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Infrared sensor-based remote controlled driving system for people with lower body disability and leg impairment

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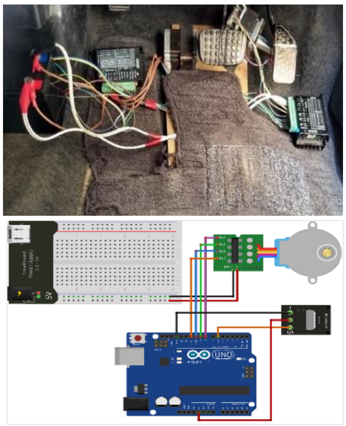

Highlights:

- A remote-controlled driving system was designed for disabled drivers to assist them in braking and accelerating operations.
- The presented system is Arduino-based and uses an IR remote control for driving the vehicle.
- The system was primarily designed for drivers with lower-body disabilities and leg impairment.
- Actual and theoretical times were compared and analyzed. It was found that both studies were in good agreement.

Abstract

The ever-increasing demand for independent mobility has escalated vehicle production across the globe. However, very less focus is given to drivers who are physically impaired or have a driving disability. Thus, the primary purpose of this research is to design a low-cost infrared sensor-based remote-operated driving system for people with lower body disabilities and leg impairment. The presented design is based on an Arduino UNO microcontroller that is programmed and coupled to an infrared sensor to press and release the brake and acceleration pedals, which can be hand-controlled by the disabled driver. Two TB6600 microstepping drivers and NEMA-23 stepper motors have been externally powered using a Volta 12V lead-acid maintenance-free battery at 2.5 amperes with a peak current of 2.7A, and 200 steps/rev. for maximum output torque. An LED and alarm have been placed on the dashboard for an emergency alert or system failure. Additionally, brake and acceleration pedals have been tied to a monofilament cord, which further connects the motor shafts to assist pedalling operation and allows the driver to control the brake and acceleration pedals through an IR remote. The findings comprise two models: theoretical and actual. Results show that theoretical braking time is around 0.7s while actual braking time is found as 0.6s, which shows a good agreement.

Keywords: IR remote control system; Disabled driving system; Lower body disability; Assistive driving; Assistive braking; Limb disability

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1. Introduction

Being able to drive a car is a major step towards independence for people with disabilities and leg impairment, but the conventional driving system installed in cars is not equipped with the utility for the disabled driver to drive the vehicle. According to an estimate by The World Health Organization, there are over 10% of people in the world with a disability, whereas 80% of the disabled majority live in the developing regions of the world such as Latin America, Asia, Africa, and the Caribbean [1]. Thus, a need ascends for the development of a driving system for people with lower body and driving disabilities [2].

Nowadays, high-end cars come pre-equipped with numerous features such as automatic braking, cruise control, assistive braking, and much more that are assistive in highway driving and

Nomencalture

S.D	Stopping distance
tr	Average reaction time
v	Vehicle velocity
µ	Co-efficient of friction between road and tire
g	Acceleration due to gravity

long commutes. However, those cars are not affordable to all due to their high initial cost and maintenance. Besides, according to the 2020 World Bank census report [3], over 9% of households in Pakistan now own cars, which has risen from 6% in 2015. Furthermore, as per the survey by the Pakistan Bureau of Statistics (PBS), motorcycle ownership went up from 41% in 2015 to 53% in 2019 [4]. Thus, in heavily populated regions like Pakistan, excessive traffic jams are a part of the everyday routine [5]–[7] which makes it difficult for drivers to make comfortable commutes due to the nerve-racking activity of foot shifting from brake to race pedals.

