Hardware Designing and Modelling of Joystick based Electric Wheelchair Drive

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ABSTRACT

This paper discusses a wheelchair that is joystick controlled and can just on just only be controlled by pointing the joystick in the direction. This wheelchair consists of a BLDC motor that is the main motor for controlling the forward and backward direction of the wheelchair. It consists of a brushed DC motor that's main function is to give direction to the wheelchair. It is connected via a gear mechanism just above the main motor, i.e., the BLDC motor. The relay controls both the BLDC and brushed motor, and the relay is operated by the Arduino that instruct according to the instruction provided by the joystick.

Keywords: Electric Wheelchair, BLDC Motor, Speed Control, Joystick, Hardware

1 Introduction

This paper uses a cheaper yet intelligent controller-based speed-controlling mechanism for the wheelchair, which is actuated by a Permanent Magnet Direct Current (PMDC) Motor. Compared to the standard PID Controller, the settling time has been reduced by 65 ms, whereas the peak overshoot has been decayed by 5% [1]. Along with this, the wheelchair's control is done by the "Tongue Drive Controller" (TDS), which helps the one who is severely disabled to navigate comfortably and easily. In this system, the operation is made by a Hall Effect Sensor and a microcontroller. This TDS system provides a faster response compared to conventional systems [2]. The electric wheelchair is designed for domestic and official purposes, whether indoor or outdoor. The use of this electric wheelchair is suited well for use around the house, in marketplaces, parks, offices, and many other workplaces. Some additional features like proximity and warning alarms have been provided in this wheelchair [3]. Wheelchairs are necessary for those disabled patients, especially those who are paralyzed or suffer from spinal cord injuries. Those wheelchairs available commonly in the markets are much more difficult to operate and expensive, which normal or poor people cannot afford. In this wheelchair, the manual wheel system has been substituted by a 'direct drive motor' to drive the wheelchair. Here, the conventional alloy wheel of the wheelchair has been replaced by aluminium, and the structure is made of steel, because they are easily available in market, and they are quite good in handling heavy stress. This makes the wheelchair more cost-efficient [4].

Here, the controlling of the wheelchair is done through an Analog Joystick, where the user can navigate the wheelchair using a joystick instead of using his upper body to direct the wheels. In order to obtain proper motion control, the longitudinal and rotational velocity-controlling mechanism is designed, which works on a reference provided by the input of the joystick. Various tests were performed for this system, and all tests confirmed that it enhances the controlling mechanics [5]. As in order to control the speed in a mechanical wheelchair, the use of our upper limbs was required, which a disabled person cannot use efficiently, so they were unable to provide proper mobility. To eliminate this problem, a servomotor has

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been introduced to control the wheelchair. This power-assisted wheelchair drastically reduces the person's effort while performing several tasks in a wheelchair compared to a standard electrical wheelchair [6]. We must consider the factors to prevent collisions and accidents for safer operation. To serve this purpose, a Safe Driving System has been introduced, which is composed of a Laser Range Finder (LFR) and an Ultrasonic sensor for obstacle detection. The degree of collision is determined via fuzzy reasoning, which is the function of the joystick's input and the distance measured by the LFR and the Ultrasonic Sensor. The speed of the motor gets suppressed bead on the output of fuzzy reasoning. Field tests on this system have verified that the probability of a collision has been reduced using this safe driving system [7].

When operating on a horizontal surface, the wheelchair works as expected, but it is not so when the operation is to be performed on a slope. A propulsion system has been developed for the wheelchair, which enhances the wheelchair's kinematics when climbing on a slope. This reduces muscle efforts as well as motor efforts a lot by adding a few propulsion cycles, not only on the slope but on horizontal surfaces as well. But this came with an issue about controlling, i.e., the controlling was not much convenient for a user when working under the propulsion mode of operation [8]. In order to reduce accidents, as told earlier, we implanted a safe driving support system, but the system is not handled much knowledgeably by older people. For that reason, we define the degree of danger, which is calculated on the basis of fuzzy reasoning, which takes the input from the joystick, and the LFR and Ultrasonic sensors used. It controls the speed of the motor semi-autonomously. Further tests clarified that it reduces the chances of accidents much more observably [9]. If we talk about the long run, if a person depends only on a wheelchair for a long time will lead to an unhealthy lifestyle with negligible physical activities, which may lead to problems like unregulated Blood Pressure, diabetes, obesity, and much more. To prevent this, one must participate in wheelchair sports and other innovative activities. For such activities, the wheelchair has been designed suitably so that it will be suitable for a user to participate in such activities [10].

