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Research Article

Autonomous Braking System Using Linear Actuator

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The most frequent cause of vehicle accidents (car, bike, truck, etc.) is the unexpected existence of barriers while driving. An automated braking system will assist and minimize such collisions and save the driver and other people's lives and have a substantial influence on driver safety and comfort. An autonomous braking system is a complicated mechatronic system that incorporates a front-mounted ultrasonic wave emitter capable of creating and transmitting ultrasonic waves. In addition, a front-mounted ultrasonic receiver is attached to gather ultrasonic wave signals that are reflected. The distance between the impediment and the vehicle is determined by the reflected wave. Then, a microprocessor is utilized to control the vehicle's speed depending on the detected pulse information, which pushes the brake pedal and applies the vehicle's brakes extremely hard for safety. For work-energy at surprise condition for velocity 20 km/hr, the braking distance is 17.69 m, and for velocity 50 km/hr, the braking distance is 73.14.

1. Introduction

Technology related to self-driving cars has grown at an exponential rate during the last decade. The global market for self-driving cars is estimated to be around 6.5 thousand units in 2019, with a compound annual growth rate (CAGR) of 63.5 percent between 2020 and 2027 [1]. By 2027, the global market for autonomous vehicles is expected to reach 560 billion. Autonomous braking is a vital technology for future safe-driving system development. Vehicles equipped with autonomous braking technology can detect an impending collision with another vehicle, person, or barrier [2]. When the system detects an impediment, it may initiate one of the two modes of autonomous braking.

The first mode is collision avoidance. Collision avoidance automatic braking prevents accidents [3]; however, the driver is not notified before the system brakes. The second option is collision mitigation or collision warning. The sensors in a collision mitigation system identify the probability of an accident but take no immediate action; rather, the driver will get a warning signal or voice message. Due to the absence of a driver in an autonomous car, the system must make a choice [4]. As a result, we developed an automated braking system in which the ultrasonic sensor is replaced by a lidar sensor. The lidar sensor emits rapid laser signals, sometimes up to 150,000 pulses per second, and provides both the location and a three-dimensional image of objects in front of the automobile [5]. The system is controlled by the microcontroller (Arduino UNO), which in turn controls the linear actuator that applies the brake. Autonomous braking systems (ABS) must be precise in a wide range of conditions. False-alarm scenarios erode driver confidence and can be dangerous [6]. Self-driving braking systems are now standard in the vast majority of automobiles. These gadgets detect approaching collisions and take corrective action to prevent them [7].

These systems operate independently of the driver, using brakes to slow and stop the vehicle, preventing collisions, or reducing impact. We examine a car equipped with an ABS from the standpoint of systems-of-systems and develop guidelines for the design of an ABS to avoid harmful emergent behavior and increase the ABS's safety [8]. The research focuses on designing enhanced brakes for autonomous vehicles utilizing a DC intelligent servo motor torque controller [9]. The primary takeaway from this workpiece is that vision sensors and high-performance braking kits, such as actuators, will be more helpful in boosting safety and upgrading the braking system. This study uses deep reinforcement learning to create a throttle and brake control system [10]. The two scenarios that are briefly covered in this article are a static obstacle and a dynamic obstacle. The main disadvantage of this research is that it does not explore the emergency and unforeseen scenarios of the obstacle [11].

According to [12], an automatic braking system that employs an ultrasonic sensor can reduce the impact of an accident. In order to partially prevent accidents, the use of such a propelled framework may be made necessary in the same way how the safety belts are used. In the automation field, designers have proposed several enhancements. A precise short-range radar system was developed for anticollision applications where automatic braking is applied in response to the detection of a collision risk where a very high probability of detection is accompanied by a very low level of false alarm. A brake strategy for an automatic parking system of the vehicle has proposed a brake controller which works with the automatic parking system and makes the process of parking smooth and stable.