As per the driving regulations of the Pakistan Safety Council (PSC), the average driving speed for all types of vehicles near hospitals, schools, and colleges is defined to be around 40 km/hr [8]. However, due to excessive traffic jams in urban residential areas, this becomes a challenge to maintain proper speed, increasing the chances of accidents and crashes. Besides, it is worth noticing that an average disabled person cannot afford the purpose-built vehicle that comes with built-in driving systems to assist leg-impaired drivers. Therefore, to alleviate the difficulty of disabled drivers, this research presents a simple Arduino-based infrared remote-operated driving system that has been designed and placed in the driving compartment that allows smooth driving without the need to use the foot to control the driving operation. For this purpose, two remote-operated NEMA-23 stepper motors have been used that help alternatively press and release the brake and race pedals. Additionally, an alarm and an LED are also fixed on the dashboard which helps alert the driver in case of danger or system failure. Consequently, in the present research, modifications have been made to the existing Continuously Variable Transmission (CVT) Japanese Domestic Model (JDM) of the Toyota Passo 2008 car using an infrared (IR) sensor that is controlled by a remote to perform braking and driving operations by pressing and releasing the brake and acceleration pedals in the car cabin.

2. Literature Review

Driving can be a hectic and uncomfortable task for people who have physical disabilities and leg impairment because almost all conventional cars require a foot-operated activity for mechanisms such as braking and acceleration [9]. However, people with lower limb disabilities cannot operate such foot controls. Car for the disabled is not a new concept, numerous technologies had been introduced to accommodate different types of disabilities. As disabled driver needs special requirements to drive a car, many adaptations have been developed by developers to fit their needs [10]–[12]. Some of the adaptations in specially-designed vehicles are hand-operated systems to control the brake and accelerator pedals; purpose-built knobs for the steering wheel to assist disabled drivers in turning wheels; comfortable seat covers, cushions, and added support; seat belts, driving safety belts, and harnesses; lifts for people, hoists for a wheelchair, options to rotate seats, and myriad more systems to support their driving.

One of the US-based companies [13] developed a hand-controlled offset that assisted disabled drivers to drive wherein both brakes and gas pedals of the vehicle were controlled with hands. This was primarily designed for those drivers who had lower body disabilities. However, a major problem was observed when the vehicle was in high-speed mode and drivers had to look for both hand controllers and steering; thus, raising the safety concerns for occupants as well as travellers. Another assistive hand-operated driving system [14] but with an accelerating pedal beside the steering wheel reduced the calamity in the previous model. This advanced mode lets disabled drivers activate the vehicle acceleration with just a little force while allowing the steering to be in a random state as the system utilized a hand-operated accelerator ring instead of a conventional pedal. However, it might still concern the driver to concentrate on controlling the brake and accelerator ring altogether specifically at the time of vehicle cornering. Hence, risk of an impending vehicle collision.

Considering a push & pull hand-operated driving system by SDL [15], the design focussed on lightweight the steering wheel and reducing the required steering force by utilizing Mountney steering owing to its smaller-sized diameter. Although it allowed drivers to use only one hand to control the steering, high-speed driving caused difficulties for disabled drivers to cope with single-handed steering. To solve this issue, Brig-Ayd provided an extension of this by replacing the push & pull system with a radial controller [16]. These rendered drivers control the pedals by a simple push to the operating handle. However, a major disadvantage was the chance of a mistake if, mistakenly, the driver pressed one of the pedals without disengaging the other.

The first case of vehicle fatality was reported to have happened in the Midlands of an Irish town in 1869 [17]. This pushed researchers [18] to study the causes of collisions with pedestrians, vulnerable users on the road, and cyclists, and ways to avoid them via automated driving controls. They used a collision avoidance method based on an elastic band. In their study, they suggested improving safety distances that provide social acceptance to accommodate manoeuvring distances that a vehicle travels when faced with a collision to prevent crashes. Additionally, they used a specially-designed automated control system that followed their calculated path to avoid any collision that may occur in case the driver lost control. Researchers [19] also used a methodology where they tested two unidirectional parallel moving vehicles. They used a LIDAR fusion and a high-speed camera to gather information such as locations, measured distances, and relative speeds of the two vehicles. Their automated system served as an emergency braking control in case the driver failed to see the forthcoming obstacle; thus, swerving the vehicle to prevent a collision.