2 Mathematical Modelling

In this paper, there is a wheelchair. A joystick fully controls its motion. The 48-volt supply is supplied to the controller and converted into a three-phase supply and provides an input to the BLDC motor. A hall sensor is connected between the BLDC motor and controller to take feedback from the shaft of the BLDC motor. An ignition switch is there, which is mandatory to be connected with the battery's positive terminal to put the BLDC motor in motion in the forward and backward direction. Hay's bridge is used to change the rotational motion by varying polarity across the terminal [11]. A PWM inside the controller is used to vary the speed of the BLDC motor. The potentiometer is used to vary the speed of the BLDC motor. The potentiometer and stepper motor are cascaded with each other for speed control through the Arduino. The PWM controlling by the controller itself by potentiometer varying. The architecture of the Electric Wheelchair drive system is shown in Fig. 1.

The Arduino takes supply from the 48-volt battery through a buck converter inserted between them, and the voltage level is decreased to the required input to the Arduino. The joystick gives the instruction to Arduino. The x-axis and Y-axis are used for the direct motion of the wheelchair. The X-axis is used for turning left and right, and Y- the axis is used for the forward and backward direction. This direction control instruction is made operated by the relay operating. R1 and R2 are used for motion in the left and right direction of the wheelchair. Hay's bridge is inserted between them to change direction according to the requirement. DC motor is used for left and right motion that is connected through the chain coupling mechanism on the back side and on the top of the BLDC motor. R3 and R4 are used to operate the BLDC motor. The stepper motor controls the speed through its controller, which the Arduino instructs through the joystick. The mathematical modelling of proposed system is shown in Table 1.

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Table 1: *Mathematical Modelling of Proposed System*

S. No	Components	Rating or Range
1	BLDC Motor	48 V,750 W,1000 RPM
2	Boost Converter	8-60 V, 20 AMP
3	Motor Controller	48 V,750 W
4	Brushed Motor	12 V,10 AMP
5	28-BYJ48 Stepper Motor, Controller	5 V DC, 4 PHASE, 100 HZ

