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Design of a Smart Car Door Stopper for Vehicle Dooring Accidents

Charles Bojos[1], Adrian Ayam[2], Paul Ordesta[3], Alexander Bojos[4], Rodel Naval[5], Bryan Calma[6]
[1]College of Engineering, Mechanical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
[2]College of Engineering, Mechanical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
[3]College of Engineering, Mechanical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
[4]College of Engineering, Electrical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
[6]College of Engineering, Mechanical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
[5]College of Engineering, Electrical Engineering Dept., University of Cebu – Main Campus, Cebu City, Philippines
Email address: [1]charlesstevenbojos@gmail.com, [2]adrianayam31@gmail.com, [3]joshuamaxilom.ordesta@gmail.com, [4]alexander.bojos@gmail.com, [5]navalrodel1970@gmail.com, [6]bcalma@uc.edu.ph

Abstract– *The paper presented a design for an automatic car door stopper intended to prevent dooring accidents and improve road and vehicular safety. Dooring occurs when an occupant of a park or stationary vehicle precariously opens their door, blocking the path of oncoming cars, motorcyclists, bicyclists, pedestrians, or other vulnerable road users, causing a collision that has the potential to be deadly. The car door stopper detailed in this paper used a vehicle's factory check strap built into the door of most automobiles. It allows the door stopper design to be easily retrofitted into existing vehicles and models that feature the check strap and have the ability for the device to be installed from the factory. It also detailed the design of the Arduino-based smart car door stopper as well as its components, functionality, and operation. The device presented and its system is simulated for validation, fabricated, and tested to be operational and function as intended.*

Keywords *– Arduino; Automotive; Bistable Mechanism; Car Door Stopper; Dooring; Safety; Ultrasonic Sensor.*

I. INTRODUCTION

Every day, pedestrians, cyclists, motorcyclists, and motorists alike face all sorts of risks and dangers while they traverse the road. One of the risks people have encountered on the street is "dooring." This accident occurs when the occupant carelessly opens the car door upon egress. The door obstructs the pathway of oncoming traffic, whether pedestrians, cyclists, or even other vehicles, which could lead to a collision. The danger occurs when the car door has been opened within the oncoming traffic's reaction time and braking distance [1].

According to multiple German daily newspapers, "So gefährlichsindparkende Autos für Radfahrer und Fußgänger," which translates to "Parked cars are very dangerous for cyclists and pedestrians" [1][2][3]. The paper mentioned that in Germany in 2019, 117,528 cyclists and pedestrians were involved in accidents, about half of which involved dooring incidents. An average of 2-3 people died daily, 60 were injured, and 260 acquired moderate injuries. Every second accident involved dooring incidents between cyclists and parked cars [1][2].

In Chicago, 344 injuries from dooring incidents were recorded in 2011, making for 19.7% of all cycling injuries[4]. The paper also stated that in 2003 in Toronto, dooring was the cause of 11.9% of all cycling-related injuries, whereas 8% of all cycling-related injuries in London were dooring incidents [4].

The same paper has also mentioned that in New York, for over nine years (1996-2005), dooring has claimed the lives of 7 people, whereas three people were killed in London between 2010-2012 due to dooring. However, note that not every case gets reported to the authorities and thus does not get recorded and recognized [4][5]. Inasmuch, police in most countries usually classify these kinds of accidents as non-specified collisions between a cyclist and a car. As a result, worldwide statistical data is incomplete [5]. However, this incident does not mean that the dooring accident should be ignored, as an opening car door is still a hazard that needs to be brought to light even if many do not realize it.

One solution the researchers proposed is to modify the car door stopper (usually referred to as the check strap) such that when a cyclist or a pedestrian is approaching the vehicle in a way that opening the door will pose a hazard to said cyclist or pedestrian. The two solenoids will press the jaws down into the path of the check strap's motion, acting as "brakes" for the door and stopping it in its tracks, thus preventing the driver and passenger from opening the door into the vulnerable road user's way. The device, therefore, actively monitors the vehicle's rear area and checks for oncoming traffic. It actively prevents the door from opening until the obstacle or the fail-safe timer has passed. The monitoring will be done by rear-facing sensors, which will feed data into a computer programmed to activate the solenoids to stop the door once conditions are met. The fail-safe timer ensures that the vehicle's occupants will not get trapped in the event of a false positive returned by the sensor or a bug or system failure.