In another study, the process of development to ensure the active safety of the driver was analysed [20]. This system was primarily focused on an assistive system that was based on the signals received via front-looking radar. Besides adding to the numerous safety features, they also targeted vehicle safety and the convenience of the driver. Meng and Spence [21] stressed the importance of impending warning signals obtained via a collision system and used them for a comparative analysis with traditional auditory and visual systems available to alert the driver and send warnings against dangers. Their study was focused on facilitating the importance of fast responses that can fairly reduce the chances of deadly collisions.

During the vehicle field testing to study the functions of Adaptive Cruise Control and Forward Collision Warning, Altan [22] utilized a prototype architecture vehicle to understand the impact of these high-end driving assistance systems. Assaad et al. [23] in their study used the frequency modulation method to test their collision-avoidance driving system, which was operated in the continuous wave mode. The primary purpose for designing this system was to keep the driven car at a nominal and safe distance from the forward-moving vehicle or any obstacle using Fast Fourier Transform to decipher information obtained via radar signals. This helped in the prediction of relative speed of the vehicle or obstacle and measure the distance.

It is undoubtedly a predicament for handicapped and disabled drivers to afford such high-end vehicles and control the operations of such devices. Besides, the installation also demands rigorous care to deliver satisfactory driving ease. Moreover, the control systems need to be imported and therefore increase the overall cost which usually people cannot afford. Thus, the main objective of this work is to make improvements to the existing system by modifying the conventional car driving system to assist drivers with lower limbs disability can drive safely with minimum cost investment.

According to a 2018-19 annual inspection by Pakistan Automotive Manufacturers Association, the number of total passenger cars produced by prominent manufacturers such as City, Honda Civic, Toyota Corolla, and Suzuki Swift was about 102,654, while their total sales crossed 100,959 [24]. This shows that car production in Pakistan is huge, which ultimately increases traffic and difficulty for disabled drivers to drive amidst heft jam-packs. Therefore, the present research work is aimed at adapting a conventional vehicle’s driving system for use by people with lower body disabilities. Many different systems have been reported in the literature for a vehicle designed for drivers with lower body disabilities, but the novelty of this system lies in its IR remote-controlled driving features and its relatively low associated cost. This system can be applied irrespective of the vehicle being used without compromising drivers’ safety. Additionally, it only requires drivers to control the steering as the system primarily focuses on drivers with limb or lower body disabilities. Thus, the present research has an active focus on cost reduction so that it is affordable to all with increased usage simplicity.

3. Methods

The present model constantly checks if any signal has been received through the IR sensor, and then feeds it as an input signal which is then decoded by the Arduino microcontroller. The system also automatically applies the brakes if the system fails to depict the response. The block diagram of the research methodology has been shown in **Figure 1**.