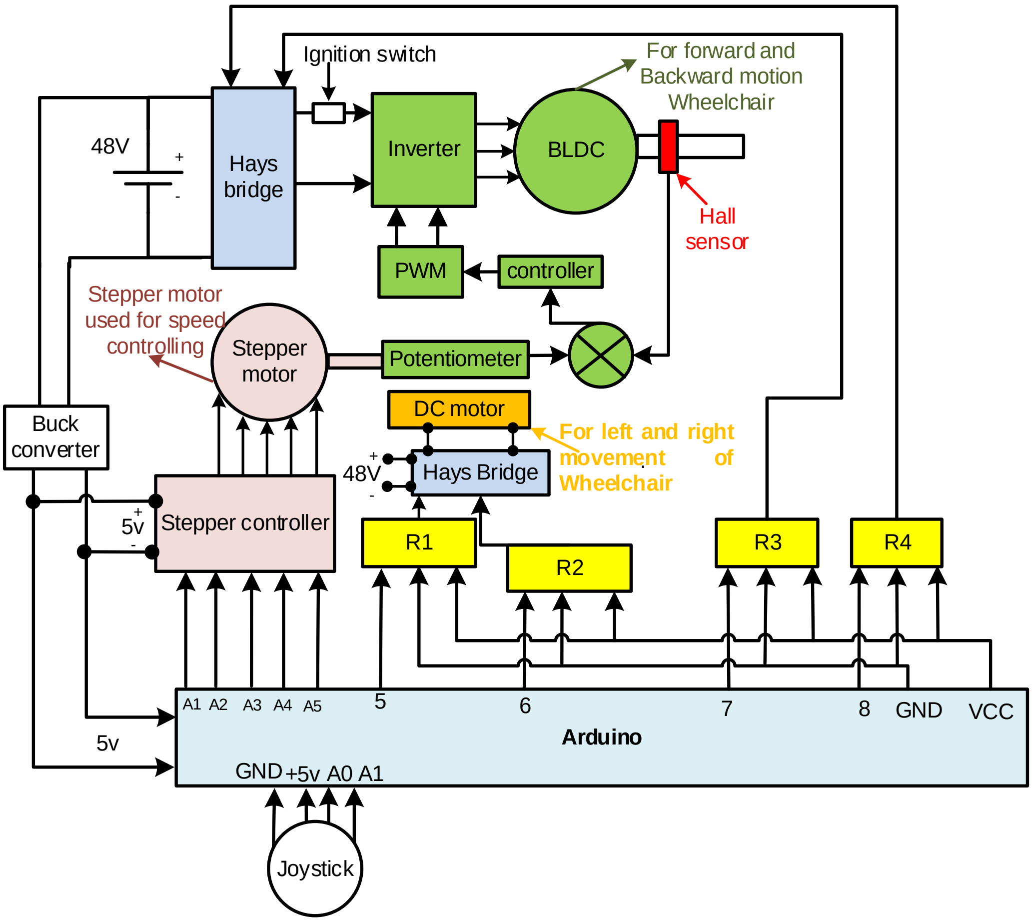

Figure 1: *Architecture of Electric Wheelchair Drive System*

2.1 Mathematical Modelling of BLDC Motor

These are permanent magnet motors, and mainly the function of the commutator and brushes was implemented by the solid-state switches. The BLDC motor comes in wide varieties. It may be a single-phase, 2 phase, and 3 phase. On average, the most popular motor among them is 3 phase type BLDC motor. It generates a trapezoidal back electromotive force (emf), and the motor current generates a pulsating torque. This is due to the special structure of the motor. The number of turns in the rotor and stator magnetic fields remains fixed or constant. The main factor that governs back emf is speed or angular velocity, and there is an increment in speed. In the case of calculating the potential difference across the winding, we have to subtract the back emf from the supply voltage. Some three-phase BLDC motor equations are mentioned. The mathematical modelling of the BLDC motor is shown in equation (1) [9], [12].

$$
\begin{aligned}
V_a &= i_a r_a + L_a \frac{di_a}{dt} + M_{ab}\frac{di_b}{dt} + M_{ac}\frac{di_c}{dt} + e_a \\
V_b &= i_b R_a + L_b \frac{di_b}{dt} + M_{ba}\frac{di_a}{dt} + M_{bc}\frac{di_c}{dt} + e_b \\
V_c &= i_c R_c + L_c \frac{di_c}{dt} + M_{cb}\frac{di_b}{dt} + M_{ca} + \frac{di_a}{dt} + e_c
\end{aligned} \tag{1}
$$

R, L, and M describe stator resistance per phase, inductance per phase, and mutual inductance between two phases. All the mutual inductances are equal. Ia, I_b, and Ic are stator current per phase. Va, V_b, and Vc are the respective voltage of the winding. We are assuming three phases balanced system. So, all the phase resistance Ra, R_b, and Rc are equal. And mutual inductance is also equal (i.e., $M_{ab} = M_{ac} = M_{bc} = M_{ba} = M_{ca} = M_{cb} = M$). It is three phases balanced system. So, all the phase resistance are also equal (i.e., $R_a = R_b = R_c = R$). Hence equation (1) can be rearranged as shown in equation (2).

$$
\begin{aligned}
V_a &= i_a R + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a \\
V_b &= i_b R + L\frac{di_b}{dt} + M\frac{di_a}{dt} + M\frac{di_c}{dt} + e_b \\
V_c &= i_c R + L\frac{di_b}{dt} + M\frac{di_b}{dt} + M\frac{di_a}{dt} + e_c
\end{aligned} \tag{2}
$$

2.2 Brushed DC Motor

This is a unidirectional or direct current motor belonging to the rotary of electrical machines. Basically, the electrical energy is converted to the mechanical energy of the rotary motion. It mainly consists of two coil systems because they have double coils. The basic model of a dc machine can be described by equation (3) [13].

$$
\begin{aligned}
u_s &= R_s.i_s + L_s.\frac{di_s}{dt} \\
u_r &= R_s.i_r + L_r.\frac{di_r}{dt} + \omega_m.M_{sr}.i_s \\
m_c &+ m_m + J_m.\frac{d\omega_m}{dt} + B_m.\omega_m \\
m_c &= M_{sr}.i_s.i_r
\end{aligned} \tag{3}
$$

2.3 Mathematical Modelling of Buck converter

In this paper, a buck converter or DC converter is used to supply the regulated or desired voltage to the DC motor as its rating is less than the supplied voltage, so it must be ensured that the voltage supplied to the DC motor is as its rating. It is a type of lossless DC transformer. The converter's value changes with time, pressure, and temperature. So, to control the output voltage, it must be compulsory to understand the dynamic behaviour, small signal characteristics, and transient response of the converter required. So, there is only one way to model them by time-independent service by their mathematical modelling. The circuit diagram of the buck converter is shown in Fig. 2. Mathematical equation of the buck converter is shown in equations (4) and (5) [14], [15].

