ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

M.Sc. Thesis Paper

On

DESIGN OF AUTOMATIC BRAKING SYSTEM FOR AN AUTOMOBILE VEHICLE

By

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Program: MSc Automotive Engineering

DEPARTMENT OF MECHANICAL AND VEHICLE ENGINEERING

Adama

JUNE, 2015

Candidate Declaration

I hereby declare that the work which is being presented in the design project entitled "Design of Automatic Braking System for an Automobile Vehicle" in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my work carried out from September 1, 2014 to May 31, 2015 under the supervision of Mekonnen Liben (Associate Professor), Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

Tewodros Fantahun	____________	__________________
Student's name	Signature	Date

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Mekonnen Liben	___________	________________
(Associate Professor)		
Advisor	Signature	Date

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APROVAL SHEET

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Advisor	**Signature**	**Date**

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Acknowledgement

I would like to thank my advisors, Mekonnen Liben (Ass. Prof.) and co-advisor Alemayehu Wakjira for their support. And I also want to thank my friends, family and Ramesh Babu (Ass. Prof.) for their valuable opinion.

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Acronyms and Abbreviations

- **I/O** – Input/ Output
- **Gnd**– Ground pins
- **VIN –** Input voltage
- **WHO –** World Health Organization
- **BAC** - Blood Alcohol Concentration
- **OECD –** Organization for Economic Co-operation and Development
- **NHTSA** - U.S. National Highway Traffic Safety Administration
- **CMBS** - Honda’s Collision Mitigation Brake System
- **ABS –** Automatic Braking System
- **NTSEL** – National Traffic Safety and Environment Laboratory
- **RTA –** Road Traffic Accident

Abstract

The objective of this paper is to design an automatic braking system for an ordinary automobile that can assist a driver to avoid collision. To achieve this first the braking force applied on a Toyota automobile was measured. Then the resulting torque was calculated. Based on the torque value calculated, the specific type of servomotor was chosen. Servomotor was found suitable for this design since it can accurately move to a specified angle. And then the brake actuating arm was designed making sure that it fits to the shaft of the servomotor. The overall design was based on the Arduino Uno microcontroller. Also ultrasonic sensor for detecting objects of up to 5 meter away and servomotor for actuating the brake pedal were considered. The brake actuator that joined the servomotor to the brake pedal arm was designed using Catia. The microcontroller acted as the bridge between the sensor and servo by receiving electrical signal from the sensor and sending that signal to the servo so that the servo can rotate clockwise or anti-clockwise depending on the signal received. The connecting arm from the servo to the brake pedal arm was designed using Catia and tested using the deformation analysis. 12V batteries were used; one to power the Arduino and one to power the servomotor. The code for the system was written using arduino programming software. This paper contributes to efforts of increasing road safety and minimizing accidents. Also, it can be used as an input for further research in the area of driver assistant systems in Ethiopia. The deformation analysis and overall design showed that it is possible to design such systems locally with minimal cost.

Keywords: Arduino Uno microcontroller, servomotor, brake actuating arm

Chapter 1

1. Introduction

1.1. Background for the paper

According to WHO approximately 1.24 million people die every year on the world's roads, and another 20 to 50 million sustain non-fatal injuries as a result of road traffic crashes. These injuries and deaths have an immeasurable impact on the families affected, whose lives are often changed irrevocably by these tragedies, and on the communities in which these people lived and worked.

Road traffic injuries are estimated to be the eighth leading cause of death globally, with an impact similar to that caused by many communicable diseases, such as malaria. They are the leading cause of death for young people aged 15–29 years, and as a result take a heavy toll on those entering their most productive years. Economically disadvantaged families are hardest hit by both direct medical costs and indirect costs such as lost wages that result from these injuries. At the national level, road traffic injuries result in considerable financial costs, particularly to developing economies. Indeed, road traffic injuries are estimated to cost low- and middle-income countries between 1–2 % of their gross national product, estimated at over US$ 100 billion a year.

The overall global road traffic fatality rate is 18 per 100 000 population. However, middle-income countries have the highest annual road traffic fatality rates, at 20.1 per 100 000, while the rate in high-income countries is lowest, at 8.7 per 100,000. [21]

There are large disparities in road traffic death rates between regions. The risk of dying as a result of a road traffic injury is highest in the African Region (24.1 per 100,000 population), and lowest in the European Region (10.3 per 100,000).

Drinking and driving increases the risk of being involved in a crash, as well as the severity of resulting injuries. Driving starts to be impaired at very low levels of alcohol consumption, with the risk of crash involvement growing rapidly as consumption increases. The vast majority of adult drivers are affected or impaired with a blood alcohol concentration (BAC) of 0.05 g/dl, while at a BAC level of 0.1 g/dl the crash risk is approximately five times higher than that of someone with a BAC level of zero(16, 17). Young and novice drivers who drink and drive have a greatly increased risk of a crash compared to more experienced drivers. The effects of alcohol impairment are magnified when combined with fatigue. This explains why alcohol is considered a particular risk for commercial drivers, who spend long hours on the road and also have legal responsibilities for the passengers or cargo they carry [21].

The latest WHO Global Status Report on Road Safety shows that almost all high-income countries have a decreasing death toll, while in the majority of low-income countries the numbers of road deaths are increasing. Nevertheless, middle-income countries are hit the hardest: 20.1 deaths per 100,000 inhabitants, 80% of all road fatalities by only 52% of all vehicles, globally. While the death rate in Africa is the highest (24.1 per 100,000 inhabitants), the lowest rate is to be found in Europe (10.3).

According to the WHO data published in April 2011, deaths resulting from road traffic accidents in Ethiopia reached 22,786 or 2.77% of the total deaths in the nation. The age adjusted death rate of Ethiopia is 37.83 per 100,000, #12 in the world.

Various studies have indicated that Ethiopia has one of the highest fatality rates per vehicle in the world. It is in excess of 100 fatalities per 10 000 vehicles. This should be compared with Kenya and United Kingdom, where the figure is about 19 and 2 per 10 000 vehicles, respectively.

Ethiopia loses about $65 million annually due to traffic accidents. In addition the victims are mainly public transport travelers in the working age group (18–30 years).

Car manufacturers have incorporated safety systems in cars for many years. There are two main categories of the safety systems that have been widely adopted in cars. The first category is “passive safety systems”, which include vehicle seatbelts, headlights, airbags, crumple zones and other structural safety elements. The second category is “active safety systems”, which include anti-lock brakes, adaptive cruise control, lane departure warning, traction control, electronic stability control, pre-crash and emergency brake assist systems. Whilst there is considerable research and implementation of active safety systems, there has only been limited commercial deployment of “intelligent” systems for vehicles, often due to legal and regulation issues (OECD 2003). So far in Ethiopia, there is no single entity that is manufacturing any active system; specifically automatic braking system [21].

1.2 Objectives

1.2.1 General objective

The main objective of this paper is to design an automatic braking system that can assist a driver to avoid collision.

1.2.2 Specific objectives

- Measurement of the force applied on the brake pedal
- Catia analysis of the brake actuator arm
- Write up of the code for automatic braking system
- Build a small prototype to demonstrate the system

1.3. Statement of the problem

Road traffic accidents are becoming a major public safety and development obstacle in Ethiopia. Analysts say the current situation necessitates immediate action.

1.4. Scope of the study

This paper shows the process of how to design an automatic braking system for an automobile. This was achieved through the application of Catia and Arduino program.

1.5. Significance of the study

The automatic braking system will assist drivers to control the car and avoid accidents. Thus, this will help to reduce Road Traffic Accident (RTA). Therefore the reduction of RTA means more lives of the working age group will be saved. This in turn will contribute to the economic growth of the country. Also less accidents means less maintenance work and since vehicles in Ethiopia are more expensive to import, it will save more foreign currency.

1.6. Limitation of the study

This paper designed the automatic braking system for an automobile vehicle but actual manufacturing of the system was not done due to cost reasons.

Chapter 2

2.1 Literature Review

This chapter explains the different literatures reviewed for active driver assistance systems of different car manufacturers around the world. Also individual research works were reviewed. In 2014 (ICRSET) Othman M.K . Alsmadi, Anas A. Al Jallad, Zaer S. Abo -Hammoud, and Fares J. Al Majal I presented their work on Arduino-Based Automatic Safety Vehicle Control. The paper focused on minimizing the occurrence of vehicle accidents due to an eye or hand movements while driving, and automatic vehicle human-voice-based safety control was proposed in this paper. The design was implemented using an arduino microcontroller. One of the most important safety control features was the automotive speed control (ASC). In this safety control function, which prevents a vehicle sudden hit, the necessary action is issued based on the vehicle-to-vehicle distance measure. To prevent the driver from attention withdraw and maintain a proper road and situation focus (as especially is the case at night), several other automated safety control operations are provided (i.e., radio, flasher, left flasher, right flasher, wipers, drive and stop) . These features are controlled according to human voice commands. Their research is different from the work undertaken in this paper in that it uses human voice to control the braking while in this paper only detection of the obstacles may initiate the braking.