3.1. Car Cabin Setup

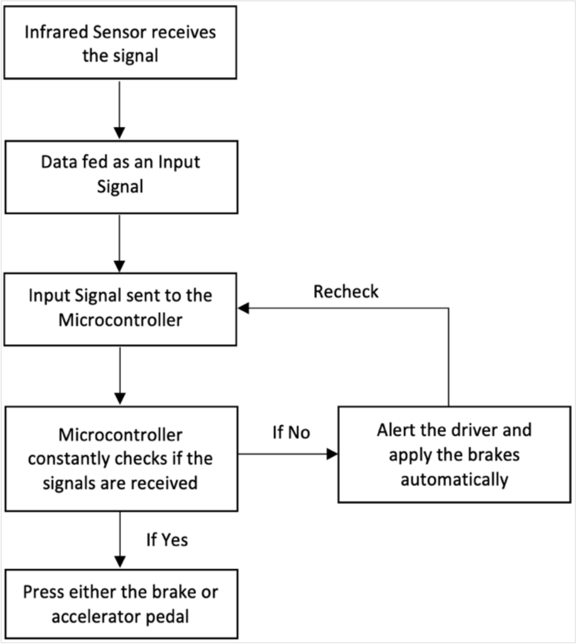

Figure 1. Block diagram of research methodology

To transfer signals to the microcontroller to operate NEMA-23 stepper motors through a remote control, an infrared (IR) sensor has been used to assist leg-impaired drivers to drive without using their feet. Moreover, if the driver is unable to react after seeing a hurdle, the buzzer alarm warns the driver and LED starts blinking to grab the driver's attention. This is because an ultrasonic sensor that is placed at the front bumper grille constantly checks for impending hurdles and makes sure the vehicle does not collide or crash by sending signals to the microcontroller. Thus, ultimately alerting the driver in case of failure or carelessness by pressing or releasing the brake or race pedals, as shown in **Figure 2**. The complete car cabin system has been shown in **Figure 3**.

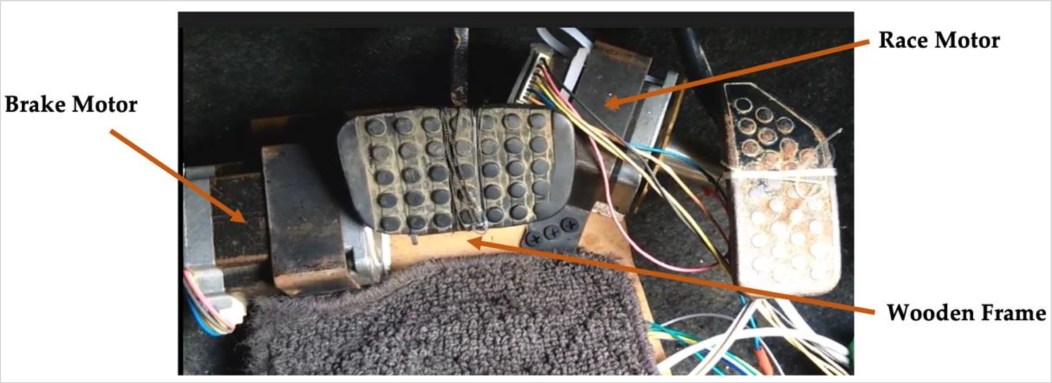

Figure 2. Brake motor (left), race motor (right)