An autonomous antilock braking system (ABS) which can take over the tracking control of the vehicle is developed for a four-wheel vehicle. The ABS is a braking system that maintains control over the directional stability of the vehicle during emergency braking or braking on slippery roads by preventing wheel lockup. There have been considerable advances in modem vehicle braking systems in recent years. Automatic emergency braking systems (AEBS), which can mitigate some crashes with stationary objects and motorbikes as well as front-to-rear shunt accidents involving two vehicles, were in production on a number of modern vehicles at the high end of the market in the early days of [13]. If they are overcome, significant casualty savings with a high likelihood of a benefit to cost ratio greater than one are possible.

This study develops an effective electric braking system with energy regeneration for a brushless DC motor in an electric vehicle (EV) [14]. Implementing the recommended approach of adjusting the inverter sequence to manage the inverse torque will enhance the EV's driving range by 16.2 percent. Braking becomes easier and more effective by harnessing and conserving the kinetic energy that is worn down by friction [15]. An extensive review of the literature was carried out. This included marketing and promotional information from manufacturers on the automated braking system and other active safety systems that they sold or were developing as well as scientific papers on the technical behavior and development of such systems and technical standards, regulations, guidelines, and research papers on the effectiveness of systems.

The Nissan brake assist system with a preview function (BAP) utilizes information provided by adaptive cruise control (ACC) sensors to judge when an emergency braking application may be required based on the distance to the followed vehicle and relative velocity. The paper by Tamura et al. [16] shows that when an impending collision is detected, a small braking force is applied to minimize the separation between the brake pad and rotor to reduce the brake response time. The small braking force is activated when the target deceleration for stopping without colliding with the vehicle ahead exceeds $5.88\,m/s^2$.

In general, most of the early models specifically attempted to explain a derived motivation to alter his or her behavior, casting the problem in items of managing or balancing various assessments of risk. While many of these models cite specific driving behaviors as evidence of risky behavior, their focus is primarily on behavior change that results from maintaining a target risk level crossing a risk threshold or as a nonspecific driver of guidance about what particular kinds of change in driver behavior are likely to result from adaptations to specific advanced driver assistance system (ADAS) functionalities. An automatic reverse braking system (ARBS) will process the sensor data and operate the vehicle to prevent accidents caused by reckless driving or trouble detecting objects in the reverse route. ARBS uses sensors to detect barriers and will process the sensor data to prevent collisions. FPGA is utilized in [17], as a control unit to which the devices and sensors are connected. This control unit will perceive the object in accordance with the digital input and conduct the appropriate action. Review of behavioral adaptations to advanced driver assistance systems was detailed in [18]; such systems are created to assist drivers with duties that were previously handled only by the drivers themselves.

Autobraking system using sensors was proposed to prevent front-end, rear-end, right-turn, and left-turn accidents on roads. This module can detect the distance between the front vehicle and the driver's vehicle to keep a constant distance using a sensor and operate the brake system. All the above-proposed design models contributed to the safety of vehicles and pedestrians. It prevented rear-end crashes and provided ABS for sharp or slippery roads. But all these are applicable for a vehicle running in the conventional direction, so we need to develop systems that enhance the performance and safety of the vehicle when it moves in the reverse direction. A model designed for reversing vehicles provided an obstacle and speed control mechanism based on binocular cameras. Thus, in this paper, we propose an automatic reverse braking system to prevent a collision by using sensors to detect obstacles. The automatic reverse braking system processes the sensor data and controls and prevents accidents.

It makes use of a microcontroller to regulate the braking and throttle of the vehicle, as well as an ultrasonic sensor and a revolutions per minute (RPM) counter [19]. The information about the surrounding environment can be accurately provided as input to the driver by incorporating a lidar sensor or radar [20]. The autonomous braking systems include components of Arduino UNO module, ultrasonic sensor, lidar sensor, linear actuator, relay switch, and power supply for microcontroller. The paper is organized into various sections as follows. An overview of the design procedure is presented in Section 2, and the results and discussion are in Section 3 and Section 4 conclusions.