In 2010, Stephen M. Chaves of Pennsylvania State University carried out a research on GPS-BASED COLLISION WARNING SYSTEM FOR VEHICLE CONVOYS. His research proposed a collision warning system that is based on a GPS receiver and wireless network for transferring data between convoy vehicles. In order to meet the accuracy requirements for successful collision avoidance, his work focused on improving the vehicle velocity measurements which are not sufficient by themselves. The GPS receiver measurements are fused with readings from an accelerometer. This work is different from the work in this paper in that it uses GPS signal to detect distance between two vehicles. This paper is unique because it deploys a new combination of ultrasonic distance sensor, arduino uno microcontroller and servomotor for a specific purpose of actuating a brake pedal of an automobile.

Other reviews revealed that car manufacturers have implemented different kind of automatic vehicle braking systems.

In 2009, the U.S. National Highway Traffic Safety Administration (NHTSA) began studying whether to make frontal collision warning systems and lane departure warning systems mandatory.

In 2011, a question was submitted to the European Commission regarding stimulation of these "collision mitigation by braking" systems. The mandatory fitting of Advanced Emergency Braking Systems in commercial vehicles will be implemented on 1 November 2013 for new vehicle types and on 1 November 2015 for all new vehicles in the European Union. This could, according to the impact assessment, ultimately prevent around 5,000 fatalities and 50,000 serious injuries per year across the EU.

A 2012 study by the Insurance Institute for Highway Safety examined how particular features of crash-avoidance systems affected the number of claims under various forms of insurance coverage. The findings indicate that two crash-avoidance features provide the biggest benefits: (a) autonomous braking that would brake on its own, if the driver does not, to avoid a forward collision, and (b) adaptive headlights that would shift the headlights in the direction the driver steers. They found lane departure systems to be not helpful, and perhaps harmful, at the circa 2012 stage of development.

Collision avoidance features are rapidly making their way into the new vehicle fleet.

2.1.1 Audi

2006: "Braking guard" radar-assisted forward collision warning introduced on Audi Q7.

2010: "Pre sense" autonomous emergency braking system uses twin radar and monocular camera sensors and was first introduced in 2010 on the 2011 Audi A8. "Pre Sense Plus" works in four phases. In the first phase, the system provides warning of an impending accident, while the hazard warning lights are activated, the side windows and sunroof are closed and the front seat belts are tensioned. In the second phase, the warning is followed by light braking, strong enough to win the driver's attention. The third phase initiates autonomous partial braking at a rate of 3 m/s². The fourth phase decelerates the car at 5 m/s² followed by automatic deceleration at full braking power, roughly half a second before projected impact. "Pre Sense Rear", is designed to reduce the consequences of rear-end collisions. The sunroof and windows are closed and seat belts are prepared for impact. The optional memory seats are moved forward to protect the car's occupants.

2015 introduced the "Avoidance Assistant": intervenes in the steering to help the driver avoid an obstacle. If an accident occurs. The "Turning Assistant" monitors opposing traffic when turning left at low speeds. In critical situation, it brakes the car. "Multi-collision brake assist" uses controlled braking maneuvers during the accident to aid the driver. Both systems introduced in 2015 on the Second generation Q7.

Analysis of accident databases reveals that some 19 percent of people injured in passenger cars are involved in longitudinal accidents. The main causes of such accidents are driver distraction or inattentiveness, and driver misperception where a driving situation is misjudged. Audi pre sense front operates, with different levels of functionality, at speeds up to 200km/h. If all cars on the road were equipped with such a system, it is estimated that over 130 lives could be saved and more than 2000 serious injuries addressed each year.

In 2012 BMW introduced "Active Protection System" + "Active Driving Assistant" on the face-lifted 2012 BMW 7 Series.

2013 "Driving Assistant Plus": A combination of front camera and full-range radar sensors detects all vehicles ahead, whether moving or stationary. Should the driver not react to the warning of a potential collision, the Driving Assistant Plus automatically slows the vehicle down – with maximum deceleration power if necessary.

Active Protection detects imminent accidents, then prepares by automatically pre-tensioning safety belts, closing windows and moon roof, backrest of the front passenger seat brought into an upright position, and activating post-crash braking. Also includes driver drowsiness detection that analyses driving behavior and, if necessary, advises the driver to rest. The advice to take a break is provided in the form of graphic symbols shown on the Control Display.

Active Driving Assistant includes lane departure warning, pedestrian protection, and city collision mitigation. Driving Assistant comprises the Lane Departure Warning as well as "Approach and Pedestrian Warning with City Brake Activation". The system detects vehicles driving ahead and, at speeds of up to 60 km/h, also persons who are on a possible collision course. In an identified hazard situation, the driver is warned by means of visual and acoustic signals. In order to shorten the stopping distance, the braking system is simultaneously preconditioned. Furthermore, at speeds of up to 60 km/h an emergency braking maneuver with medium deceleration is also activated in order to reduce speed and draw the driver’s attention to the critical situation.

"Lane Change Warning assistant", also available as an individual option, can be used from a speed of 20 km/h. The system monitors the traffic situation on the adjacent lane in the area called the dead spot and warns the driver of potential critical situations during overtaking maneuvers.

After an accident, automatic braking can bring the vehicle to a standstill, thus preventing or reducing the likelihood of follow-on collisions [9].

2.1.3 Cadillac

In 2012, Cadillac introduced two systems on the Cadillac XTS, now also available on ATS, CTS and Escalade: Forward Collision Alert which uses a camera to detect and warn you when an impact may be imminent. Front and Rear Automatic Braking detects when a frontal or rear collision is imminent and automatically applies the brakes to lessen impact severity, helping the driver avoid certain low speed impacts all together. Featured automatic braking at low speeds (in heavy traffic or even in parking lots and driveways) when a collision is imminent.

2.1.4 Chrysler

2010: The 2011 Jeep Grand Cherokee with Forward Collision Warning.

2014: Chrysler200 and 300 introduced Full-Speed Forward Collision Warning (FCW) with Active Braking. System readies the brakes and alerts the driver when it senses a potential frontal impact. If the driver doesn't respond and the risk of a collision continues, the brakes can bring the vehicle to a full stop. Advanced Brake Assist will increase the brake force automatically if the force applied is not sufficient.

2.1.5 Fiat

Fiat's autonomous emergency braking system, dubbed City Brake Control, is an urban low-speed crash avoidance system that works between 5 and 30 km/h. It was first made available as an option on the third generation Panda; it was consequently introduced on the 500L and its variants, again as an option. The system employs a laser Lidar sensor located on top of the windscreen that communicates with the ESP. If an impending collision is detected it intervenes in three steps: at first with brake pre-fill, for quicker response at the driver's reaction; secondly enhancing the hydraulic brake assist sensitivity; finally, if the driver still has not reacted, it automatically applies the brakes and simultaneously warns the occupants through a buzzer.

In 2013 City Brake Control was tested and deemed effective by Euro NCAP, obtaining the Euro NCAP Advanced reward.

2.1.6 Ford

2009 Ford introduced the Collision Warning with Brake Support on the Lincoln MKS and MKT and the Ford Taurus. This system provides a warning through a Head Up Display that visually resembles brake lamps. If the driver does not react, the system pre-charges the brakes and increases the brake assist sensitivity to maximize driver braking performance. Ford demonstrated its Obstacle Avoidance technology relying on a mix of sensors, including a camera tucked behind the rearview mirror, to scan the road for vehicles and pedestrians and steer away if the driver does not take any action.

2.1.7 General Motors

2012 GM's collision alert system is introduced in the GMC Terrain SUVs and uses a camera to provide warning when there is a vehicle ahead or there is a lane departure.

In 2013 the 2014 Chevrolet Impala received the radar and camera based Crash imminent braking (radar technology detects a possible crash threat and alerts the driver. If the driver does not appear to react quickly enough or doesn’t react at all, this feature intervenes to apply the brakes in an effort to avoid the crash. Forward collision alert, Lane departure warning, Side blind zone alert (Using radar sensors on both sides of the vehicle, the system “looks” for other vehicles in the blind zone areas of the Impala and indicates their presence with LED-lit symbols in the outside mirrors. Rear cross traffic alert features.

The 2016 Chevrolet Malibu will feature Forward Collision Alert with Following Distance Indicator, Adaptive Cruise Control with Front Automatic Braking and Front Pedestrian Alert with last-second automatic braking [22].

2.1.8 Honda

In 2003, Honda introduced the first pre-crash system with autonomous braking (Collision Mitigation Brake System CMBS, originally CMS) on the Inspire and later in Acura, using a radar-based system to monitor the situation ahead and provide brake assistance if the driver reacts with insufficient force on the brake pedal after a warning in the instrument cluster and a tightening of the seat belts. The Honda system was the first production system to provide automatic braking. The 2003 Honda system also incorporated an "E-Pretensioner", which worked in conjunction with the CMBS system with electric motors on the seat belts. When activated, the CMBS has three warning stages. The first warning stage includes audible and visual warnings to brake. If ignored, the second stage would include the E-Pretensioner's tugging on the shoulder portion of the seat belt two to three times as an additional tactile warning to the driver to take action. The third stage, in which the CMBS predicts that a collision is unavoidable, includes full seat belt slack take-up by the E-Pretensioner for more effective seat belt protection and automatic application of the brakes to lessen the severity of the predicted crash. The E-Pretensioner would also work to reduce seat belt slack whenever the brakes are applied and the brake assist system is activated.