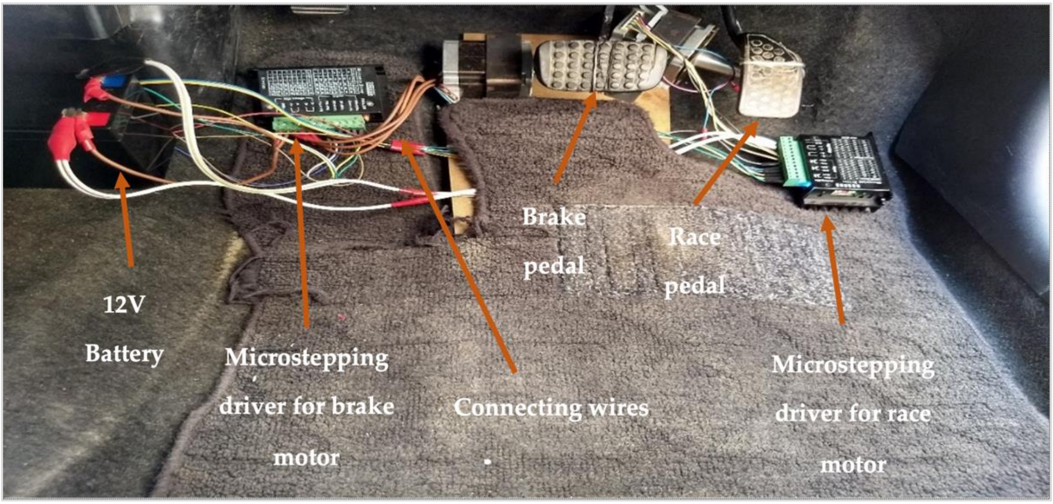

Figure 3. Actual setup inside the car cabin

3.2. System Components

The system will allow the driver to operate the brake and race pedals without needing to use the legs, the assembly components have been shown in **Figure 4**. Upon pressing the buttons of the remote, the motor will rotate subsequent steps defined in the Arduino code. The schematic of the connections of the stepper motor with the Arduino microcontroller is shown in **Figure 5**. Here, the motor has been set at a setting of 200 steps/rev. for higher torque and maximum power output without missing the steps when the remote buttons are kept pressed for a longer duration. An LED blinks when the motor completes the defined rotations of 200 steps/rev. and the alarm also goes high to alert the driver of the halt. The complete setup of the IR remote-operated system in the car cabin is shown in **Figure 6**.