2. Methodology

2.1. Work on the Braking System. If a collision is imminent, the driver does not intervene, and the autonomous emergency braking (AEB) system begins braking automatically. The AEB can detect a probable collision and activate the braking system to slow the vehicle down in order to avoid or mitigate the impact of the accident. The AEB is part of the second wave of active safety features that are being installed in passenger cars. These features include onboard sensors, radar, cameras, GPS, and lasers. Active safety technology can either prevent an accident from occurring or actively assist the driver in reducing the severity of an emergency scenario. In a dangerous situation, active systems provide additional driver control. To that purpose, a vehicle's performance and surroundings are constantly monitored by numerous safety systems. The automated braking system is an Arduino-based mechatronic system.

The microcontroller of the device receives information from a lidar sensor (constant data collectors of the environment). As soon as the engine starts, the lidar sensors begin collecting data and transmitting it to Arduino, which then performs the required steps. The automobile will continue to accelerate unabatedly until it comes into contact with or passes close to an obstruction. When considering the technology of autonomous vehicles, the ultimate goal is to assist the driver in the operation of the vehicle. To mimic the same, sensors are used to perceive the environment. Namely, these sensors include a camera, lidar, radar, and ultrasonic sensor. After perception of the environment, necessary actions are needed to be taken to actuate the vehicle; in that condition, the actuators place a role.

These include the actuation of the braking system, steering motor, and acceleration pedals. When a barrier or impediments are identified, the sensors transmit the information to the microcontroller, which reacts by bringing the vehicle to a complete stop or slowing down, as desired in Figure 1.

2.1.1. The Process of Breakdown

(1) To begin, sensors will gather data from their immediate environment and transmit it to the Arduino UNO

(2) The data will be processed by Arduino and compared to the programmer (safe distance)

(3) Once the comparison is complete, the Arduino will perform the actions assigned to the various cases: (a) no action has been taken, (b) the vehicle will slow down by the distance between it and the impediment ahead, and (c) the vehicle will come to a complete stop

2.2. Braking Distance Calculation. The braking distance is the distance a vehicle travels before coming to a complete stop when the brakes are completely engaged. Braking is affected by the friction between the tires and the road surface, the weight of the vehicle, the wind, the type of braking system, and air resistance.

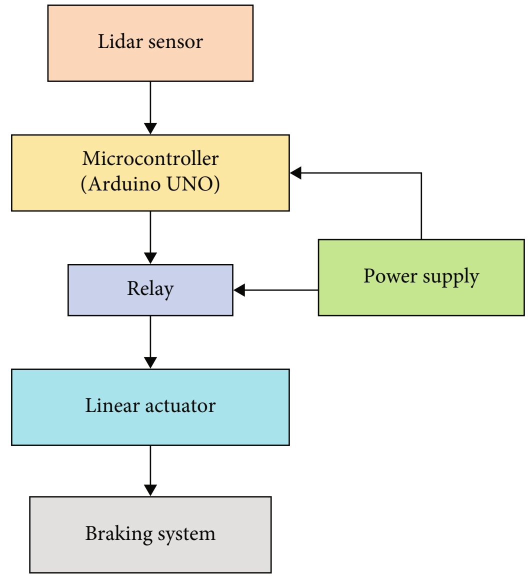

Figure 1: Block diagram of the proposed model.

Table 1: Reaction distance for various situations.

S. no	Velocity (km/hr)	Reaction distance (m) Expected	Unexpected	Surprise
1	10	2.77	3.46	4.98
2	20	5.55	6.93	9.99
3	30	8.33	10.41	14.99
4	40	11.11	13.88	19.99
5	50	13.88	17.35	24.98

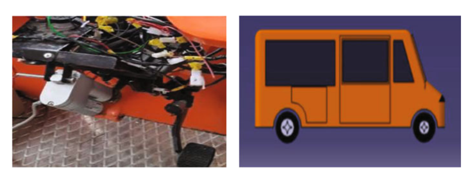

Figure 2: Hardware model of actuator and vehicle.