In late 2004, Honda developed a night vision system that highlights pedestrians in front of the vehicle by alerting the driver with an audible chime and visually displaying them via HUD. The system only works in temperatures below 30 degrees Celsius (86 Fahrenheit). This system first appeared on the Legend.

Honda’s Collision Mitigation Brake System (CMBS) is a radar-based autonomous emergency braking system. At speeds above 15km/h, moving and stationary vehicles are detected along a path some 100m ahead of the vehicle. When the system senses that the car is likely to hit one of these obstacles, a three stage process is initiated. In the first, typically around 3 seconds before impact, the driver is alerted by visual and audible warnings. In the second stage, when the system senses that a collision is still likely (typically some 2 seconds before impact), three sharp tugs are given on the seat belt and the car automatically starts to apply some braking. Finally, when a collision is unavoidable, CMBS tightens the front seat occupants' seatbelts (using reversible tensioners different from the pyrotechnic devices used during the collision itself) and applies a high level of braking force. This braking can be supplemented by the driver up to the maximum that the car is capable of. All of the actions taken by CMBS are reversible: if an accident is averted (for example, if the vehicle moves out of the way at the last moment), the tension is removed from the seatbelts and the visual and audible warnings stop.

2.1.9 Hyundai

Hyundai Equus introduced "Vehicle Stability Management". VSM manages the function of all active and passive safety features. The VSM System incorporates electronic stability control (ESC), traction control (TCS), anti-lock braking (ABS), electronic brake-horse distribution (EBD), brake assist, and lane departure warning. This fully equipped system also incorporates electronic parking brake, smart cruise control and seatbelt tensioning.

Hyundai Genesis DH features Automatic Emergency Braking that uses radar and windshield camera.

2.1.10 Mazda

Mazda's Smart City Brake Support system uses lasers to detect vehicles or obstacles in front of the car. The system is able to apply the brakes and cut engine power, and if the difference in speed between the car and the obstacle is 30 km/h (19 mph) or less, the system can avoid or at least lessen potential damage from a collision.

2.1.11 Mercedes-Benz

In 2002 Mercedes' "Pre-Safe" system was unveiled in the fall of at the Paris Motor Show on the 2003 S-Class. Using electronic stability control sensors to measure steering angle, vehicle yaw, and lateral acceleration and brake assist (BAS) sensors to detect emergency braking, the system can tighten the seat belts, adjust seat positions including rear seats (if installed), raise folded rear headrests (if installed), and close the sunroof if it detects a possible collision (including rollover).A later version of the Pre-Safe system was supplemented by an additional function that can close any open windows if necessary.

In 2005 "Brake Assist BAS plus" was Mercedes-Benz's first forward warning collision system, introduced on the redesigned 2006 W221 S-Class, incorporates the autonomous cruise control system and adds a radar-based forward collision warning.

In 2006, the "Pre-Safe Brake" on the CL-Class C216 was the first partial autonomous braking (40%, or up to 0.4g deceleration) if the driver does not react to the BAS Plus warnings and the system detects a severe danger of an accident.

In 2009, Mercedes introduced the first Pre-Safe Brake with full autonomous braking with maximum braking force approximately 0.6 seconds before impact, on the Mercedes-Benz E-Class (W212).

In 2011 occurred the introduction of the radar-based assistance system in the B-Class (as standard) [9].

2.1.12 Nissan

Nissan's Infiniti brand offers both laser-based and radar-based systems.

Brake Assist with Preview: Preview function anticipates the need to apply emergency braking and pre-pressurize the brake system to help improve brake response.

Intelligent Brake Assist (IBA) with Forward Emergency Braking (FEB) (on QX80) uses radar to monitor approaching speed to the vehicle ahead, helping detect an imminent collision. It provides a two-stage warning to alert the driver, and if the driver takes no action, the system automatically engages the brakes to help reduce collision speed and impact.

Predictive Forward Collision Warning system warns the driver of risks that may be obscured from the driver's view. It senses the relative velocity and distance of a vehicle directly ahead, as well as a vehicle travelling in front of the preceding one.

Forward Emergency Braking: When the system judges that deceleration is required, it alerts the driver using both a screen display and sound, then generates a force that pushes the accelerator pedal up and smoothly applies partial braking to assist the driver in slowing the vehicle down. When the system judges that there is the possibility of a collision, it will automatically apply harder braking to help avoid a one.

2.1.13 Peugeot

2014: Peugeot introduced active emergency braking system on 2014 Peugeot 308.

2.1.14 Renault

2014: Renault introduced radar active emergency braking on 2015 Renault Espace.

2.1.15 Skoda

Skoda introduced four new security system in 2013, alongside other car models of the VW group. The systems include Multi Collision Brake,Crew Protect Assist, Lane Assistant and Front Assistant. The first Skoda model with these new systems was the Skoda Citigo in June 2012, along with the VW up and the Seat Mii, the new Skoda Octavia (2013).

2.1.16 Subaru

In 2008, Subaru introduced the ja:EyeSight (Japanese) system to Japanese drivers on the Legacy sedan, wagon and Outback, which, unlike radar-based systems, uses two CCD stereo cameras mounted to the roof beside the rear view mirror. This system also offers lane departure warning and adaptive cruise functions. As of model year 2014, it is optional on the Legacy, Forester, or Impreza, and only on vehicles with the automatic or CVT transmission. In 2014 Subaru updated the system using cameras that can detect color (brake lights) and reducing the bulk of the system.

2.1.17 Tesla

The Avoidance Assist feature automatically engages the brakes to reduce the impact of an unavoidable frontal collision. Automatic Emergency Braking will stop applying the brakes when the driver presses the accelerator pedal, the brake pedal, or sharply turns the steering wheel.

2.1.18 Toyota

2008 LS 600h forward PCS diagram, with radar (blue) and stereo camera (red) coverage

Toyota's "Pre-Collision System (PCS) was the first production forward collision warning system. The radar-based system that uses a forward-facing millimeter-wave radar. When the system determines that a frontal collision is unavoidable, it preemptively tightens the seat belts, removing any slack, and pre-charges the brakes using brake assist to give the driver maximum stopping power instantly when the driver depresses the brake pedal.

2003 February: Toyota launched PCS in on the redesigned Japanese domestic market Harrier.

2003 August: added an automatic partial pre-crash braking system to the Celsior.

2003 September: PCS made its first appearance in North America on the Lexus LS 430, becoming the first radar-guided forward collision warning system offered in the US.

2004: In July 2004 the Crown Majesta Radar PCS added a single digital camera to improve the accuracy of collision forecast and warning and control levels.

2006: Pre-Collision System with the first Driver Monitoring System introduced in March 2006 on the Lexus GS 450husing a CCD camera on the steering column. This system monitors the driver's face to determine where the driver is looking. If the driver's head turns away from road and a frontal obstacle is detected, the system will alert the driver using a buzzer, and if necessary, pre-charge the brakes and tighten the safety belts.

2006: the Lexus LS featured a further advanced version of the PCS. Advanced Pre-Collision System (APCS), added a twin-lens stereo camera located on the windshield and a more sensitive radar to detect for the first time smaller "soft" objects such as animals and pedestrians. A near-infrared projector located in the headlights allows the system to work at night. With the Adaptive Variable Suspension (AVS) and electric power steering, the system can change the shock absorber firmness, steering gear ratios, and torque assist to aid the driver's evasive steering measures. The lane departure warning system will make automatic steering adjustments to help ensure that the vehicle maintains its lane in case the driver fails to react. Driver Monitoring System was introduced on the Lexus LS. Rear-end Pre-Collision system includes a rearward-facing millimeter-wave radar mounted in the rear bumper. This system adjusts the active head restraints by moving them upward and forward to reduce the risk of whiplash injuries if an imminent rear collision is detected.

2008 Updated Driver Monitoring System added on the Crown for detecting whether the driver's eyes are properly open. It monitors the driver's eyes to detect the driver's level of wakefulness. This system is designed to work even if the driver is wearing sunglasses, and at night.

2008 PCS with GPS-navigation linked brake assist function on the Crown. The system, which is designed to determine if the driver is late in decelerating at an approaching stop sign, will then sound an alert and can also pre-charge the brakes to provide optimum braking force if deemed necessary. This system works in certain

Japanese cities and requires Japan specific road markings that are detected by a camera.

2009 on the redesigned Crown, Toyota again further advanced the PCS, adding a front-side millimeter-wave radar to detect potential side collisions primarily at intersections or when another vehicle crosses the center line. The latest version tilts the rear seat upward, placing the passenger in a more ideal crash position if it detects a front or rear impact.

2012: Higher Speed A-PCS on facelifted Lexus LS: enables deceleration of up to 37 MPH as compared to the current generation system of 25 MPH. This higher speed A-PCS uses the same technologies as the current A-PCS. This system increases the braking force up to twice that applied by average drivers. (Not available in U.S. markets due to regulatory considerations.