Similar systems have been developed by other individuals and automotive companies to combat the problem. Typically, these solutions are either merely warning systems or may also incorporate a locking mechanism. One example is Ford's Exit

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Warning System which produces warning sounds and blinking lights to warn the driver or passenger[6][7][8][9]. Another solution is "The Dutch Reach Project," which uses the arm away from the car door to reach the handle, enabling the upper torso to twist and see any incoming obstacle when opening the door[10]. Technologies like "Rear Radar to Warn Driver of Cyclist Approach," "Bike Sign Laser," "Rider Reminder," and "Side view mirror LED alarm" also works in similar nature to the first two systems since they involve tactile, visual, or auditory warnings to the vehicle occupants [10].

The "Anti dooring Tech by Audi, Aston Martin & Faurecia," however, involves a three-camera system involving a tri-color distance indicator that locks the door when a cyclist is near, physically stopping the vehicle occupants from exiting [10]. Car manufacturers that offer similar exit assist systems include Audi, BMW, Ford, Hyundai, Kia, Genesis, Mercedes-Benz, Lexus, and Toyota, with the Hyundai Group being the first to market the ADAS technology [11].

A patent filed in the United States Patent Office named Vehicle Door Control System (US10017975B2) involves brake pistons pushing against the check strap with the usage of brake fluid actuated by a motor [12]. The device Safe Remote-Control Door Opening-and-Closing Device for an Automotive Vehicle (US4458446A) by Nissan Motor Co. is also to be noted due to its capabilities of locking the vehicle doors using a set of switches located in the driver's area. It also makes it possible for sensors to be attached to the mechanism and lock the door automatically when detecting nearby obstructions [13]. It's important to note that the Vehicle Door Opening Angle Control System or the Automobile Door Opening Angle Control System (KR20030067779A) is similar to the study's product due to its ability to be able to stop the door at any angle at which it is opened [14].

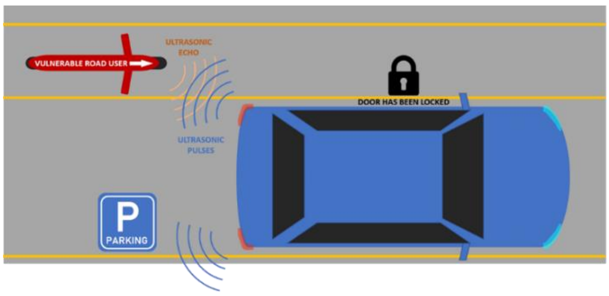

Fig. 1. Illustration demonstrating device's functionality.
Note: Door is automatically "locked" as obstacle approaches.

Hyundai Motors has also recently released a new feature for their new generation of automobiles called the "Safe Exit Assist," which builds upon their already existing "Electronic Child Safety Lock" [15]–[19]. Electronic Child Safety Lock disables backseat occupants, typically children, from opening the rear door and window to keep them safe and secure. Safe Exit Assist uses radars to detect oncoming vehicles. It prevents the driver from disabling the Electronic Child Safety Lock, preventing the child from inadvertently opening the door onto oncoming traffic [15]–[19].

Rolls-Royce Inc. and its parent company BMW have also filed a patent with the German Patent and Trade Mark Office (DPMA)[20]. Modern Rolls-Royce vehicles have fairly heavy doors and thus need electronic assistance in the form of electric motors to help open and close the door. The new patent builds upon this by allowing the motor to prohibit the vehicle occupant from opening the door, wherein it poses a risk to oncoming traffic [20].

II. Methodology

This paper uses the deductive approach with a pretest-posttest design due to its experimental nature by designing a car door stopper and its system, simulating it, and implementing it through a prototype [21].

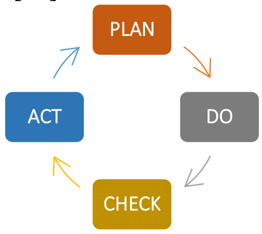

Fig. 2. Schema of the Study.