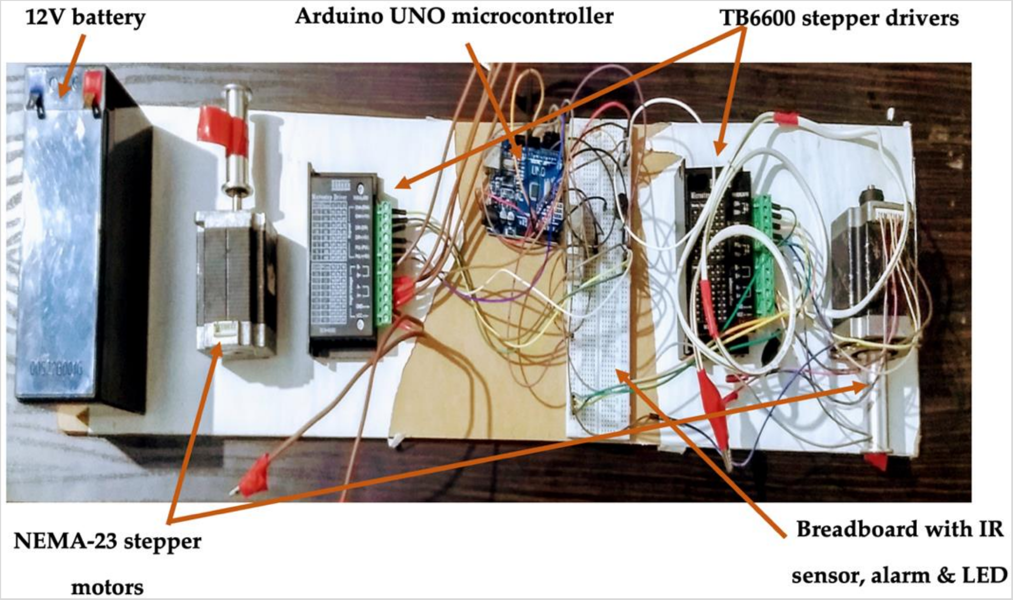

Figure 4. Components of the driving system

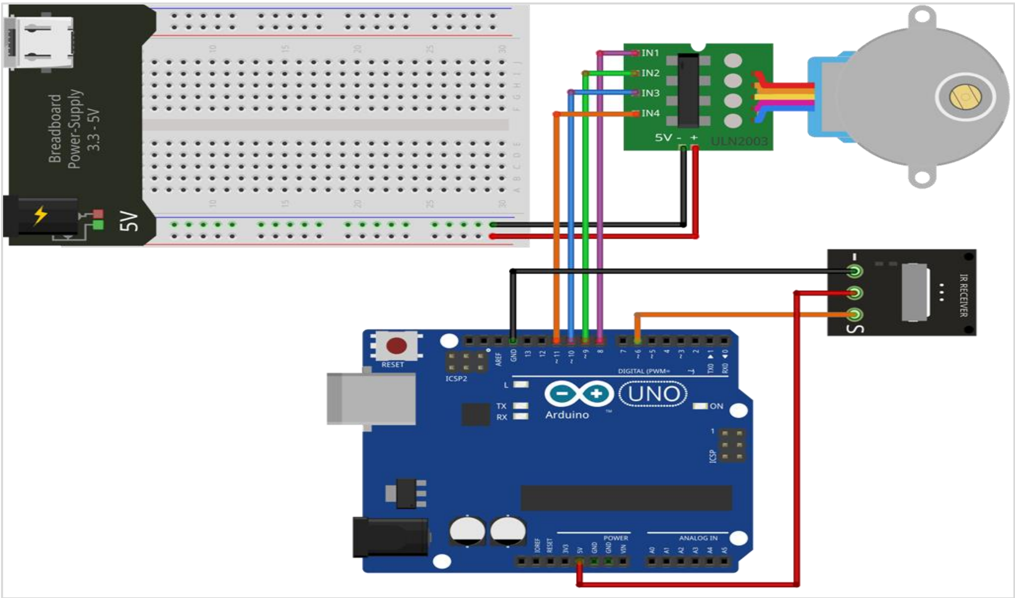

Figure 5. Schematic of the Arduino-connected IR remote-controlled stepper motor

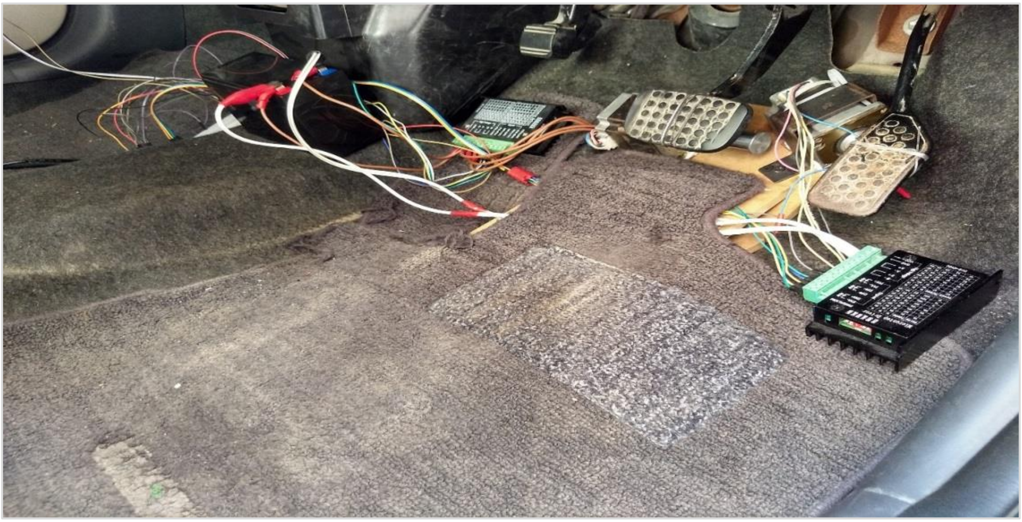

Figure 6. Complete setup of IR remote-controlled system

4. Results and Discussion

To perform actual analysis, theoretical braking time has been calculated first. Then, to validate the results, the actual braking time has been calculated to identify if the outcomes are synchronized. Both of the methods have been described in the forthcoming sections:

4.1. Theoretical Braking Time

To calculate the theoretical braking time, a survey has been performed at five different instances with three different drivers to depict their reaction time amidst driving when they see a hurdle on the way. The reaction time (t_r) is simply defined as the time taken by each driver to react before hitting on the brakes after seeing any impending obstruction. Reaction time can also be understood as the time the driver takes to shift the foot from the race pedal to the brake pedal to prevent a collision. The complete data of the reaction time by each driver has been summarized in **Table 1**.