2013: Pre-Collision System with Pedestrian-avoidance Steer Assist and Steering Bypass Assist can help prevent collisions in cases where automatic braking alone is not sufficient, such as when the vehicle is travelling too fast or a pedestrian suddenly steps into the vehicle’s path. An on-board sensor detects pedestrians and issues a visual alert on the dashboard immediately in front of the driver if the system determines that there is a risk of collision. If the likelihood of a collision increases, the system issues an audio and visual alarm to encourage the driver to take evasive action, and the increased pre-collision braking force and automatic braking functions are activated. If the system determines that a collision cannot be avoided by braking alone and there is sufficient room for avoidance, steer assist is activated to steer the vehicle away from the pedestrian [8].

2.1.19 Volkswagen

2010: "Front Assist" on the 2011 Volkswagen Touareg can brake to a stop in case of an emergency and tension the seat belts as a precautionary measure.

2012: In 2012, Volkswagen Golf Mk7 introduced their "Proactive Occupant Protection", which will close the windows and retract the safety belts to remove excess slack if the potential for a forward crash is detected. Multi-collision brake system (Automatic Post-Collision Braking System) to automatically brake the car after an accident in order to avoid a second collision. City emergency braking automatically activates brakes at low speeds in urban situations.

2014: Volkswagen Passat B8 introduces pedestrian recognition a part of the system. It uses a sensor fusion between a camera and the radar sensor. There is an "emergency assist" in case of a non-reacting driver, the car takes the control of the brakes and the steering until a complete stop.

2.1.20 Volvo

Volvo City Safety multiple camera: 2006: Volvo's "Collision Warning with Auto Brake", developed in cooperation with Mobileye, was introduced on the 2007 S80. This system is powered by a radar/camera sensor fusion and provides a warning through a head up display that visually resembles brake lamps. If the driver does not react, the system pre-charges the brakes and increases the brake assist sensitivity to maximize driver braking performance. Later versions will automatically apply the brakes to minimize pedestrian impacts. In some models of Volvos, the automatic braking system can be manually turned off. The V40 also included the first pedestrian airbag.

2013: Volvo introduced the first cyclist detection system. All Volvo automobiles now come standard with a lidar laser sensor that monitors the front of the roadway, and if a potential collision is detected, the safety belts will retract to reduce excess slack. Volvo now includes this safety device as an optional in FH series trucks.

2015: "IntelliSafe" with Auto brake at intersection. The Volvo XC90 is the first technology that features automatic braking if the driver turns in front of an oncoming car. This is a common scenario at busy city crossings as well as on highways, where the speed limits are higher.

While the original system, introduced in the Volvo S80, is radar-based, Collision Warning with Auto Brake uses both radar and a camera to detect vehicles in front of the car. The long-range radar reaches 150 meters in front of the car while the camera range is 55 meters. By using Data Fusion to combine information from the radar and the camera, the system becomes more efficient.

If the car approaches another vehicle from behind and the driver does not react, a red warning light flashes in the head-up display on the windscreen. At the same time, an audible signal can be heard. This helps the driver react and an accident can be avoided in most cases.

If the risk of a collision increases despite the warning, the brake support is activated. To shorten the reaction time the brakes are prepared by the brake pads being placed against the discs. The brake pressure is also reinforced hydraulically, ensuring effective braking even if the driver does not press the brake pedal particularly hard.

If the driver doesn't brake and the sensor system determines that a collision is imminent, the brakes are activated. Auto Brake is designed to lower the impact speed as much as possible and thereby reduce the risk of injury to the occupants of both vehicles. A reduction in collision speed from 60 km/h to 50 km/h, for example, gives approximately 30 percent less impact energy. This can mean the difference between a serious injury and minor consequences for the occupants. Depending on the circumstances, it is also possible that the Auto Brake can help avoid the impact entirely.

To make driving more comfortable, Volvo Cars has developed Adaptive Cruise Control, ACC. It helps the driver by maintaining the distance to the car in front and the system contributes to relaxed driving control when the traffic flow is uneven. Adaptive Cruise Control uses a radar sensor to continuously measure the distance to the vehicles in front and the system automatically adapts the speed of the car to ensure that the distance is maintained. The driver activates the cruise control, sets the desired maximum speed between 30 and 200 km/h and chooses a time interval to the car in front. There is a choice of five different time intervals between 1 and 2.6 seconds.

When the radar sensor detects a slower vehicle in front of the car, the speed is automatically adapted to that vehicle even when it changes speed. Since Adaptive Cruise Control handles part of the routine driving operations the driver can focus further ahead and drive with greater safety margins.

Distance Alert is another new comfort feature that helps the driver keep a proper distance to the vehicle in front even when the Adaptive Cruise Control is disengaged. Distance Alert is activated via a button in the center console. As with ACC, the driver can choose between five settings. If the time gap to the car in front becomes shorter than the selected value, the driver gets visual information in the head-up display on the lower part of the windscreen. If Distance Alert is engaged and ACC is activated, the DA system becomes temporarily disengaged. Both ACC and Distance Alert are tailored to help the driver comfortably follow certain national regulations defining the required distance to the vehicle in front [1].

2.1.21 Mitsubishi

Mitsubishi Forward Collision Mitigation (FCM) is a radar-based autonomous emergency braking system. A single 77GHz radar is situated behind the front grille and is used to detect objects up to around 200m ahead which might present a risk of collision. The system operates up to a maximum speed of 180km/h. In the first stage, when the risk of collision is low, FCM issues a visual and audible warning to alert the driver to the threat. At the same time, the brakes are pre-filled and brake assist is activated, which boosts the braking pressure should the driver respond to the warning and apply the brakes. If the driver does not respond and the risk of collision increases, the system continues to warn the driver but also autonomously applies moderate braking, to begin to mitigate the severity of any collision but also to serve as an additional warning to the driver. If the risk of collision escalates, FCM autonomously applies a high brake pressure to try to avoid the accident or to reduce its severity. Up to 30km/h, the system will apply a maximum deceleration of 8ms-2. Beyond that speed the maximum is 6ms-2 [14].

(Bosch, 2011) In order to reduce the risk of a rear-end collision or mitigate the consequences of such a collision, Bosch has developed the Predictive Emergency Braking System. The system, which is based on the networking of a radar sensor with the Electronic Stability Program or Electronic Stability Control, continuously analyzes the traffic ahead [5].

The Predictive Emergency Braking System becomes active as soon as the vehicle is started, and supports the driver at all speeds – both by day and by night. Nevertheless, the driver still has a responsibility to pay attention and drive carefully at all times.

When the Predictive Emergency Braking System detects that the distance to the preceding vehicle is becoming critically short at a vehicle speed above 30 km/h, it prepares the braking system for potential emergency braking. Thus, full braking power is available to the driver valuable hundredths of seconds earlier.

If the driver fails to react to the critical situation and the Predictive Emergency Braking System detects that the vehicle is continuing to approach the vehicle ahead, the system warns the driver by means of a visual and/or audible signal followed by a brief but clearly perceptible brake jerk. The driver is made aware of the immediate risk of a collision and can react earlier to potentially avoid the rear-end collision by braking or by an avoidance maneuver.

The time at which the warning is given is based on the required stopping distance and average motorist reaction time. When making the calculation, the system can also take into account whether the driver is active or inactive and must therefore be warned earlier.

Valuable time can pass before a driver reacts to a critical situation. The Predictive Emergency Braking System can use this time effectively: Following the collision warning, it can initiate partial braking in the detected rear-end collision situation. This intervention decelerates the vehicle and gives the driver more time to react.

As soon as the driver presses the brake pedal, the system provides braking support. To do this, the system continuously calculates the degree of vehicle deceleration needed to avoid the collision. When the Predictive Emergency Braking System detects that the driver is not braking hard enough, it increases the braking pressure to the required level so that the driver can attempt to bring the vehicle to a standstill before a collision occurs.

Should the driver fail to react at all to the immediate risk of collision and the Predictive Emergency Braking System detects that a rear-end collision is unavoidable, it can automatically initiate full braking. As a result, the vehicle is traveling considerably slower when the collision occurs, reducing the severity of the crash for the passengers of both vehicles.

The initiation of full braking calls for superior object recognition and collision risk assessment capabilities. For this reason, the radar sensor is supplemented by an additional surround sensor, such as a video camera.

Chapter 3

3.1 Materials and Methodology

Materials

The materials that are considered for the design are ultrasonic sensor, arduino uno microcontroller, 12V batteries, jumper wires, servomotor and brake actuating arm.

Methodology

3.1.1 Brake actuation

The approach considered for the design of the automatic braking system (ABS) is to design some kind of brake actuation mechanism. The first step is to detect an object that is in front of the vehicle. For this, the ultrasonic distance sensor was chosen which will be explained later. The signal from the sensor is received by a microcontroller. Then the microcontroller will pass on the signal to a brake actuating mechanism. Then based on the signal received, the brake actuator mechanism will actuate the brake without the driver's help.

Before designing the brake actuator a number of conditions should be taken into consideration: safety of the driver and the passengers, does not interfere with the driver's operational activities and normal functionality of the vehicle, effective brake actuation and controllable, easy operation, compatible with Arduino micro-controller and tolerable level of accuracy.

Since the brakes are the most important safety feature of the vehicle, the design and integration of the brake actuating mechanism should not interfere with the normal operation of the vehicle's brake system.