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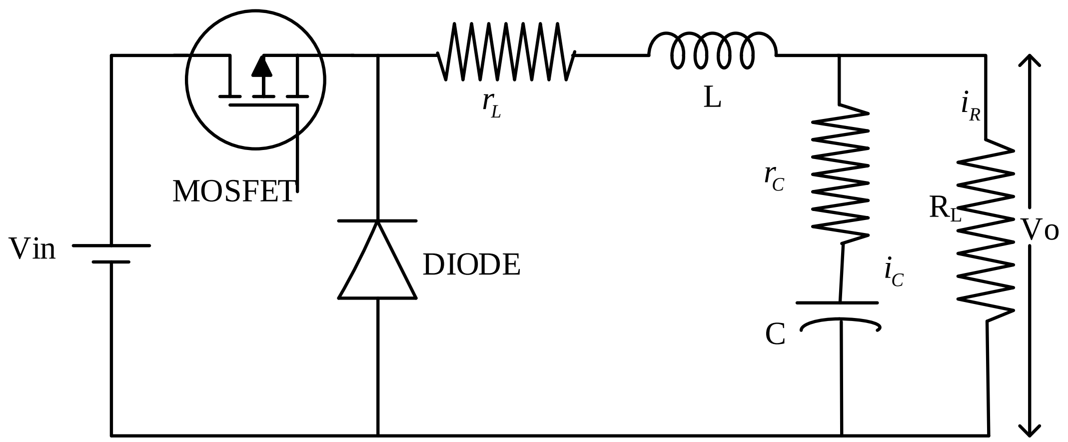

Figure 2: *Circuit Diagram of Buck Converter*

$$Vi(t) = Vo(t) + \frac{Ldi_L(t)}{dt} + r_L i_L(t)$$
$$i_L(t) = \frac{1}{L}\int (Vi(t) - Vo(t) - r_L i_L(t)) \quad (4)$$
$$Vo(t) = \frac{1}{C}\int i_C(t)dt + i_C(t)r_C$$

$$i_C(t) = i_L(t) + i_R(t)$$
$$i_c(t) = \frac{CdV_c(t)}{dt}$$
$$V_c(t) = V_o(t) + r_C i_C(t) \quad (5)$$
$$V_o(t) = \frac{1}{C}\int i_L(t)dt - \frac{1}{C}\int \frac{V_o(t)}{R}dt + r_C i_C(t)$$

These equations are representing the mathematical modelling of the buck converter.

2.4 Byj48 Stepper Motor

It is a 5-wire unipolar stepper motor that uses a 5 V supply to run. The main and best function of the motor is that it can be precisely moved to a specific angle at a time or a step. It is used in papers that basically require preside positioning and many more things. This motor provides a decent torque of 35. 0mn.m at a speed of around 16 rpm. And it provides excellent torque in standstill conditions which maintain power as long as to supply the motor.

The 28byj-48 motor is working in full step mode, and each mode step corresponds to rotation around 11.26 degrees. This defines that there are 32 steps per revolution. The motor contains 1/64 reduction gear set. So, there are actually 2038 steps. Its power consumption is around 24 milliampere. So, this motor consumes a lot of power; the best thing is that it consumes power from a direct external 5 V supply instead of consuming from Arduino. To maintain its position, the motor consumes power in standstill conditions. The Stepper motor is cascaded with a potentiometer for speed control as its controller is programmed to make motion according to the given input from the Arduino, and the input to the Arduino is given by the joystick.

2.5 The ULN2003 Driver Board

The stepper motor draws a high current, and a microcontroller or Arduino cannot provide the supply or cannot control the motor directly. So, a stepper motor requires a driver named ULN2003 to control the motor, which comes with the stepper motor. The ULN2003 contains an array of seven Darlington transistor pairs; each pair can drive a load up to 505 milliampere. And 50 **V** on this board, four of seven pairs.

3 Hardware Model

Hardware model of electric wheelchair is shown in Fig. 3.

Figure 3: *Hardware Model of Electric Wheelchair*

4 Conclusion

In this paper, an electric wheelchair is designed for people who are disabled or unable to move in their house or office work or in their local region. This wheelchair provides them mobility in that particular region. This joystick-controlled electric wheelchair increases the confidence of the people using this wheelchair, and this is also an effortless transport; you have to only provide some effort by providing it instruction only. And it runs on safer operation as it does not harm the system or the person using this wheelchair. It is very comfortable. This joystick-controlled electric wheelchair can be updated in the future. It can be developed according to the disability of the people. It can further be developed like to be controlling the motion of the wheelchair by the gestures by the voice of the disabled person or by many other controllers. So, it can be developed by various technology according to the need of the people.

5 Declarations

5.1 Competing Interests

There is no conflict of interest involved in the work.

5.2 Publisher's Note

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