Plan: Design

The Smart Car Door Stopper studied in this paper uses an HC-SR04Ultrasonic Sensor array which calculates distance based on the speed of sound. The sensors operate at 30kHz-500kHz, well above the human hearing range of 20Hz-20kHz [22]. Ultrasonic Sensors are prevalent in today's cars for Advanced Driver-Assistant Systems (ADAS), specifically in parking assist sensors [22]. The sensor transmits ultrasound pulses every10μS to measure distance with an accuracy range of about 2cm to 4m. The pulse then reflects off the object's surface, whose distance is to be measured and echoes back to the source, which then the sensor's receiver picks up and uses to calculate the distance using the equation D=ST, where D is the distance between the sensor and the object, S is the speed of sound taken as a constant, and T is the time elapsed between transmission and echo reception [22][23][24].

Fig. 3. HC-SR04 Ultrasonic Sensor

Using the equation S= ΔD, where S is the speed of the obstacle, ΔD is the change in distance between the sensor and the obstacle, and T is the given refresh rate of distance, measuring the approximate speed of the oncoming object. It can be measured to determine if the scenario has an imminent collision. In a case when a collision is imminent, the approaching obstacle is moving faster than the average walking speed of 5km/h[25].

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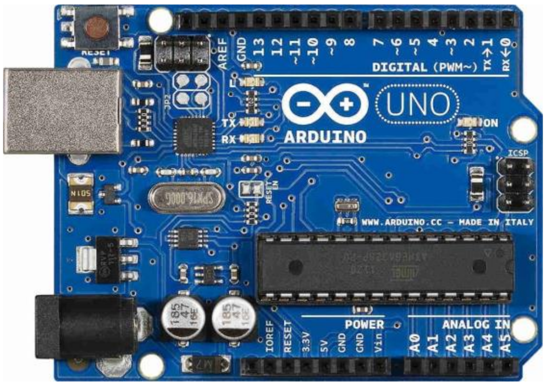


Fig. 4. Arduino Uno Microcontroller

An Arduino Uno microcontroller drives the ultrasonic sensors with an ATmega328P processor. Upon an imminent collision, the Arduino Uno signals a 12V relay to activate a pair of XRN-0530 12VDC Solenoids rated at 5.1N each and a stroke of 10mm. Through a couple of L-arms to redirect the direction of the force perpendicularly, the solenoids will be pushing against a pair of jaws with teeth designed to block the motion of the check strap, effectively preventing further door opening. The jaws will be held in tension by springs, creating a bistable mechanism.


Fig. 5. XRN-0530 Push/Pull Solenoid

Bi-stability is defined as the coexistence in phase space of two different attractorsfor the same values of parameters. A bistable device is any device capable of assumingtwo stable states, requiring two input pulses to complete a cycle, also known as a flip flop[26].

The force exerted on a spring upon a body is determined by Hooke's Law, which is governed by the equation FS=kx, where FS is the spring force, k is the spring constant, and x is the spring's strain or linear displacement. Accounting for the angle at which the spring acts on the lever (jaw), the equation is FS=kx(sin θ). Fs is the spring force, k is the spring constant, x is the spring's strain or linear displacement, and θ is the angle between the spring and the lever (jaw). These theories and policies functioned as the foundation for the research paper.