To design the brake actuating mechanism, first the force that is applied on the brake pedal of a typical automobile should be calculated. For this a weight measuring instrument to measure the weight applied by a driver's foot on the brake pedal was considered. To take a reading, another person records the readings while the driver drives the car with the weighing instrument is on the brake pedal. Using a digital camera successive pictures of the initial and final position of brake pedal were taken as well as the positions in between. Then tracing the initial and final positions of the pedal on a paper from the picture, measurement of the angle was found to be approximately 15°. After taking reading of the weighing instrument on an automobile, the following results were summarized in the table below:

Table 1: Measurement of force applied on the brake pedal

Vehicle type	Brake length	Mass applied	Force applied	Torque needed
Automobile	300mm	9kg	90N	27 N-m

As per the result above, the torque value that is needed to actuate the brake is estimated as 27 N-m. This torque value corresponds to a calculated angle value of 15° which is the final position of the brake pedal. The next step is to find a motor that can produce a torque greater than 27 N-m. The motor should also satisfy the following conditions:

- The fitting place for the brake actuator and motor is below the dash board just above the brake pedal.
- The motor should be able to actuate the brake to a full extent when required.
- According to a study done by NTSEL, the average brake stroke speed should be 456mm/s by a human driver.
  In this case the brake stroke can be calculated as follows:

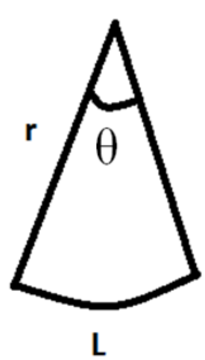

Figure 1. Brake pedal swept distance diagram [23]

$$L = (\theta/360) \times (2\pi r) \qquad (1)$$

$= (15°/360) \times (2\pi \times 300mm)$

$= 78$ mm

L is the brake stroke for the vehicle that is to be calculated. The brake arm length (r) is measured as 300mm. The angle (θ) is measured as approximately 15°.

78 mm/456 mm per second is 0.17 second. Therefore, the motor chosen should be able to actuate the brake fully in 0.17 second.

In general the motor to be chosen should have a torque value greater than 27 N-m and be able to actuate the brake in 0.17 second to its final position. Thus, a servomotor was chosen for this purpose because servos can accurately move to a specified position. The servomotor size has to fit in the space between the brake pedal and the dashboard. It should not interfere with driver's operation. The next step is to design the actuator arm that can transfer the rotational force of the motor to the brake arm. To do that the specific dimensions of the motor have to be specified. Based on evaluation of different servomotor size, the following dimensions are selected for design purpose. The central rotating shaft of the servo is of 22mm. The outer part has holes for attachment. Thus, the actuating arm to be designed has to have an inner hole with diameter of 22mm and outer diameter of 40mm. Then fastening screws can be used to attach the actuating arm to servo. Accordingly, the design was done using Catia. I chose aluminum alloy material since it is lighter and stronger than steel.

3.1.2 Brake Actuator

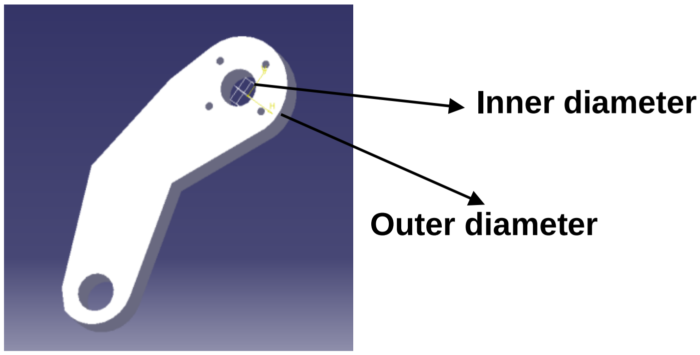

Figure 2. Catia drawing of brake actuator design

Figure 2 shows the designed brake actuating arm. This was done based on the diameter of the servomotor shaft. The diameter of the shaft is 22mm. And the thickness was set as 20mm which was found to withstand the deformation analysis. The four holes were also made so that the brake actuator arm can fit on top of the servomotor encircling its shaft.

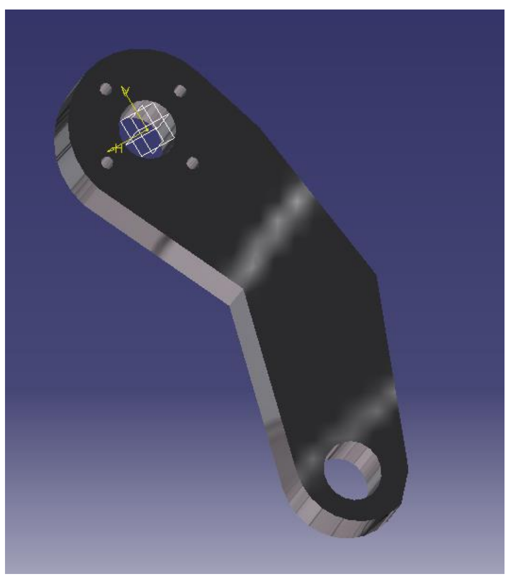

Figure 3. Catia drawing of brake actuator design with aluminum alloy material

The figure in above shows the designed brake actuating arm in aluminum color. The aluminum alloy material was chosen due to its light weight and high strength characteristics. This made it ideal for the servo motor to easily rotate the arm.

3.1.3 Deformation test

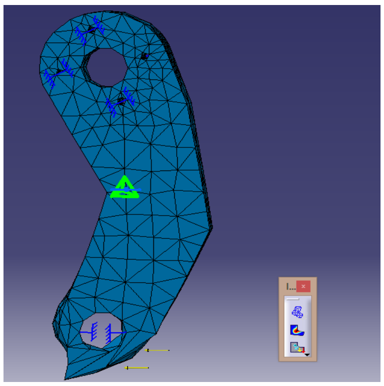

Figure 4. Catia deformation simulation test of brake actuator design

As per the simulation result, the 20mm thick aluminum brake actuator was able to withstand the 27 N-m torque applied on it on the edges. But at the lower edge where the arm gets connected to the brake pedal, some deformation was observed.

3.1.4 Design of the Automatic Braking System

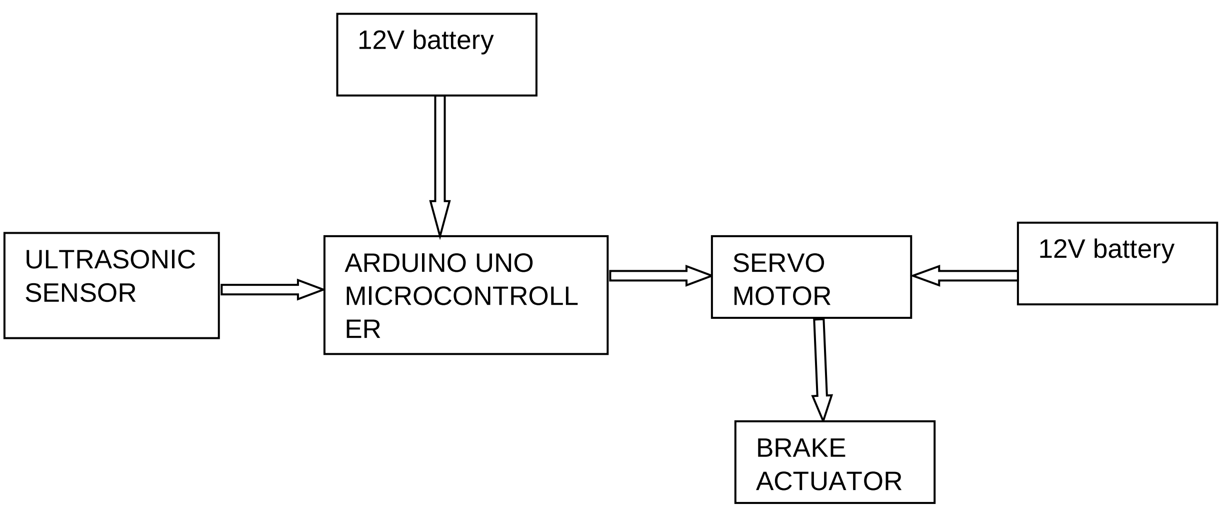

Figure 5. Automatic Brake System design diagram

3.1.5 Ultrasonic sensor

The ultrasonic distance sensor that chosen for this design provides precise, non-contact distance measurements from about 2 cm to 5 meters. It can be connected to microcontrollers; in this case to Arduino Uno microcontroller.

The sensor works by emitting an ultrasonic sound waves and providing an output pulse that corresponds to the time required for the sound wave echo to return to the sensor. By measuring the echo pulse width, the distance to target can be calculated.

The sensor detects objects by emitting a short ultrasonic burst and then "listening" for the echo. Under control of a host microcontroller, the sensor emits a short 40 kHz (ultrasonic) burst. This burst travels through the air, hits an object (vehicle surface) and then bounces back to the sensor as shown in figure 6. The sensor provides an output pulse to the host that will terminate when the echo is detected; hence the width of this pulse corresponds to the distance of the target.

The sensor chosen for this design has a male 4-pin header used to supply ground, power, trigger and echo. Thus, the ground header will be connected to the ground of the arduino microcontroller. Accordingly, the echo header to any digital I/O pin, the trigger header to any digital I/O pin and the power will be attached to 5V of the microcontroller.