Table 1. Calculated reaction time at five different instances for three different drivers

No. of Instances	1st Driver	2nd Driver	3rd Driver
1	1.57s	2.34s	2.10s
2	1.87s	1.88s	1.65s
3	2.01s	2.51s	1.86s
4	1.33s	2.38s	2.13s
5	2.18s	1.66s	1.90s
Average	1.79s	2.15s	1.93s
Average Reaction Time (t_r)		1.96s	

For simplicity, assuming the speed of the car to be around 40 km/hr. or 11.1 m/s, as suggested by Pakistan Safety Council [8]. Additionally, assuming the friction coefficient μ = 0.8 [25] between the road and tires. Mathematically, the expression for stopping distance is presented as Equation (1) [26].

$$S.D = tr.v + \frac{v^2}{2\mu g} \tag{1}$$

$$S.D = (1.95s)(11.1m/s) + \frac{(11.1)^2}{2(0.8)(9.8)}$$

$$S.D = 21.64\,m + 7.86\,m$$

$$S.D \cong 30\,m$$

The value is extremely high and appears ambiguous. Applying limit to the velocity to see the changes in Equation (1) as:

$$S.D = \lim_{v\to 0}\left(t_r.v + \frac{v^2}{2\mu g}\right) \tag{2}$$

$$S.D = 0$$

The above analogy also appears irrational because it implies that the car is already at a halt. Now, using Equation (1) to limit only the expression of time value as:

$$S.D = \lim_{t_r\to 0}\left(t_r.v + \frac{v^2}{2\mu g}\right) \tag{3}$$

$$S.D = \frac{v^2}{2\mu g}$$

$$S.D = \frac{(11.1)^2}{2(0.8)(9.8)}$$

$$S.D = 7.86\,m$$

This supposition is rational because lowering the reaction time is a viable option. Now using the Equation (4) to calculate the stopping time as:

$$S.D = v.t \qquad \{\because a = 0\} \tag{4}$$

$$7.86\,m = (11.1\,m/s)(t)$$

$$t = 0.7\,sec$$

Therefore, the above calculation shows that the car can be brought to a dead stop in just 0.7 seconds theoretically; thus, proving the assumption to be legit.

4.2. Actual Braking Time

For the calculation of actual braking time, the delay of 1500µs has been set between each ON state and OFF state (or HIGH and LOW states, respectively). The braking motor takes 200 steps per revolution in total to fully compress the braking pedal. Thus, to get higher motor torque for easily pressing the brake pedal, the TB6600 motor driver current was limited to 2.5A with a peak current value of 2.7A. The actual application of the system in the car can be seen in **Figure 7**.

Figure 7. Ultrasonic sensor at the front of the vehicle to calculate the actual braking time

Hence, the actual braking time is calculated as:

$$Braking\ Time = \left(\frac{HIGH\ state\ time}{step} + \frac{LOW\ state\ time}{step}\right) x\ Total\ no.of\ steps$$
$$Braking\ Time = (1500\mu s + 1500\mu s) x\ 200$$
$$Braking\ Time = 0.6\ sec$$

4.3. Research Outcome

The primary purpose of the research is to assist disabled people to drive without the use of their legs. For this reason, a simple Arduino-UNO-based microcontroller has been connected to an IR remote controller to help leg-impaired persons in driving without the need to use their feet to drive the vehicle. To perform braking and accelerating operations, two remote-controlled NEMA-23 stepper motors were used. These motors were further attached to a wooden frame to eradicate vibrations and motor noise.