Table 2: Calculation of dry roads in an expected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	2.77	0.558	3.328
2	20	5.55	2.24	7.79
3	30	8.33	5.05	13.38
4	40	11.11	8.98	20.09
5	50	13.88	14.02	27.9

The braking distance, on the other hand, is divided into two parts: (1) total stopping distance and (2) reaction distance. The reaction distance is the distance traveled before using the brake. It is essentially the time it takes for the

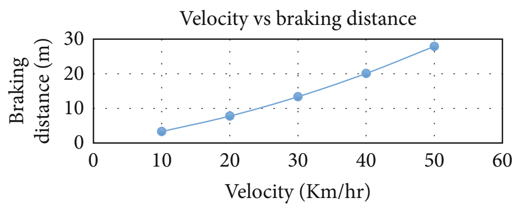

Figure 3: Dry road at an expected situation.

Table 3: Calculation of dry roads in the unexpected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	3.46	0.558	4.016
2	20	6.93	2.24	9.16
3	30	10.41	5.05	15.44
4	40	13.88	8.98	22.82
5	50	17.35	14.02	31.31

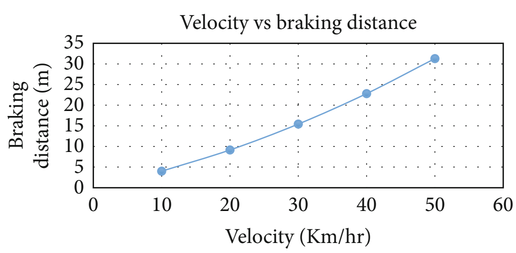

Figure 4: Dry road at the unexpected situation.

driver to apply the brakes. Reaction distance is the product of velocity and reaction time.

$$\text{Reaction distance} = \text{Velocity} * \text{Reaction time}. \quad (1)$$

Reaction time is obtained based on the various situations. There are three situations: (a) expected, (b) unexpected, and (c) surprise.

Reaction times vary depending on the situation, with expected braking distances ranging from 0.7 to 1.0 seconds, unexpected braking distances ranging from 1.25 to 1.5 seconds, and surprise braking distances ranging from 1.5 to 2 seconds.

Since we are calculating reaction distance for various situations, reaction distance is expected as

$$\text{Reaction distance} = V * \text{Rt}. \quad (2)$$

10 Km/hr =2.77 m/s
Reaction time expected is 1.0 sec
Reaction distance =2.77 * 1.0 =2.77 m
Reaction time for unexpected is 1.25 sec
Reaction distance =2.77 * 1.25 = 3.46 m
Reaction time for surprise is 1.8 sec
Reaction distance =2.77 * 1.8 = 4.98 m

Various scenarios' reaction distances are mentioned in Table 1. The distance traveled by a vehicle before coming

Table 4: Calculation of dry roads at surprise situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	4.98	0.558	5.538
2	20	9.99	2.24	12.23
3	30	14.99	5.05	20.04
4	40	19.99	8.98	28.97
5	50	24.98	14.02	39.01

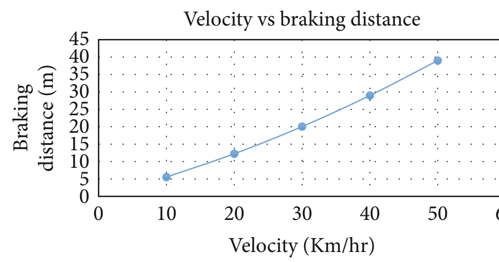

Figure 5: Dry road at surprise situation.

