Design and Implementation of an Electric Wheelchair Operating in Different Terrains

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***Abstract*—Wheelchairs are essential assistive devices for many people with disabilities. This paper describes the design and implementation of an environmentally−friendly, flexible electric wheelchair that can change sitting postures according to the user's demand and can change its structure to operate in different terrains. Furthermore, a safety system that observes and informs the wheelchair user about the operating status of the wheelchair such as speed, temperature, and tilt angle, and about the health status of the user such as heart rate, was developed. Additionally, experimental results showed that the proposed wheelchair operated stably at a speed of 5 km/h and a load of 65 kg, and the effectiveness of the safety system was also clearly confirmed.**

***Index Terms*—electric wheelchair, sensor, electronic control unit, calculation, simulation**

I. Introduction

Wheelchairs are essential assistive devices for many the elderly and the disabled who have difficulty in a body-movement and encounter physical challenges [1], [2]. In developing countries, conventional wheelchairs that use human power, providing a low-cost solution, have attracted by many users. However, a person operating an affordable wheelchair with their hands may lead to a stiff muscle and limitation of hand activity [3].

Compare with conventional wheelchairs, electric wheelchairs that use electrical power have several advantages such as reducing human power and lower risk of strain-induced injuries [4]‒[12]. Consequently, electric wheelchairs have been increasingly become popular in recent years [13]. Nevertheless, it is still a challenging task for conventional or electric wheelchairs to overcome the existing environmental barriers such as the building or civil infrastructure stairs [14]. Especially for some users living in a building without an elevator, it is difficult for them to travel up and down the stairs using a standard electric wheelchair.

Therefore, this study proposed a flexible electric that can overcome different terrains and change sitting postures according to the user's demand. Furthermore, in this study, we developed a safety system that can automatically inform the relatives of the user as occurring any problems with the wheelchair.

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The rest of the paper is structured as follows. Section II describes the design of the wheelchair, including mechanical and control system design. The results of the research are presented in Section III. Section IV covers conclusions and future work.

II. Design of an Electric Wheelchair

A. Mechanical Design

In order to travel in different terrains, the electric wheelchair is designed with flexible structure, as described in Fig. 1.

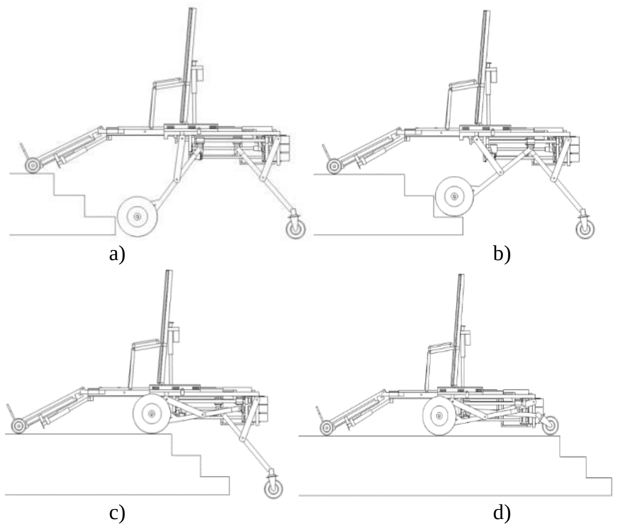

Figure 1. The step-climbing stages of the wheelchair. a) Start climbing; b) -c) During climbing; d) Complete the climbing.

The proposed wheelchair is driven by two rear wheels (No. 4) using two electric motors. Moreover, the wheelchair can move forward and backward, turn left and right via acting operation panel (No. 9) on the armrest. Besides, the position of the seat (No. 8) can be adjusted using electric cylinders (No. 1 and No. 7), and the wheelchair can change the structure to overcome terrace terrains using a screw motor (No. 2) and an electric cylinder (No. 5). Fig. 2 describes the details of the proposed electric wheelchair, and Table I presents the overall parameters of the proposed wheelchair.