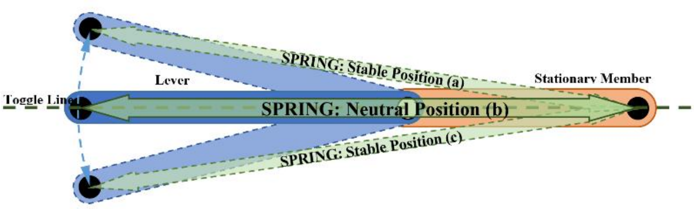


Fig. 6. Bistable Toggle Mechanism Diagram

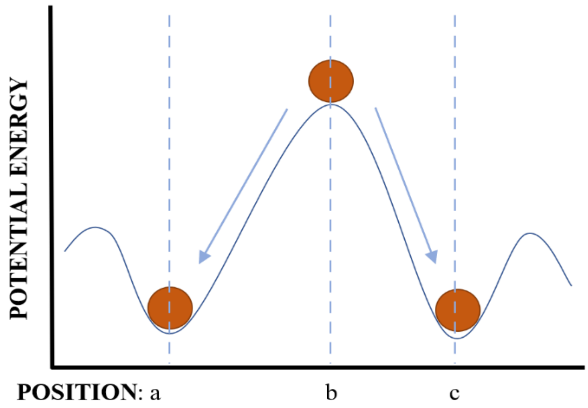


Fig. 7. Bistable Mechanism potential Energy vs Position Diagram

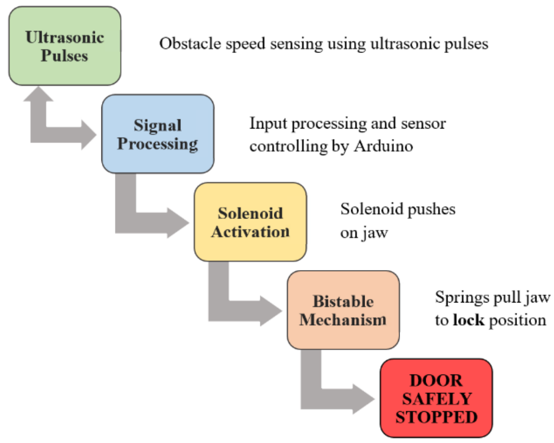
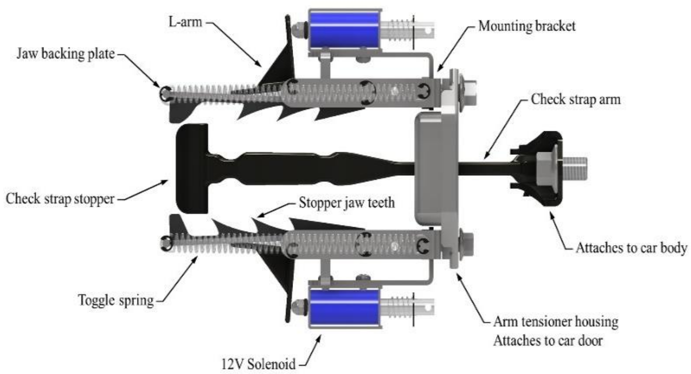


Fig. 8. Smart Car Door Check Strap Basic Operation Concept

Do: Model

Figure 5, shown below, details the smart car door stopper assembly and its significant parts. Note that the check strap assembly is pre-built and comes with most vehicles from the factory. The figure below shows how the smart car door stopper can be retrofitted around the existing component. The model is created in Autodesk Inventor.



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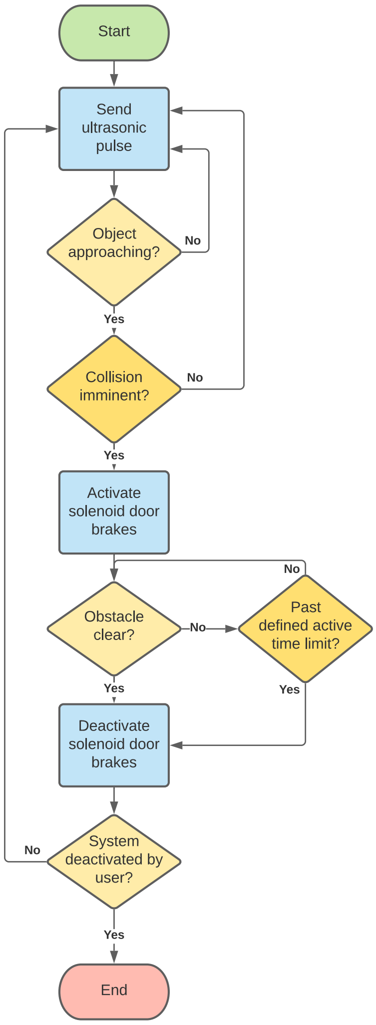

Fig. 10. Smart Car Door Stopper Operation Procedure Flow Chart

The figure above demonstrates the flow of the logical operation of the Smart Car Door Stopper from system start to checking for oncoming objects, checking for the speed of the object to determine whether or not a collision is imminent, and deciding whether or not to activate the Smart Car Door Stopper. The system then waits for either a clean condition or for the timer to run out to unlock the door. The cycle repeats until the user shuts the system off.

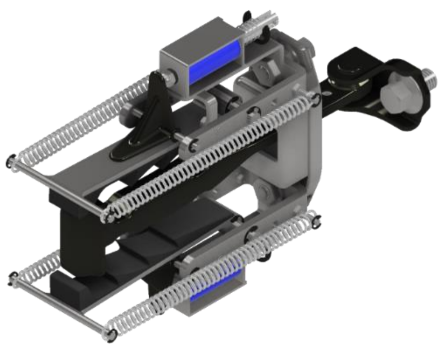

Fig. 11. Smart Car Door Stopper Isometric View

The Smart Car Door stopper is designed to attach to and interact with the existing check strap of a car door. The pins, brackets, and jaw backing are made of sheet steel, and the jaws and L-arms are 3D printed.