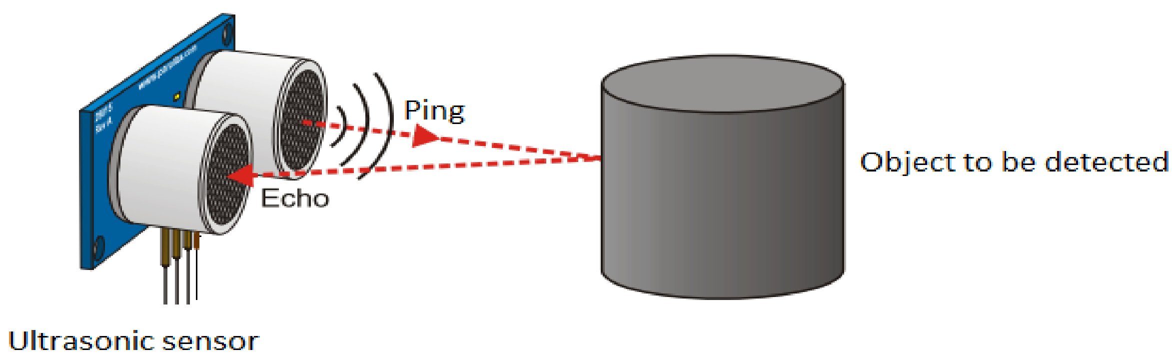

Figure 6. Object detection scenario with ultrasonic sensor [4]

For accurate measurement, the object of interest should not be more than 5m away. If the reflective surface is at angle less than 45° the reflected sound will not be towards the sensor. If the objected to be detected is too small, enough sound will not be reflected back to the sensor. The sensor should be protected from external environment except for the front part. Ultrasonic measurements work in any lighting condition. Objects that absorb sound or have a soft or irregular surface may not reflect enough sound to be detected accurately. The measurements to be read are assumed in room temperature (20°C).

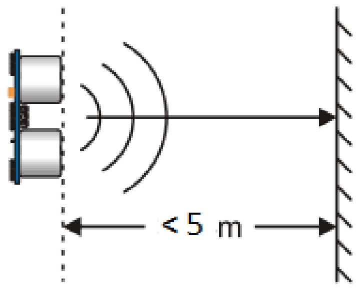

Figure 7. The ultrasonic distance sensor cannot detect objects that are more than 5m away

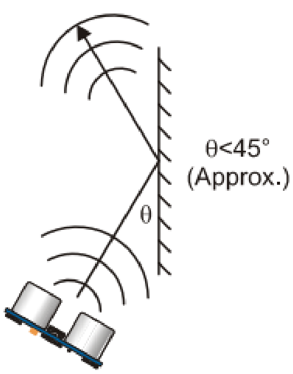

Figure 8. Sound will not be reflected back if the surface angle is less than 45°

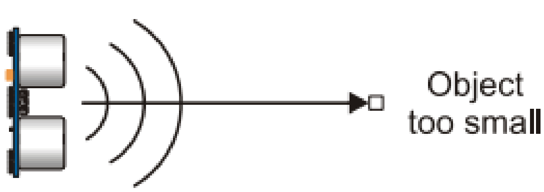

Figure 9. Enough sound will not be reflected back if the surface angle is less than 45° [4]

3.1.6 Arduino Uno Microcontroller

The microcontroller selected for the design is Arduino Uno. The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; it can be powered by a 12V battery. It can sense the environment by receiving input from ultrasonic sensor. The program was written for the microcontroller on the board using the Arduino programming language. Based on the program the microcontroller sends a signal to the sensor to emit ultrasonic sound and receives an impulse from the sensor and sends this signal to a servo driver. The servo driver sends this signal to servo motor. Then the servo motor rotates to a specified angle between 0° and 180° based on the signal received. The board can be powered by the vehicle's 12V battery. For convenience, the battery snap leads can be soldered to a DC power plug of part number 28760and connect to the power jack on the board. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts. The power pins are: VIN-the input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). Voltage can be supplied through this pin, or, if supplying voltage via the power jack, it can be accessed through this pin. 5V-the regulated power supply used to power the microcontroller and other components on the board. GND- Ground pins. The Atmega328 has 32 KB of flash memory for storing code. Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. LED: 13-There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off [11].

The Arduino Uno can be programmed with the Arduino software. The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows a new code to be uploaded to it without the use of an external hardware programmer. Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. The Arduino software uses this capability to allow upload of code by simply pressing the upload button in the Arduino environment. The maximum length and width of the microcontroller are 68.58 mm and 53.34 mm respectively. Three screw holes allow the board to be attached to a protective case. The small size of the microcontroller allows it to easily fit in the space below the dashboard. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). The Arduino programming language is a simplified version of C/C++.

An important feature of the Arduino is that it lets a control program be created on the host PC, downloaded to the Arduino and it will run automatically. Even if the USB cable connection to the PC is removed, the program will still run from the top each time the reset button is pushed. Remove the battery and put the Arduino board in a closet for six months. When the battery is reconnected, the last program stored will run. This means that connection of the board to the host PC is used to develop and debug a program, but once that is done, the PC is no longer necessary to run the program.

Now let us see how to connect the Arduino board to the computer and upload a sketch. So first Arduino Uno board and a standard USB cable is necessary. Then the arduino software can be downloaded online. When the download finishes, unzip the downloaded file. Make sure to preserve the folder structure. Double-click the folder to open it. There should be a few files and sub-folders inside. Once downloaded no installation is required. Then connect the Arduino board to a computer using the USB cable. The green power LED (labelled PWR) should go on.

Installing drivers for the Arduino Uno with Windows7, Vista, or XP:

- Plug in your board and wait for Windows to begin its driver installation process. After a few moments, the process will fail
- Click on the Start Menu, and open up the Control Panel.
- While in the Control Panel, navigate to System and Security. Next, click on System. Once the System window is up, open the Device Manager.
- Look under Ports (COM & LPT). You should see an open port named "Arduino UNO (COMxx)"
- Right click on the "Arduino UNO (COmxx)" port and choose the "Update Driver Software" option.
- Next, choose the "Browse my computer for Driver software" option.
- Finally, navigate to and select the Uno's driver file, named "ArduinoUNO.inf", located in the "Drivers" folder of the Arduino Software download (not the "FTDI USB Drivers" sub-directory).
- Windows will finish up the driver installation from there.

The Arduino application can be opened by double-clicking the arduino icon. Then we can enter the code in the new window opened. We need to select the entry in the Tools > Board menu to choose the arduino uno. Then we select the serial device of the Arduino board from the Tools **|** Serial Port menu. This could be COM1, COM2 or COM3. Now, simply click the "Upload" button in the environment. Wait a few seconds - you should see the RX and TX LEDs on the board flashing. If the upload is successful, the message "Done uploading." will appear in the status bar. A few seconds after the upload finishes, pin 13 LED on the board start to blink (in orange). This means the arduino programme has started running.

3.1.7 Servo Motor

The servo motor has three connections. Its red cable will be connected to the positive 12V battery terminal while the black cable will be connected to the negative battery terminal. The other cable can be connected to any digital pin on the microcontroller. After assessment of the different options in the market, a servo that has a 38 N-m torque value was chosen. Since the torque value needed to actuate the brake pedal is 27 N-m, such a servo is a safe choice. It takes 0.95sec to cover 90° for the servo. That means it will take it 17°*0.95sec/90° or 0.17 seconds to actuate the brake pedal fully. The motor has a weight of 780g. It has a size of 132mm*55*118mm. It is water and dust resistant. Its casing is aluminum die-cast. It also has screw holes so that it can be screwed to a surface.

Chapter 4

RESULTS AND DISCUSSION

The proposed design of automatic braking system shows that it is feasible for such a system to prevent frontal crashes. The deformation test for the design of the brake actuating arm shows that it is stable and the thickness which is 20mm of aluminum is suitable for the purpose. But based on catia analysis, the thickness of the brake actuator around the lower edge should be increased to withstand deformation. As for the sensor, if better range and all weather sensor are used robust operation may be achieved. For now it was not possible to actually manufacture the system due to the high cost of the different parts of the system. But as per the objective, the basic design is as stated in the methodology.

The design of the brake actuator can be tricky; thus, care should be taken while designing the arm. The material selection and its shape depend on the operation requirement of braking. The servomotor has proved to be a reliable motor for such precision demanding activity. Depending on the response of the servo, voltage regulator maybe deployed to make the interaction between the microcontroller and the motor. Also a switch can be made available on the dashboard which can be used by the driver to engage or disengage the automatic braking system. The switch can turn on or off the system by interrupting the power line for the microcontroller or the servo.

The deformation observed on the lower edges of the brake actuating arm can be overcome with increasing the thickness of the arm towards the edges. The servomotor would not interfere with the normal braking action of the driver since its shaft can rotate to any direction when it is not receiving instructions from the microcontroller. In the event of system malfunction or if the driver wants to take over just after the application of an emergency braking, the driver can just push a button on a dashboard that can cut the power supply to the microcontroller.