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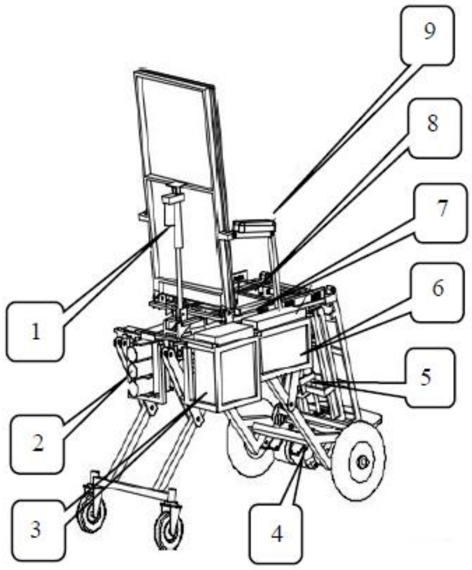

Figure 2. The overall layout of the designed wheelchair: 1,5,7- Electric cylinders; 2-Screw motor; 3-Battery; 4-Motors; 6-Electronic control unit; 8- Seat; 9- Operation panel.

TABLE I. PARAMETERS OF THE DESIGNED WHEELCHAIR

No.	Parameter	Value	Unit
1	Cover size	1200x680x1500	mm
2	Ground clearance	50	mm
3	Weight	60	kg
4	Electric motor power	2x250	W
5	Max speed	7	km/h

1) Frame design

The frame of the wheelchair is an essential part of the wheelchair. To ensure the structure is durable, the material for the wheelchair includes a galvanized steel box with the following dimensions: 30x30x1.0 galvanized steel box, 25x25x1.0 galvanized steel box, 10x20x1.0 galvanized steel box.

In the first stage, the 3D model of the wheelchair was designed using CATIA V5R21 software. The 3D model of the frame is used to calculate the stress of structure by using the finite element method [15]–[17]. The simulation results showed that the wheelchair suffered the most massive displacement of 0.0193 mm. Fig. 3 indicates the model of the frame.

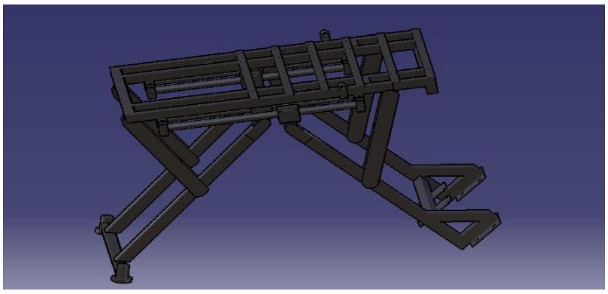

Figure 3. The frame of the wheelchair.

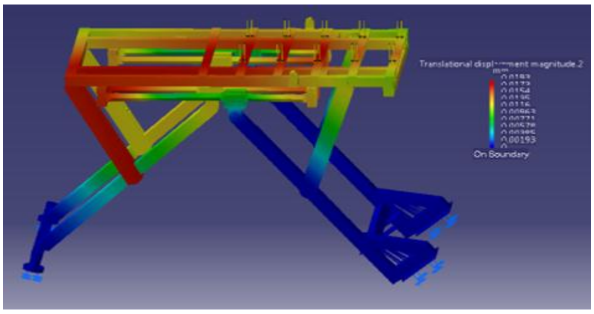

Figure 4. Deformation of the frame.

With the most massive displacement of 0.0193 mm, the wheelchair has the highest stress of 11.9 MPa, concentrated between the bearing beam and the chassis, as shown in Fig. 4.

The allowable pressure, according to yield strength [σ] ch = 225 MPa [17]. Comparing yield strength, we can see that the frame still ensures durability. Fig. 5 presents the stress of the structure.

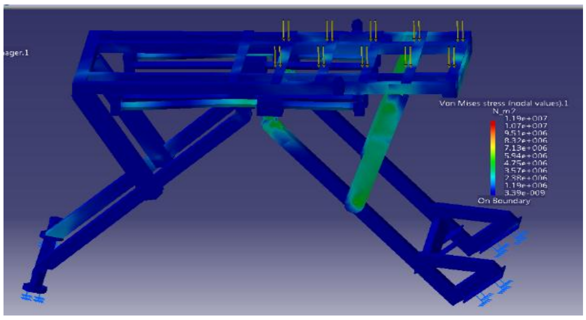

Figure 5. The stress of the frame.