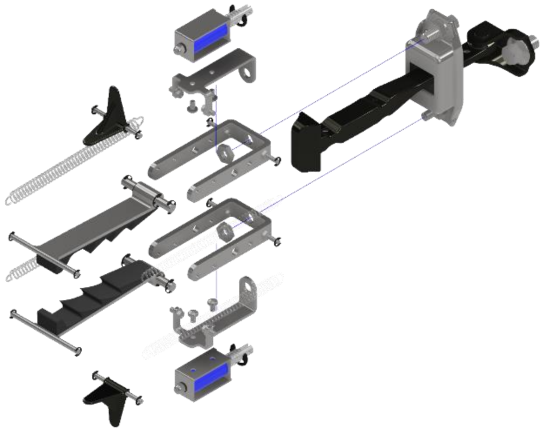

Fig. 12. Smart Car Door Stopper Exploded View

The device attaches to the interior cavity of a car door and bolts onto the door frame along with the factory check strap. When the door is opened, the check strap is pulled and retracted into the housing and extends out of the door. When the door stopper system is activated, the solenoids push the jaws into the path of the check strap, blocking its motion and preventing the vehicle occupant from further opening the door and posing a collision hazard for the vulnerable road user, thus, effectively stopping the door.

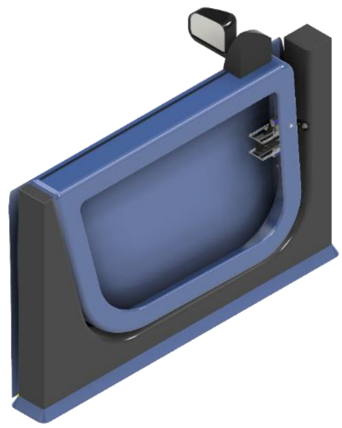

Fig. 13. Smart Car Door Stopper Installed in Car Door

Check: Testing and Simulation

The design must undergo simulation to find its operational stresses to see whether or not it would survive daily use and abuse when installed in an automobile. The Finite Element Analysis test is conducted using Autodesk Inventor, where forces are applied to each tooth of the mechanism. The stresses, displacement, and safety factors of each simulation are recorded, with special attention paid to the safety factor.

In order to establish a baseline force value to use for the simulation, the force required to push a car door open was recorded. The test was conducted on the driver-side door of a

2010 Kia Rio 2 sedan, and A weighing scale was placed against the interior car door, right where the door handle is. The researcher then pushes on the weighing scale to open the car door. The peak force exerted when opening the car door was recorded by the weighing scale, around 3kg-f.

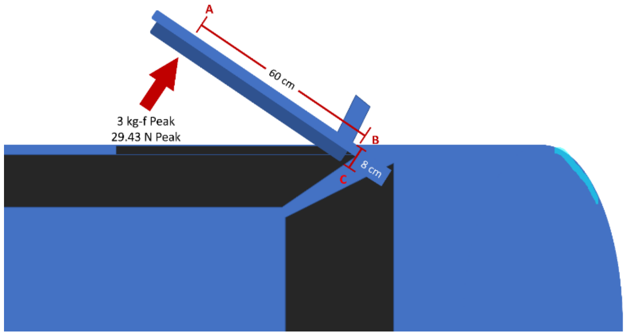

Fig. 14. The Opening of a Car Door

As tested in a 2010 Kia Rio, the front door required a peak force of 3kg (29.43N) to swing open. The center of the door handle, where the door should be pushed when opening, was located 60cm (0.6m) from the door's hinge. Using the torque (T) formula of T=Fd, where F was the force applied to swing the door open and d was the distance between the force application and the door hinge, the torque the hinges experience can be calculated. These values might differ slightly from vehicle model to vehicle model due to differing designs, though they should not vary too wildly.

$$T_{hinge} = Fd$$
$$T_{hinge} = (29.43N)(0.6m)$$
$$T_{hinge} = 17.66\ Nm$$

The door check strap was adjacent to the door hinge and was 8cm away from it. Using the same Torque (T), we could calculate the maximum tension force experienced by the check strap during typical door opening scenarios. These values also differ from vehicle to vehicle.

$$T_{hinge} = Fd$$
$$17.66 = (F)(0.08m)$$
$$F_{strap} = 220.73\ N = 22.5\ kg\text{-}f$$

The Smart Door Locker's mechanism and assembly should, therefore, be able to withstand forces of at least 22.5kg, although having it designed to be able to withstand only that does not suffice. For testing, the device is designed to be able to withstand no less than thrice the peak normal operation force to ensure that it does its intended job reliably.