Table 5: Calculation of wet road at an expected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	2.77	1.107	3.877
2	20	5.55	4.44	9.99
3	30	8.33	10.01	18.34
4	40	11.11	17.81	28.92
5	50	13.88	27.81	41.69

to a complete stop when the brake is applied is referred to as braking distance. The braking distance can be calculated by using two methods: (a) kinematics and (b) work-energy method. The experimental setup of the actuator and vehicle is illustrated in Figure 2.

2.2.1. Kinematics Method. The general equation for calculating braking distance is given below.

$$Vt^2 = V^2 + 2ad, \quad (3)$$

where V_f is the final velocity, V_i is the initial velocity, a is the acceleration rate, and d is the distance during acceleration.

We assume that the end velocity will be zero when calculating the braking distance. Based on this equation, the distance traveled during braking can be calculated.

$$d = \frac{(vi)^2}{2a}. \quad (4)$$

The acceleration rate is calculated by multiplying gravity's acceleration by the sum of the coefficients of friction and road slope. Calculating dry roads in a scenario that is anticipated is illustrated in Table 2.

$$d = \frac{(vi)^2}{2g(u = G)}, \quad (5)$$

where g is the gravitational acceleration (9.81 m/s^2), u is the coefficient of friction between road and tires, dry road is 0.7, wet road is 0.35, and G is the road grade percentage at 0.06.

From Figure 3, at 10 km/hr, the braking distance is 3.328 m, and for 40 km/hr, the braking distance is 20.09 m. Table 3 shows the calculation of dry roads in unexpected conditions.

From Figure 4, for a velocity of 20 km/hr, the braking distance is 9.16 m, and for 50 km/hr, the braking distance will be 31.31 m. Dry road calculations at a surprise situation are presented in Table 4.

From Figure 5, for a velocity of 20 km/hr, the braking distance is 12.23 m, whereas for 50 km/hr velocity, the braking distance is 39.01. The calculation of a wet road in a scenario that is anticipated is given in Table 5.

From Figure 6, the wet road at different velocities has a stopping distance of 1.107 m and a braking distance of 3.877 m for a velocity of 10 km/hr and a stopping distance of 17.81 m and a braking distance of 28.92 m for a velocity of 40 km/hr. Table 6 mentions the determination of wet road in the unexpected situation.

From Figure 7, at a velocity 30 km/hr, the braking distance is 20.42 m, and for a velocity 50 km/hr, the braking distance is 45.16 m. Table 7 shows the determination of wet road as a surprise situation. The wet road at surprise situation is illustrated in Figure 8.

2.2.2. Work-Energy Method. The work-energy formula for calculating a braking distance is kinetic energy = work done.

$$\text{Work done} = \text{braking force} * \text{distance} = F * d, \quad (6)$$

$$\frac{1}{2} m * V^2 = \text{kinetic energy}. \quad (7)$$

The average braking force is 2000 N, automobile weight is 1000 kg, and speed is 10 m/s.

The formula for braking distance using work-energy is given below:

$$d = \frac{(m * v^2)}{2F}. \quad (8)$$

The braking distance for an anticipated circumstance is mentioned in Table 8. From Figure 9, work-energy at the predicted condition for velocity 30 km/hr is 25.67 m and for velocity 50 km/hr is 62.04. Table 9 shows the braking distance for an unexpected situation.

From Figure 10, the work-energy at different velocities has a braking distance of 5.378 m at 10 km/hr and a braking distance of 65.51 m at 50 km/hr. Braking distance in case of surprise is mentioned in Table 10.

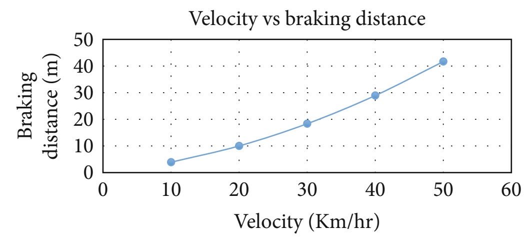

Figure 6: Wet road at an expected situation.