2) Powertrain

After analyzing the dynamics of the wheelchair under different operating conditions [18]–[20], the powertrain of the wheelchair was designed as in Fig. 6.

Two motors used for the proposed vehicle are 250W 12V MY1016Z DC motors with gear reduction and rotary encoder attached to them, which have the advantages of simple installation and high torque output, as shown in Fig. 7. These motors were specially chosen not only for their ability to support the load of various weights but also for their ability to provide enough power to carry out high-performance driving. Table II shows the specifications of the motor.

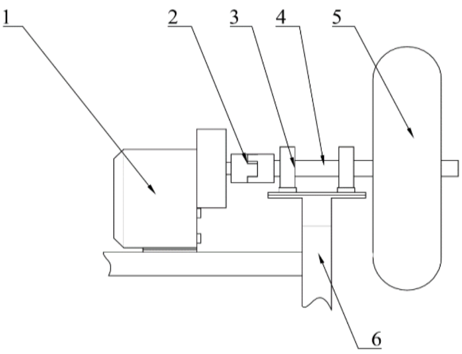

Figure 6. The proposed powertrain of the wheelchair: 1 - Motor; 2 - Coupling; 3 - Bearing; 4 - Axes; 5 - Wheel; 6 – Forelegs.

Figure 7. The electric motor.

TABLE II. THE SPECIFICATIONS OF THE ELECTRIC MOTOR

No.	Parameter	Value	Unit
1	Electric motor power	2x250	W
2	Motor speed	2700	rpm
3	Maximum amperage	28	A
4	Voltage	12	V
5	Angular speed output gearbox	300	rpm
6	Gear reduction	9:1	

B. Control System Design

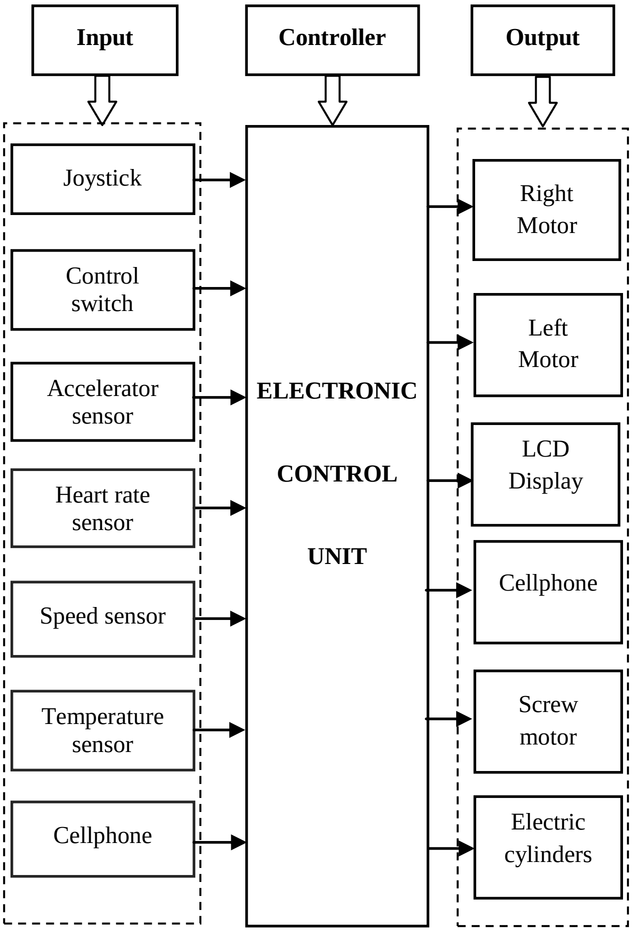

Figure 8. Control block diagram of the designed wheelchair .

In this study, the controller is responsible for both wheelchair motion control and the safety system. The controller receives signals from the sensors, then processes, calculates, and generates signals to control actuators appropriate with the operational mode of the wheelchair.