With this in mind, the FEA simulation will be done by loading the Smart Car Door Stopper with 662.175N. The toggle spring shall have a stiffness of k=4.6979M/mm. Von Mises Stress, Displacement, and Safety Factors values will be recorded for each FEA test. Still, for the purpose of simplification, only Safety Factor result screenshots will be attached to this paper. Pretest materials will include steel for the brackets and jaw backing and ABS plastic for the L-arm and jaws. FEA simulation results shall be presented and discussed in Section III of this paper.

Act: Prototyping

The device is fabricated, assembled, and installed into the driver-side door of a 7th generation Toyota Corolla E100 (1991-1998) procured from a junk shop. A prototype is fabricated not for stress and endurance testing but as proof of concept and to test the program's functionality and the system's electronics.


Fig. 15. Toyota Corolla E100 Driver Side Door

The metal brackets are made of steel. The solenoid bracket is cut with a laser cutting machine at the University of the Philippine-Cebu's FabLab. The main bracket is cut and drilled by hand at the University of Cebu-Main Campus machine shop.

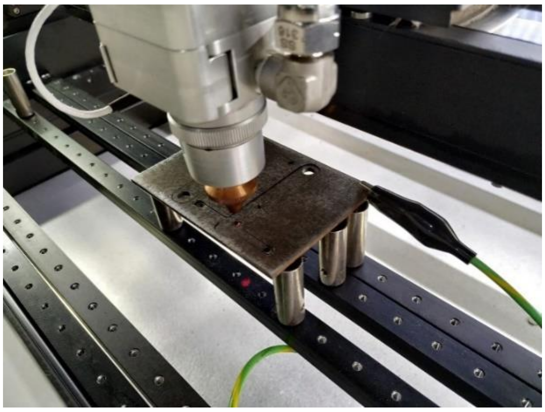
Fig. 16. Solenoid Bracket Laser Cutting

The plastic parts, namely the jaws and the L-arms, are 3D printed using a Creality Ender 3 V2, an FDM machine with PET-G plastic, the best material readily available at the time of fabrication, and will serve its purpose.

The researchers developed an Arduino program in the Arduino IDE environment in C++ to load into the microcontroller and activate the relays when the criteria are met. The code is as follows:

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;; AN
ADRUINO UNO CODE FOR THE SMART ;
; CAR DOOR STOPPER                ;
; BY: CHARLES STEVEN L. BOJOS, BSME ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

int trigPin = 11;    // Trigger
int echoPin = 12;    // Echo
```

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```
int powerPin = 13;

int ADLtriggerPin = 7;  // trigger mechanism

long duration;
int distance1=0;
int distance2=0;
double Speed=0;
int distance=0;

void setup() {
  //Serial Port begin
Serial.begin (9600);
  //Define inputs and outputs
pinMode(trigPin, OUTPUT);
pinMode(echoPin, INPUT);
pinMode(powerPin, OUTPUT);
pinMode(ADLtriggerPin, OUTPUT);
}

void loop() {
  //calculating Speed
   distance1 = ultrasonicRead()+distance; //calls
ultrasonicRead() function below

delay(500);//giving a time gap

   distance2 = ultrasonicRead()+distance; //calls
ultrasonicRead() function below

   //formula change in distance divided by change in
time
   Speed = fabs((distance2 - distance1)/.5);

   //Displaying Speed
Serial.print("Speed in cm/s: ");
Serial.println(Speed);

  if (Speed < 139)
  {
delay(750);
digitalWrite(ADLtriggerPin,HIGH);
  }

  if (Speed >= 139)
  {
delay(750);
digitalWrite(ADLtriggerPin, LOW);
delay(3000);
  }
}

float ultrasonicRead()
{
// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(5);

// Sets the trigPin on HIGH state for 10 micro
seconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
digitalWrite(powerPin, HIGH);

// Reads the echoPin, returns the sound wave travel
time in microseconds
duration = pulseIn(echoPin, HIGH, 1000*1000);

//calculating distance
distance = (duration/2) / 29.1;
}
```

III. Results and Discussion

This section of the paper discusses the results gathered from the FEA simulations and the prototype's functioning. Pretest runs use Steel and ABS Plastic.