Table 6: Calculation of wet road at the unexpected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	3.46	1.107	4.567
2	20	6.93	4.44	11.37
3	30	10.41	10.01	20.42
4	40	13.88	17.81	31.69
5	50	17.35	27.81	45.16

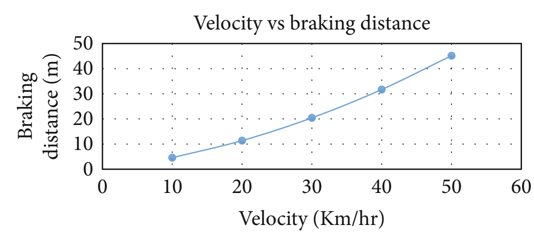

Figure 7: Wet road at the unexpected situation.

Table 7: Calculation of wet road a surprise situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	4.98	1.107	6.087
2	20	9.99	4.44	14.43
3	30	14.99	10.01	25.07
4	40	19.99	17.81	37.8
5	50	24.98	27.81	52.79

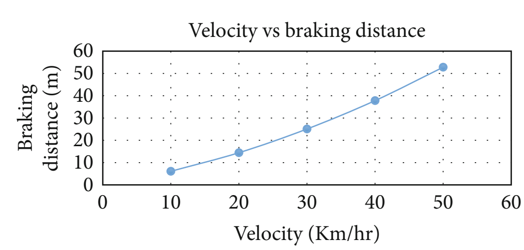

Figure 8: Wet road at surprise situation.

From Figure 11, for work-energy at surprise condition for velocity 20 km/hr, the braking distance is 17.69 m, and for velocity 50 km/hr, the braking distance is 73.14.

2.2.3. Linear Actuator with Brake Pedal Travel Distance. When the brakes are applied, the distance traveled by the

Table 8: Braking distance for an expected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	2.77	1.918	4.688
2	20	5.55	7.70	13.25
3	30	8.33	17.34	25.67
4	40	11.11	30.85	41.96
5	50	13.88	48.16	62.04

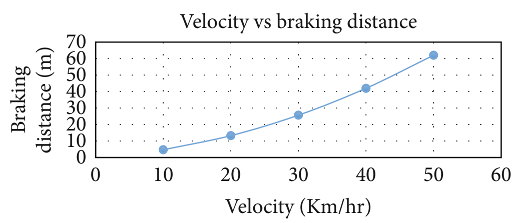

Figure 9: Work-energy for expected situation.

Table 9: Braking distance for an unexpected situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	3.46	1.918	5.378
2	20	6.93	7.70	14.63
3	30	10.41	17.34	27.75
4	40	13.88	30.85	44.73
5	50	17.35	48.16	65.51

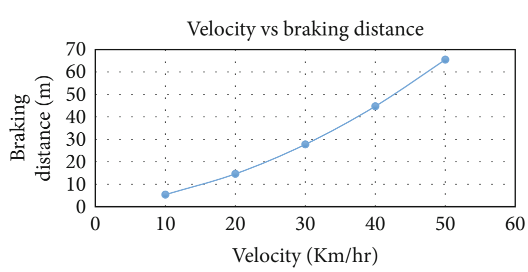

Figure 10: Work-energy for an unexpected situation.

Table 10: Braking distance for surprise situation.

S. no	Velocity (km/hr)	Reaction distance (m)	Stopping distance (m)	Braking distance (m)
1	10	4.98	1.918	6.898
2	20	9.99	7.70	17.69
3	30	14.99	17.34	32.33
4	40	19.99	30.85	50.84
5	50	24.98	48.16	73.14

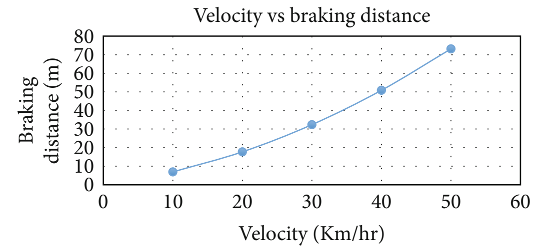

Figure 11: Work-energy for surprise situation.