The control system consists of an Arduino Mega 2560 microcontroller covering an 8-bit, 16-MHz low-power AVR RISC-based processor, 256KB ISP flash memory, 8KB SRAM, 4KB EEPROM. Furthermore, the microcontroller has a diversity of input/output interfaces, including pulse-width modulation, analog-to-digital converters, and an inter-integrated circuit, allowing the controller to have the ability to interface with a variety of sensors and actuators. Fig. 9 and Table III describe the pinout diagram and specifications of the microcontroller [23].

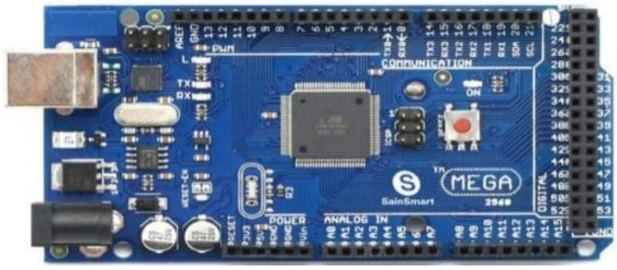

Figure 9. Pinout diagram of the microcontroller.

Besides, this microcontroller is compatible with web-based C/C++ programming environment and online/offline compiler, allowing designers to develop and prototype embedded systems efficiently and rapidly.

TABLE III. THE SPECIFICATIONS OF THE MICROCONTROLLER

No.	Parameter	Value	Unit
1	Operating Voltage	5	V
2	Clock Speed	16	MHz
3	Input Voltage (recommended)	7-20	V
4	Input Voltage (limits)	6-20	V
5	Digital I/O Pins	54	
6	Analog Input Pins	16	
7	DC Current per I/O Pin	40	mA
8	DC Current for 3.3V Pin	50	mA
9	Flash Memory	256	KB
10	SRAM	8	KB
11	EEPROM	4	KB

For the motion control of the wheelchair, the data from speed control potentiometer, joystick, angular speed sensor, and control switches are fed to the controller. When the wheelchair proceeds straight forward or backward, the speed of the wheel on both sides will be equal, this time, the difference in angular speed ($\Delta\omega$) will be zero.

The angular speed of each wheel can be expressed as

$$\text{Left wheel:} \quad \omega_L = \omega_S + \Delta\omega/2 \qquad (1)$$

$$\text{Right wheel:} \quad \omega_R = \omega_S - \Delta\omega/2 \qquad (2)$$

where ω_L and ω_R are respective angular speeds of the left and right wheels of the wheelchair when the driver applies a steering angle to the handle, and $\Delta\omega$ *is* the difference between the angular speeds of the two-vehicle wheels. ω_S is the factor of the angular speed of the wheels that makes the vehicle travel straight.

To control the DC motors with high current, power electronics need to be equipped. In this study, the MDL-BDC24 motor drivers from Texas Instruments were equipped to drive the motors by using its PWM input signals. The driver uses dual H-bridge circuitry with power MOSFET transistors that enable the driver to control 12 V or 24 V DC motors up to 40A continuously (Fig. 10). Moreover, the high-frequency PWM input signals allow the motors to run smoothly over a wide speed range and to change direction (forward/reverse) quickly. Fig. 11 shows an overview of the MDL-BDC24 motor driver.

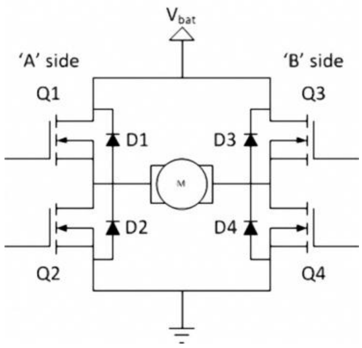

Figure 10. Diagram of H-bridge circuit.

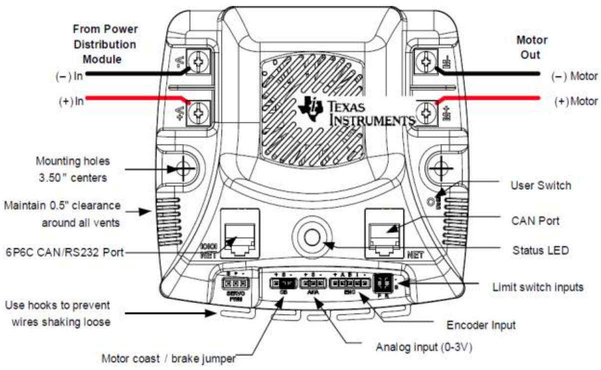

Figure 11. Top view of MDL-BDC24 motor driver.