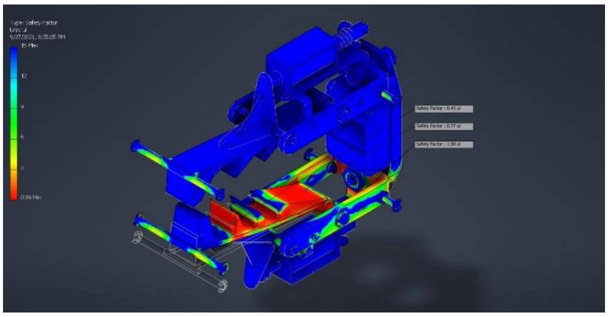

Fig. 17. Position 1 Safety Factor Pretest

TABLE 1. Position 1 Pretest Data

Parameter	Minimum Value	Maximum Value
Von Mises Stress	*0 MPa*	***2,250 MPa***
Displacement	*0 mm*	***8.956 mm***
Safety Factor	***0.09***	*15*

It can be noted that this result shows a significantly poor safety factor. ABS Plastic is inappropriate material for this application.

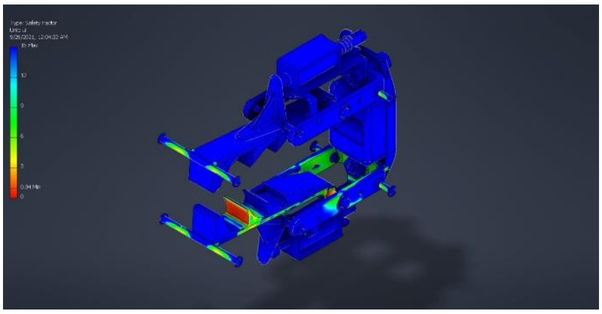

Fig. 18. Position 1 Safety Factor Posttest

TABLE 2. Position 1 Posttest Data

Parameter	Minimum Value	Maximum Value
Von Mises Stress	*0 MPa*	***221.2 MPa***
Displacement	*0 mm*	***0.5939 mm***
Safety Factor	***0.94***	*15*

After the jaw material was changed to Acetal Resin, the FEA test yielded a much more favorable 0.94 safety factor which can be considered acceptable.

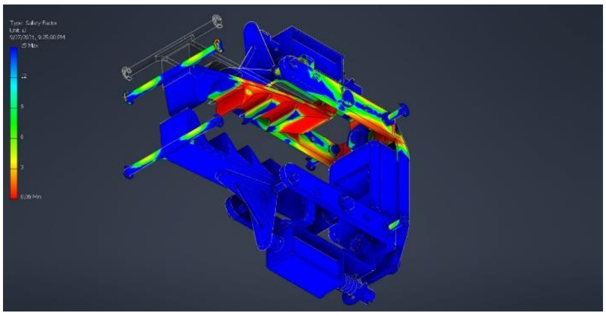

Fig. 19. Position 2 Safety Factor Pretest

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TABLE 3. Position 2 Pretest Data

Parameter	Minimum Value	Maximum Value
Von Mises Stress	*0 MPa*	***2,293 MPa***
Displacement	*0 mm*	***11.97 mm***
Safety Factor	***0.09***	*15*

The pretest result once again demonstrates a poor safety factor value of 0.09 with ABS Plastic.

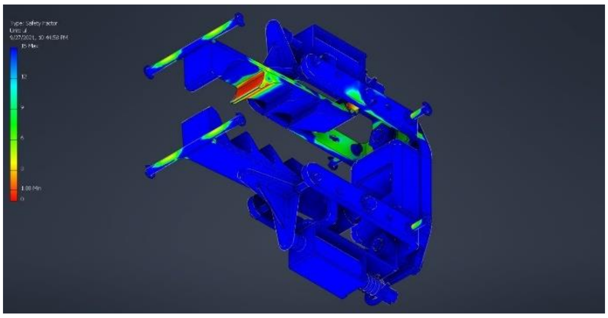

Fig. 20. Position 2 Safety Factor Posttest

TABLE 4. Position 2 Posttest Data

Parameter	Minimum Value	Maximum Value
Von Mises Stress	*0 MPa*	***191.7 MPa***
Displacement	*0 mm*	***0.6355 mm***
Safety Factor	***1.08***	*15*

Position 2 post-test results show the same trend where switching to Acetal Resin improved performance with an optimal safety factor of 1.08.