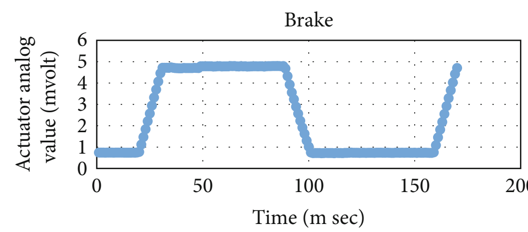

Figure 12: Analog range of braking values.

Table 11: Braking distance at various situations.

Conditions	Braking distance Linear actuator (mm)	Time (sec)	Distance traveled (m)
No braking	0	0	0
Partial barking	40	3.5	9.32
Full barking	70	6	4.95

brake pedal. Depending on the conditions, it may traverse the whole distance or only half of it. Similarly, the linear actuator's travel distance will vary depending on the scenario. The simulation of real-world scenarios with utmost precision so that the real-life conditions and opportunities can be modeled and analyzed in the simulation world reduces the hazard to human life. The program and function used in the real-life simulation for an autonomous world include functions for various real-life obstacles like humans, animals, and various vehicles, physical conditions like potholes, weather conditions, and driver consciousness, and vehicle dynamics like inertia and braking conditions. Actuator analog values are shown in Figure 12. Distance to brake in different situations is mentioned in Table 11.

Calculate the brake pedal travel distance:

(i) The pedal has a mechanical advantage of 6 : 1

(ii) The pedal height is 650 mm from the pivot, and the angle is 45°

(iii) As a result, the bottom end of the brake pedal's travel distance is 720 mm

(iv) Linear actuator has a speed of 20 mm/s

2.2.4. Control System. The control system is vital to automated braking. The lidar sensor is essential to the control system. The object reflects light waves onto the lidar sensor. The sensor measures distance by counting the duration between each pulse (time of flight). To identify an impediment and transmit input to the relay switch to decide whether or not the actuator has to go in or out to apply or release the brake, the GPS receiver interprets the incoming wave and sends information to the Arduino UNO. Controlling linear actuators is straightforward when two SPDT relays are utilized. Relays direct the movement of your actuator by stimulating a magnet, which activates high-power currents with an electric current. Such a system can be powered and run by a microcontroller, such as Arduino. It is a feature of ADAS in which the driver is assisted from obstacles like humans, animals, lane departure, and cruise control, so that braking can be applied when the driver is not at attention while driving. Arduino is a very good and standard controller tool with GPIO, which includes the PWM and digital control along with a communication stack. Most of the actuators can be actuated through it or via it, and at the same time, it can be used for piecewise testing of each test case and later can be taken to a high-level controller like RPI or NVIDIA Jetson boards. The interfacing of the components system is shown in Figure 13.

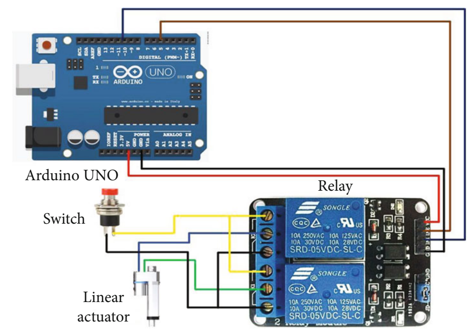

FIGURE 13: Interfacing of components.

3. Results and Discussion

In this paper, the real-time fabrication of an autonomous braking system is carried out using electronic components and also tested in real-life situations. The range of values used for testing is considered as per UN Regulation standards of various car models. Therefore, the prototype of an autonomous braking model worked successfully under different conditions.

In three different situations, the kinematics method of determining the braking distance for dry roads, wet road conditions, and work-energy method is discussed in this research.