Furthermore, in this study, the safety system that observes the operating status of the wheelchair such as speed, temperature, tilt angle, and the health status of the user such as heart rate was developed. As the user has health problems or operating conditions of the wheelchair are unsafe, the controller will send an emergency message about the issue to the relatives of the user through the SIM800A module so that the relatives can assist the wheelchair user immediately.

Additionally, the proposed wheelchair is equipped wireless remote-control system to allow the user to control the wheelchair remotely via cellphone. This system helps the user can easily control the vehicle without the help of relatives. The remote-control system is based on the Bluetooth Module HC-05 that connects the wheelchair controller with the cellphone to handle the wheelchair remotely. Fig. 12 indicates the cellphone interface controlling the wheelchair.

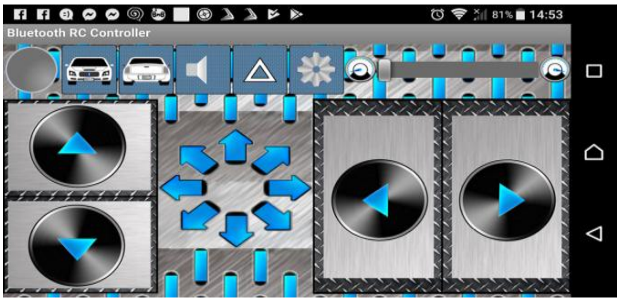

Figure 12. The interface of cellphone controlling the wheelchair.

III. Results and Discussion

Fig. 13a and 13b describe the proposed electric wheelchair. The experiment was conducted with ten users of the wheelchair at the University of Danang – University of Science and Technology campus under the condition that the wheelchair operated in flat and terraced terrains. Fig. 14 indicates the stair-climbing process of the wheelchair.

The experiment results showed that the proposed wheelchair operated smoothly, and the safety system instantly informed the relatives of the user about emergency problems.

Figure 13a. The designed electric wheelchair.

Figure 13b. The designed electric wheelchair.

Figure 14. The wheelchair performing stair-climbing.

IV. Conclusions and Future Work

In this work, we proposed the electric wheelchair that can operate in different terrains such as pedestrian areas, hospitals, schools, and workplaces, and can change the sitting posture according to the user's demand. Furthermore, the safety system was proposed to assist the user with their relatives as an emergency problem occurs. The experiment results revealed that the designed wheelchair operated stably and smoothly in different terrains, and the effectiveness of the safety system was also clearly confirmed.

This study is the first step towards developing the compact and human-friendly wheelchair operating in different terrains. Further work will continue enhancing the safety system measuring more factors of the wheelchair user's health and improving the safety for the user as the wheelchair operates in more complex terrains. Furthermore, we will consider experiments in more realistic scenarios.

Conflict of Interest

No potential conflict of interest was reported by the authors.

Author Contributions

Pham Quoc Thai is the corresponding author of this research work. He was in charge of the overall research direction and planning, control system design, and final editing of the manuscript; Van Cong Tai contributed to the mechanical design and analysis results; Le Minh Tien conducted the safety system and the experiment. Overall, all authors had approved the final version.

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References

[1] B. Rebsamen, E. Burd, "Controlling a wheelchair indoors using thought," *IEEE Intelligent Systems*, vol. 22, pp. 18–24, 2007.

[2] M. Onishi, K. Kobayashi, and K. Watanabe, "A study of intuitive electric wheelchair control interface based on weight shift," in *Proc. IEEE SICE Annual Conference*, 2008, pp. 2710-2713.

[3] G. A. Angel, D. A. E. Antonio, P. R. Enrique, P. N Soraya, P. Luis Rodríguez-Rodríguez, "Upper limb joint kinetics during manual wheelchair propulsion in patients with different levels of spinal cord injury," *Journal of Biomechanics*, vol. 43, no. 13, pp. 2508–2515, 2010.