Structural analysis of the brake actuating arm was also done using ansys. This was done based on mesh refinement. The lower end area of the arm was taken as the refined area. The ansys simulation showed that maximum deformation occurs at the lower end of the brake actuating arm. Also the von mises stress simulation in ansys showed that the maximum stress occurs on the middle edge where there is a sharp joint. Thus, this sharp joint should be redesigned as smooth curve to reduce the stress around this area.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This paper designed an automatic braking system for an ordinary automobile that can assist a driver to avoid collision. To achieve this first the braking force applied on a general automobile was estimated. Then the resulting torque was also estimated. Based on the torque value calculated, the specific type of servomotor was chosen.. And then the brake actuating arm was designed using catia. The overall design was centered on the Arduino Uno microcontroller. Also ultrasonic sensor for detecting obstacles was considered. The microcontroller acted as the connector between the sensor and servo by receiving electrical signal from the sensor and sending that signal to the servo. The connecting arm from the servo to the brake pedal arm was designed using Catia and tested using the deformation analysis. The code for the system was written using arduino programming software. This paper contributes to efforts of increasing road safety and minimizing accidents. Also, it can be used as an input for further research in the area of driver assistant systems in Ethiopia. The deformation analysis and overall design showed that it is possible to design such systems locally with minimal cost.

In general the design showed that it is possible to design automatic braking system with minimum cost. This paper can initiate automatic braking system designs in Ethiopia in the context of technology transfer so that there will be a positive impact on road traffic accidents reduction. It can also be a benchmark for next generation of students who may use it for their own specific similar projects and also they may take this research work further.

Most collision mitigation systems manufactured by major car companies are expensive. Thus, this paper proposes the technology and the know-how to design the system.

5.2 Conclusions

- The designed brake actuating arm can be fit for operation with a minor modification of its thickness towards the lower portion.
- Aluminum alloy proved to be suitable for the operation with only a slight problem.
- This paper can be used as a reference in context of technology transfer.
- It is possible to write a code that can run the whole automatic braking operation. The written code was verified by the arduino software.
- Ultrasonic sensor can be instrumental when measuring obstacles. Specially if an all weather sensor is used, better results can be achieved. Also if long range sensors are used, they can yield good results by offering long range detection. In addition frontal collision, side and rear end collision warning systems can be deployed and integrated in the automatic braking system design by making changes to the code and by adding additional sensors. The feedback from this can be expressed as a visual warning or as an audio warning.
- The servomotor selected is enough to actuate the brake pedal to a required speed and position. Since the servomotor’s torque value is greater than the torque required to actuate the brake pedal, the servo can operate well without being overloaded.
- Overall, the design showed that it is possible to design and manufacture the automatic braking system with acceptable cost value. Roughly the design

could cost as follows: around 1000 birr for arduino uno microcontroller, 600 birr for ultrasonic sensor, two batteries for 4000 birr, brake actuating arm for 3000 birr, cables and accessories for 2000 birr and servomotor for 12000 birr.

- This research paper proves that the technology of automatic braking system is within grasp, even for developing country like Ethiopia. If the appropriate fund to build the actual system is obtained, the system can be designed as explained in this paper.

5.3 Recommendations

- The design presented in this paper should be manufactured and tested on an actual car with the necessary funds provided.
- Deployment of long range sensors can improve obstacle detection range.
- This design can also be implemented on any other vehicle. But the design parameters of the brake actuating arm may vary. Also the servomotor requirement will vary depending on the brake force and torque requirement of a specific vehicle.

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Appendix 1: Code for automatic braking system

/* Ping))) Sensor

This sketch reads a PING))) ultrasonic rangefinder and returns the distance to the closest object in range. To do this, microcontroller sends a pulse to the sensor to initiate a reading, then listens for a pulse to return. The length of the returning pulse is proportional to the distance of the object from the sensor.

The circuit:

* +V connection of the PING))) attached to +5V
* GND connection of the PING))) attached to ground
* Trigpin connection of the PING))) attached to digital pin 7
* Echopin connection of the PING))) attached to digital pin 8

// The setup() function is called when a sketch starts. It is used to initialize variables, pin modes, start using libraries, etc. The setup function will only run once, after each powerup or reset of the Arduino board.

// loop()

After creating a setup() function, which initializes and sets the initial values, the loop() function does precisely what its name suggests, and loops consecutively, allowing the program to change and respond. It is used to actively control the Arduino board.

// if (conditional) and ==, !=, <, > (comparison operators)

if, which is used in conjunction with a comparison operator, tests whether a certain condition has been reached, such as an input being above a certain number. The format for an if test is:

```
if (someVariable > 50)
{
  // do something here
}
```

The program tests to see if someVariable is greater than 50. If it is, the program takes a particular action. Put another way, if the statement in parentheses is true, the statements inside the brackets are run. If not, the program skips over the code.

// using the single equal sign (e.g. if (x = 10))is not desirable. The single equal sign is the assignment operator, and sets x to 10 (puts the value 10 into the variable x). Instead use the double equal sign (e.g. if (x == 10)), which is the comparison operator, and tests *whether* x is equal to 10 or not. The latter statement is only true if x equals 10, but the former statement will always be true.

This is because C evaluates the statement if (x=10) as follows: 10 is assigned to x (remember that the single equal sign is the assignment operator), so x now contains 10. Then the 'if' conditional evaluates 10, which always evaluates to TRUE, since any non-zero number evaluates to TRUE. Consequently, if (x = 10) will always evaluate to TRUE, which is not the desired result when using an 'if' statement. Additionally, the variable x will be set to 10, which is also not a desired action.

// if / else

if/else allows greater control over the flow of code than the basic **if** statement, by allowing multiple tests to be grouped together. For example, an analog input could be tested and one action taken if the input was less than 500, and another action taken if the input was 500 or greater. The code would look like this:

```
if (pinFiveInput < 500)
{
  // action A
}
else
{
  // action B
}
```

else can proceed another **if** test, so that multiple, mutually exclusive tests can be run at the same time.

// pinMode()

Description

Configures the specified pin to behave either as an input or an output.

Syntax

pinMode(pin, mode)

Parameters

pin: the number of the pin whose mode you wish to set

mode: INPUT or OUTPUT

digitalWrite()

Description

Write a HIGH or a LOW value to a digital pin.

If the pin has been configured as an OUTPUT with pinMode(), its voltage will be set to the corresponding value: 5V for HIGH, 0V (ground) for LOW.

If the pin is configured as an INPUT, writing a HIGH value with digitalWrite() will enable an internal 20K pullup resistor.

Syntax

digitalWrite(pin, value)

Parameters

pin: the pin number

value: HIGH or LOW

digitalRead()

Description

Reads the value from a specified digital pin, either HIGH or LOW.

Syntax

digitalRead(pin)

Parameters

pin: the number of the digital pin you want to read (*int*)

Returns

HIGH or LOW

HIGH

The meaning of HIGH (in reference to a pin) is somewhat different depending on whether a pin is set to an INPUT or OUTPUT. When a pin is configured as an INPUT with pinMode, and read with digitalRead, the microcontroller will report HIGH if a voltage of 3 volts or more is present at the pin.

When a pin is configured to OUTPUT with pinMode, and set to HIGH with digitalWrite, the pin is at 5 volts. In this state it can source current, e.g. light an LED that is connected through a series resistor to ground, or to another pin configured as an output, and set to LOW.

LOW

The meaning of LOW also has a different meaning depending on whether a pin is set to INPUT or OUTPUT. When a pin is configured as an INPUT with pinMode, and read with digitalRead, the microcontroller will report LOW if a voltage of 2 volts or less is present at the pin.

When a pin is configured to OUTPUT with pinMode, and set to LOW with digitalWrite, the pin is at 0 volts. In this state it can sink current, e.g. light an LED that is connected through a series resistor to, +5 volts, or to another pin configured as an output, and set to HIGH.

; semicolon

Used to end a statement.

Forgetting to end a line in a semicolon will result in a compiler error. The error text may be obvious, and refer to a missing semicolon, or it may not. If an impenetrable or seemingly illogical compiler error comes up, one of the first things to check is a missing semicolon, in the immediate vicinity, preceding the line at which the compiler compiled.

{} Curly Braces

Curly braces (also referred to as just "braces" or as "curly brackets") are a major part of the C programming language.

An opening curly brace "{" must always be followed by a closing curly brace "}". This is a condition that is often referred to as the braces being balanced. The Arduino IDE (integrated development environment) includes a convenient feature to check the balance of curly braces. Just select a brace, or even click the insertion point immediately following a brace, and its logical companion will be highlighted.

Unbalanced braces can often lead to cryptic, impenetrable compiler errors that can sometimes be hard to track down in a large program. Because of their varied usages, braces are also incredibly important to the syntax of a program and moving a brace one or two lines will often dramatically affect the meaning of a program.

Comments

Comments are lines in the program that are used to inform yourself or others about the way the program works. They are ignored by the compiler, and not exported to the processor, so they don't take up any space on the Atmega chip.