From Figure 14, when stopping distances for unexpected and predicted conditions are compared on a dry road at the same speed, the braking distance for surprise is longer. The shorter braking distance is because it is proportional to velocity. From Figure 15, the increase in velocity can be interpreted as increasing the difference in braking distance for three different situations with the same velocity. Wet road conditions have a longer braking distance than dry road conditions, which can lead to a collision. Shortening the braking distance can help to avoid accidents.

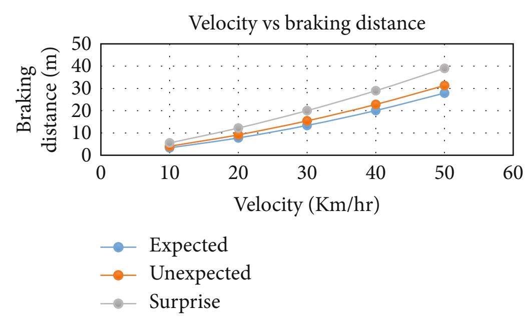

FIGURE 14: Dry road conditions in three different situations.

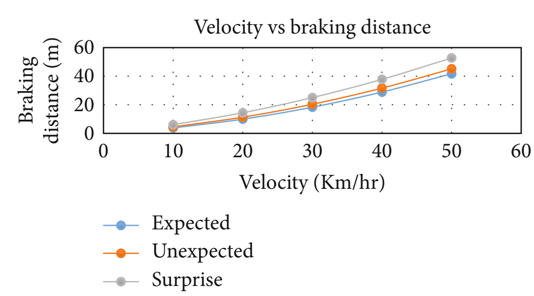

FIGURE 15: Wet road conditions in three different situations.

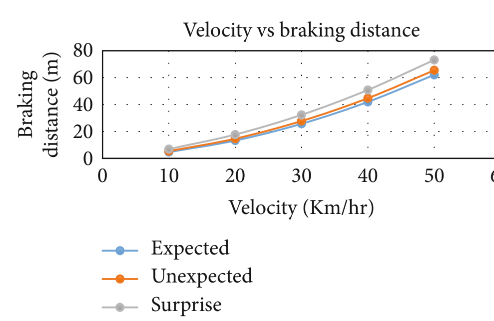

FIGURE 16: Work-energy for three different situations.

From Figure 16, as the kinematics method has taken the coefficient of friction and road grade way into account, it is found to be more accurate than the work-energy method. The braking distance rises as the speed increases due to the work-energy approach in this instance. In contrast to kinematics, this approach requires more braking time. The autonomous emergency braking (AEB) features are considered level 2 of autonomy for any autonomous vehicle; they help in assisting the driver in cases like lane departure, cruise control, drowsiness detection, and other condition in which the driver is diverting from the standard ways of driving. Let's take the example of a car approaching a barrier in front of it when the driver is drowsy. This is where linear actuators are helpful. In such case, if the driver fails to press the pedal, sensors will perceive the obstacle and actuate the linear actuator, which will actuate the braking mechanism.

4. Conclusions

Automated braking is crucial since it not only helps to minimize traffic fatalities but also opens the road for completely autonomous driving. The installation of a lidar sensor expands the sensing range of the automobile, allowing for improved awareness of the vehicle's surroundings, resulting in more efficient braking and accident avoidance. We just utilized the lidar sensor to estimate the distance between the barrier and the ego vehicle in this situation. In the future, we will be able to construct a three-dimensional image of the barrier and acquire a deeper knowledge of its dynamics using the same lidar sensor. Throttling can be used in conjunction with similar principles to enable the vehicle to operate independently and successfully. Advanced cruise control systems use a combination of throttle and brakes to maintain a constant speed in the vicinity of another vehicle.

Data Availability

No underlying data was collected or produced in this study.

Disclosure

This research and publication was performed as a part of the Wollega University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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