scenarios in Table I are tested using the smart wheelchair in the obstacle avoidance mode using both the Joystick and voice input. The response of the motion input in the joystick is higher that the voice input. As the voice input varies according to different users and requires adaptation for the specific user. However, after the proper adjustment to the user voice, it performs as expected.

Moreover, the motion scenarios are tested using the wheelchair without the obstacle avoidance feature. This results in touching the obstacles and required extra input from the user to have a safe motion along his path.

Figure 8. Testing the Smart Wheelchair motion in case of forward obstacle.

Figure 9.Testing the smart wheelchair motion in case of left obstacle while the joystick motion is go left from the middle of the obstacle.

Figure 10. Testing the smart wheelchair motion in case of left and front obstacle while the joystick motion is to go left from the middle of the left obstacle.

V. Disucssion and Conclusion

A smart obstacle avoidance wheelchair is designed with three operation modes with a simple switch selection to change between the different modes. It can operate as a normal powered wheelchair using the joystick only and the sensors will be disabled in this mode. It can operate in a smart obstacle avoidance mode with either the joystick or voice commands and the sensors data will be included in these two modes. However, it can't operate with both the joystick and the voice commands at the same time as there is no precedence of between the voice and joystick commands. The testing of the smart wheelchair proved it can avoid obstacles and navigate safely through corridors. However, the voice commands has to be adjusted for the specific user. The design being lighter than the powered wheelchairs available in the market make it easier in transporting it. Since it can accommodate users up to 120 kg made it a valid product not just a proof of concept one. The battery charge will give the user four- five hours of continuous operation which is reasonable for a normal user. It costs about 820 US dollars which is very cheap price for a smart obstacle avoidance wheelchair. Further improvement to the design can be a foldable design which can be easier in transport. Moreover, implementation of mapping system which it can make it easier for a user to move within a known environment like home or work. For different class of users, new input devices can be utilized to suit the user condition.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mohamed Badran identified point of research, supervised the research and its execution and wrote the paper. Amira Elkodama and Donia Saleem conducted the electrical design and control. Samer Ayoub, Clark Potrous, and Mostafa Sabri conducted the mechanical design and fabrication. All authors contributed to the testing and had approved the final version.

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References

[1] "WHO | Wheelchair publications – an overview," *WHO*, 01-Jun-2019. [Online]. Available: http://www.who.int/phi/implementation/assistive_technology/wheelchair-publications/en/. [Accessed: 01-Jun-2019].

[2] L. Fehr, W. E. Langbein, and S. B. Skaar, "Adequacy of power wheelchair control interfaces for persons with severe disabilities: a clinical survey," *J Rehabil Res Dev*, vol. 37, no. 3, pp. 353–360, Jun. 2000.

[3] D. Kairy *et al.*, "Exploring powered wheelchair users and their caregivers' perspectives on potential intelligent power wheelchair use: a qualitative study," *Int J Environ Res Public Health*, vol. 11, no. 2, pp. 2244–2261, Feb. 2014.

[4] R. Simpson, E. Lopresti, S. Hayashi, I. Nourbakhsh, and D. Miller, "The smart wheelchair component system," *J Rehabil Res Dev*, vol. 41, no. 3B, pp. 429–442, May 2004.

[5] H. A. Yanco, "Wheelesley: A robotic wheelchair system: Indoor navigation and user interface," in *Assistive Technology and Artificial Intelligence*, Springer, Berlin, Heidelberg, 1998, pp. 256–268.

[6] E. Prassler, J. Scholz, and P. Fiorini, "A robotics wheelchair for crowded public environment," *IEEE Robotics Automation Magazine*, vol. 8, no. 1, pp. 38–45, Mar. 2001.

[7] A. Lankenau and T. Röfer, "A versatile and safe mobility assistant," *IEEE Robot. Automat. Mag.*, vol. 8, pp. 29–37, 2001.

[8] M. Mazo, J. C. García, F. J. Rodríguez, J. Ureña, J. L. Lázaro, and F. Espinosa, "Integral system for assisted mobility," *Information Sciences*, vol. 129, no. 1–4, pp. 1–15, Nov. 2000.

[9] A. Hartman and V. K. Nandikolla, "Human-machine interface for a smart wheelchair," *Journal of Robotics*, 2019. [Online]. Available: https://www.hindawi.com/journals/jr/2019/4837058/. [Accessed: 10-Jul-2019].

[10] Y. Rabhi, M. Mrabet, and F. Fnaiech, "Intelligent control wheelchair using a new visual joystick," *J Healthc Eng*, vol. 2018, Feb. 2018.

[11] G. Pires and U. Nunes, "A wheelchair steered through voice commands and assisted by a reactive fuzzy-logic controller," *Journal of Intelligent and Robotic Systems*, vol. 34, no. 3, pp. 301–314, Jul. 2002.

[12] C. Joseph, S. Aswin, and J. S. Prasad, "Voice and gesture controlled wheelchair," in *2019 3rd International Conference on*

Computing Methodologies and Communication (ICCMC), 2019, pp. 29–34.

[13] R. G. da Cruz, V. da S. Souza, T. F. B. Filho, and V. F. de Lucena, “Electric powered wheelchair command by information fusion from eye tracking and BCI,” *2019 IEEE International Conference on Consumer Electronics (ICCE)*, pp. 1–2, 2019.

[14] J. O. Gray, P. Jia, H. H. Hu, T. Lu, and K. Yuan, “Head gesture recognition for hands‐free control of an intelligent wheelchair,” *Industrial Robot: An International Journal*, Jan. 2007.

[15] P. Dey, Md. M. Hasan, S. Mostofa, and A. I. Rana, “Smart wheelchair integrating head gesture navigation,” in *2019 International Conference on Robotics,Electrical and Signal Processing Techniques (ICREST)*, Dhaka, Bangladesh, 2019, pp. 329–334.

[16] J. E. Vázquez, M. Martin-Ortiz, I. Olmos-Pineda, and A. Olvera-Lopez, “Wheelchair control based on facial gesture recognition,” *IJITSA*, vol. 12, no. 2, pp. 104–122, Jul. 2019.

[17] J. Kim *et al.*, “The tongue enables computer and wheelchair control for people with spinal cord injury,” *Sci Transl Med*, vol. 5, no. 213, p. 213ra166, Nov. 2013.

[18] M. M. Tahsin, R. Khan, and A. K. S. Gupta, “Assistive technology for physically challenged or paralyzed person using voluntary tongue movement,” in *2016 5th International Conference on Informatics, Electronics and Vision (ICIEV)*, 2016, pp. 293–296.

[19] K. Joshi, R. Ranjan, E. Sravya, and M. N. A. Baig, “Design of voice-controlled smart wheelchair for physically challenged persons,” in *Emerging Technologies in Data Mining and Information Security*, Springer, Singapore, 2019, pp. 79–91.

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