[4] Y. Yang, W. Huang, and C. Lai, "Optimal design of rim motor for electric powered wheelchair," *IET Electric Power Applications*, vol. 1, no. 5, pp. 825–832, 2007.

[5] Y. S. Kung, M. S. Wang, C. Y. Yang, "Realization of a motion control IC for electric-powered wheelchair," in Proc. *the 8th IEEE International Conference on Industrial Infor-matic*, Jul 13–16, 2010, Osaka, Japan. pp. 523–28.

[6] Y. P. Yang., H. C. Lin, F. C. Tsai, C. T. Lu, K. H. Tu, "Design and integration of dual power wheels with rim motors for a powered wheelchair," *IET Electric Power Applications*, vol. 6, no. 7, pp. 419–28, 2012.

[7] A. Phinyomark, P. Phukpattaranont, C. Limsaku, "A review of control methods for electric power wheelchairs based on electromyography signals with special emphasis on pattern recognition," *IETE Technical Review*, vol. 28, no. 4, pp. 316–26, 2011.

[8] T. Shibata, T. Murakami, "Power-assist control of pushing task by repulsive compliance control in electric wheelchair," *IEEE Transactions on Industrial Electronics*, vol. 59, no. 1, pp. 511–20, 2012.

[9] F. C. Wang, Y. S. Chiang, "Design and control of a PEMFC powered electric wheelchair," *International Journal of Hydrogen Energy*, vol. 37, no. 15, pp. 11299–11307, 2012.

[10] H. C. Lo, K. H. Tsai, F. C. Su, C.Y. Yeh, "Functional electrical stimulation cycling wheelchair for stroke patients: Design and preliminary evaluation results," *Journal of Medical and Biological Engineering*, vol. 31, no. 4, 2011, pp. 295–300.

[11] R. A. Cooper, "Engineering manual and electric powered wheelchairs," *Critical Reviews in Biomedical Engineering*, vol. 27, no.1–2, 1999, pp. 27–73.

[12] L. Fehr, W. E. Langbein, S. B. Skaar, "Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey," *Journal of Rehabilitation Research and Development*, vol. 37, no. 3, pp. 353–60, 2000.

[13] D. Ding, R. A. Cooper, "Electric-powered wheelchairs: A review of current technology and insight into future directions," *IEEE Control Systems Magazine*, vol. 25, no. 2, pp. 22–34, 2005.

[14] R. A. Cooper, T. A. Corfman, S. G. Fitzgerald, M. L. Boninger, D. M. Spaeth, W. Ammer, J. Arva, "Performance assessment of a pushrim activated power-assisted wheelchair," *IEEE Transactions on Control Systems Technology*, vol. 10, no. 1, pp.121–26, 2002

[15] N. N. Le, *Optimization and Application*, Hanoi Publishing House, 2001.

[16] H. Vinh, "Strength of materials," *the University of Danang - he University of Science and Technology*, 2015.

[17] R. K. Bansal, *A Textbook of Strength of Materials*, Laxmi Publications, 2017.

[18] N. H. Viet, *Design of Automotive Systems*, University of Science and Technology, the University of Danang, 2017.

[19] P. M. Duc, "Automotive theory," the University of Danang - University of Science and Technology, 2016.

[20] N. H. Can, *Design and Calculation Of Automobile*, vol. 1,2,3, Vietnam Education Publishing House, 1984.

[21] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Evaluation of the Effects of a Personal Mobility Vehicle on Multiple Pedestrians Using Personal Space," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 4, pp. 2028–2037, 2015.

[22] T. Q. Pham, C. Nakagawa, A. Shintani. and T. Ito, "The effect of a semi-active driving assistance system on the driver of a four-wheeled personal mobility vehicle," *International Journal of Mechanical Engineering and Robotics Research*, vol. 6, no. 4, pp. 322–326, 2017.

[23] S. Monk, Programming Arduino: Getting Started with Sketches (2nd Edition), McGraw–Hill Education, 2016.

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