Additionally, the system continuously checks if any signal has been received through the IR sensor, then feeds it as an input signal which is then decoded by the Arduino microcontroller. The motor has been set at a setting of 200 steps/rev. for higher torque and maximum power output without missing the steps when the remote buttons are kept pressed for a longer duration. An LED blinks when the motor completes the defined rotations of 200 steps/rev. and the alarm also goes high to alert the driver of the halt. As the programming of microstepping drivers requires delay times to perform “steps” between ON and OFF states (also known as HIGH and LOW current states), each of them was programmed at 1500µs to prevent jerks and lags during braking and accelerating of the vehicle while completing the cycle of 200 steps/revolution to completely press and de-press the pedals. Furthermore, the current was limited to 2.5A, while fixing the peak current value at 2.7A max. This was done to prevent short-circuiting of the system due to excessive current of system failure. These observations gave the actual braking time of 0.6s, which showed a good agreement with the theoretical braking time value of 0.7s.

5. Limitations

The present research highlights a system that assists leg-impaired drivers to control the vehicle through an IR remote controller. However, the steering is yet to be controlled by the driver since the research primarily focuses on those drivers who cannot use their legs to control the pedals. Thus, steering control is the limitation of the presented research. Besides, speed is assumed to be uniform by keeping in mind the urban driving conditions and safety of both driver and vulnerable road users as a remote-operated vehicle is prone to skews and drifts at higher speeds.

6. Future Scope

Mitigation of the research limitations such as the addition of a steering control system and stability controllers at high speeds can be regarded as the future works of the presented driving system. Furthermore, advanced features such as the applicability of the system to a manual car would enhance the scope of the research as well as its adaptability to all types of cars.

7. Conclusion

The paper presents an IR remote-controlled based driving system for people with disability and leg impairment. The system is based on an Arduino UNO microcontroller that is connected to two 12-volt NEMA-23 stepper motors, one for braking operation and the other for accelerating the vehicle, which is powered by two TB6600 microstepping drivers. Additionally, to get higher torque output, both stepper motors are further connected in parallel to a 12-volt rechargeable lead-acid DC battery that has a maximum output current rating of 7.2 Ah @ 20hr. Hence, making the system independent of the car battery by connecting it with an external power source.

Moreover, in case the driver is unable to react after seeing a hurdle, a buzzer alarm placed on the frontal dashboard warns the driver and LED starts blinking to grab the driver's attention. This is because an ultrasonic sensor that is placed at the front bumper grille constantly checks for impending hurdles and makes sure the vehicle does not collide or crash by sending signals to the microcontroller. Thus, ultimately alerting the driver in case of failure or carelessness by pressing or releasing the brake or race pedals. Thus, the remote-operated system allows the driver to drive without using his foot by controlling the braking and accelerating operations via IR remote. However, the steering must be controlled by the driver.

When the remote buttons are pressed, the motor will rotate subsequent steps defined in the Arduino code. Here, the motor has been set at a setting of 200 steps/rev. for higher torque and maximum power output without missing the steps when the remote buttons are kept pressed for a longer duration. The LED also blinks when the motor completes the defined rotations of 200 steps/rev. and the alarm also goes high to alert the driver of the halt.

To calculate the theoretical braking time, a survey has been performed at five different instances with three different drivers to depict their reaction time amidst driving when they see a hurdle on the way. The reaction time is defined as the time taken by each driver to react before hitting on the brakes after seeing any impending obstruction. Furthermore, to prevent lags and jerks, the delay between each HIGH and LOW state of the current cycle is set to 1500µs. Additionally, to completely press the pedals, motors required 200 steps to complete this cycle with a peak current of 2.7A.

For experimentation and demonstration, a Toyota Passo car had been utilized with an average weight of 1000 kg. The car was a 2008 Japanese Domestic Model (JDM) with a CVT transmission. The speed was kept to 40 km/hr. to meet the standards defined by the Pakistan Safety Council for driving in urban and residential areas. Besides, high current settings in the microstepping drivers were used to eradicate the need to calculate pedal forces. This way, maximum output torque was obtained to work on any type of vehicle without the need to change settings to meet the pedal forces of different vehicle models. The theoretical braking time obtained was 0.7s while the actual braking time came to be 0.6s; thus, showing a good agreement.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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