To further simplify this section, the following test results will only feature graphed data of the pretest vs. post-test safety factor results without accompanying FEA screenshots and tabulated data. To view the FEA screenshots for the remaining tests, as well as the tabulated data, please send the researchers an email requesting it. All FEA pretest runs used ABS jaws, and post-test ran with Acetal Resin jaws.

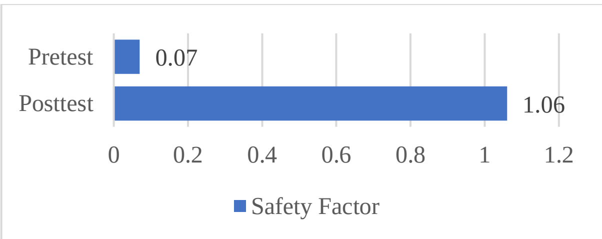

Fig. 21. Position 3 Safety Factor

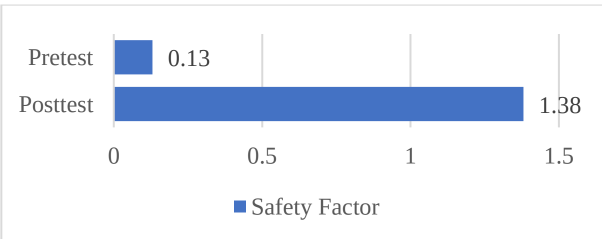

Fig. 22. Position 4 Safety Factor

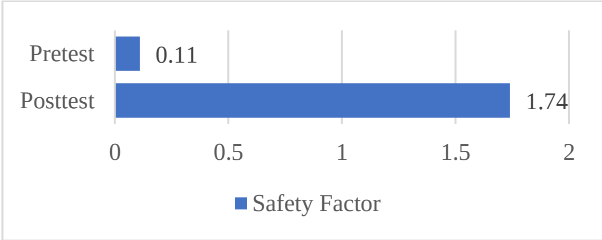

Fig. 23. Position 5 Safety Factor

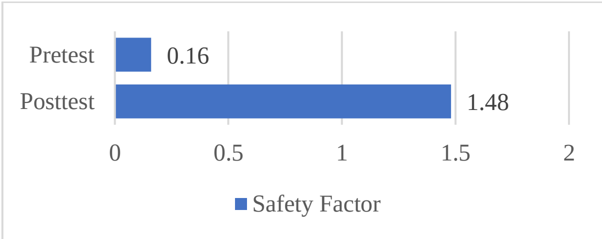

Fig. 24. Position 6 Safety Factor

As evident in the graphs above, the use of Acetal Resin significantly improved the performance of the Smart Car Door Stopper by allowing it to better withstand the stresses of abuse by asserting the average door opening force thrice.

Aside from the safety factor improvements, the change of material decreased the stress by up to 95.35% and reduced deflection by up to 94.69%.

The prototype proved completely functional and operated as intended when tested in controlled conditions (sunny weather, no other moving objects in the ultrasonic sensor range, and no other possible sources of interference within the vicinity.)

IV. Conclusion

The post-test performance of the device improved well when the adjustments were made. It showed excellent results, especially after finding out the percentage decrease in both maximum stress and displacement. The post-test data ensured the device's success and, thus, proves that the study could help provide a safety mechanism for pedestrians and vehicles.

Moreover, the prototype performed as expected, showing that the system can stop a car door from opening into the path of a vulnerable road user and posing a road hazard.

Recommendation

After collecting the data needed for the study and finding out the results, the researchers were able to propose recommendations for future researchers to help them improve this study which would serve as a basis for future reference.

- The researchers recommended that future researchers and engineers collaborate to improve the design and make it a more cost-effective and reliable device.
- The researchers recommended studying the feasibility of having the device installed on every for-hire vehicle, such as taxi cabs, available on the market for retrofitting and licensable to car manufacturers/suppliers to be installed in new cars from the factory as part of its safety system.
- This study could be further developed and prepared for commercialization.

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