Comments only purpose are to help you understand (or remember) how your program works or to inform others how your program works. There are two different ways of marking a line as a comment:

Example

```
 x = 5;  // This is a single line comment. Anything after the slashes is a comment
         // to the end of the line

/* this is multiline comment - use it to comment out whole blocks of code
```

#include

#include is used to include outside libraries in your sketch. This gives the programmer access to a large group of standard C libraries (groups of pre-made functions), and also libraries written especially for Arduino.

void

The void keyword is used only in function declarations. It indicates that the function is expected to return no information to the function from which it was called.

```
*/

// this constant won't change.  It's the pin number
// of the sensor's output:


#include <Servo.h>

Servo myservo;  // create servo object to control a servo


int pos = 0;    // variable to store the servo position
const int pingPin = 7;

void setup() {
 // initialize serial communication:
 Serial.begin(9600);
 pinMode(13, OUTPUT); // assigns pin 13 as OUTPUT

pinMode(12, OUTPUT); // assigns pin 12 as OUTPUT
```

```
 myservo.attach(9);  // attaches the servo on pin 9 to the servo object

}

void loop()
{
 // establish variables for duration of the ping,
 // and the distance result in centimeters:
 long duration, cm;

 // The PING))) is triggered by a HIGH pulse of 2 or more microseconds.
 // Give a short LOW pulse beforehand to ensure a clean HIGH pulse:
 pinMode(pingPin, OUTPUT);
 digitalWrite(pingPin, LOW);
 delayMicroseconds(2);
 digitalWrite(pingPin, HIGH);
 delayMicroseconds(5);
 digitalWrite(pingPin, LOW);

 // pin 8 is used to read the signal from the PING))): a HIGH
 // pulse whose duration is the time (in microseconds) from the sending
 // of the ping to the reception of its echo off of an object.
 pinMode(pingPin, INPUT);
 duration = pulseIn(pingPin, HIGH);

 // convert the time into a distance
  cm = microsecondsToCentimeters(duration);
```

```
 Serial.print(cm);


 Serial.print("cm");
 Serial.println();

 delay(100);

 if (cm > 400)digitalWrite (13, HIGH); // LED attached to pin 13 will light up to warn
the driver
if (300 < cm < 400)digitalWrite (12, HIGH); // sound speaker attached to pin 10 will
make a sound to warn the driver
if (cm < 300)
{
   //
   digitalWrite(9, HIGH);
    for(pos = 0; pos < 180; pos += 1)  // goes from 0 degrees to 180 degrees
 {                                   // in steps of 1 degree
   myservo.write(pos);              // tell servo to go to position in variable 'pos'
   delay(200);                      // waits 15ms for the servo to reach the position
 }
 for(pos = 180; pos>=1; pos-=1)     // goes from 180 degrees to 0 degrees
 {
   myservo.write(pos);              // tell servo to go to position in variable 'pos'
   delay(200);                      // waits 15ms for the servo to reach the position
 }

   } else {
   //
   digitalWrite(9, LOW);   }
```

```
}

long microsecondsToCentimeters(long microseconds)
{
 // The speed of sound is 340 m/s or 29 microseconds per centimeter.
 // The ping travels out and back, so to find the distance of the
 // object we take half of the distance travelled.
 return microseconds / 29 / 2;
}
```

Appendix 2: Catia analysis of the brake actuator

To do an analysis on the object, the first thing to do is to select the material type. So in this case aluminum is chosen as the material.

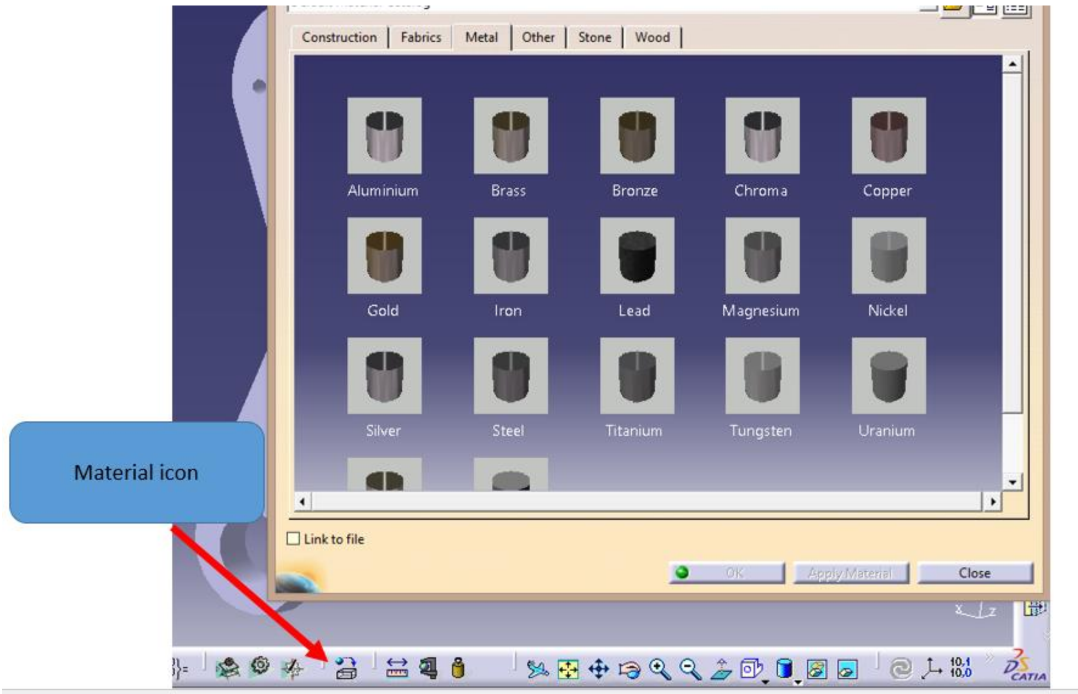

Figure 10: Material selection window in Catia

After selecting the material in the tree, then clicking the material icon, we can select aluminum as the material type in the metal tab. In Start, Analysis & Simulation, Generative Structural Analysis, the following window opens.

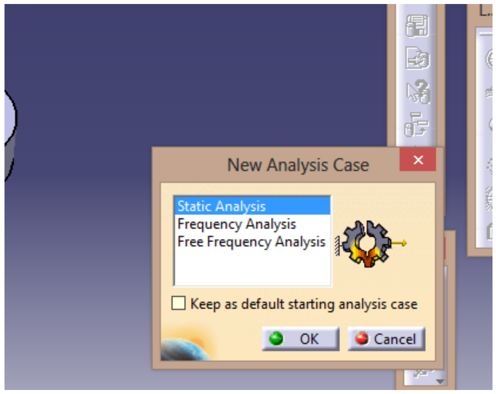

Figure 11: Static Analysis should be selected to proceed with the analysis.

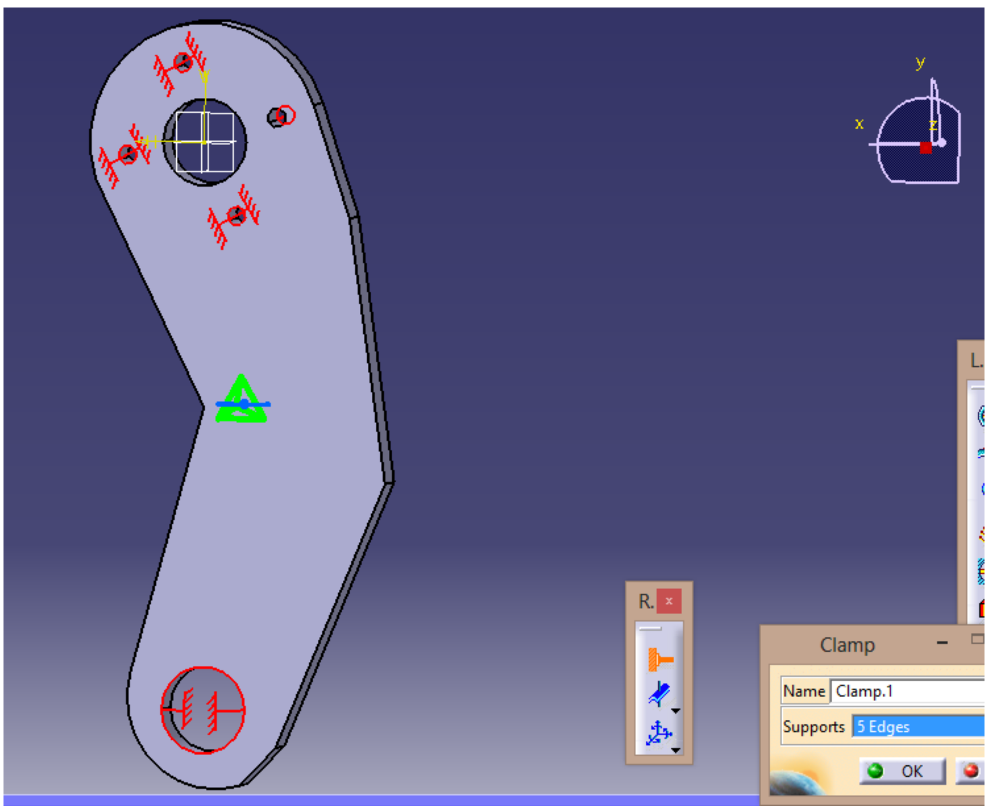

Figure 12: Application of clamps

Then we can select the clamp icon and click on parts of the object that we intend to put the clamp on. The clamps are shown in the picture above on five different positions.

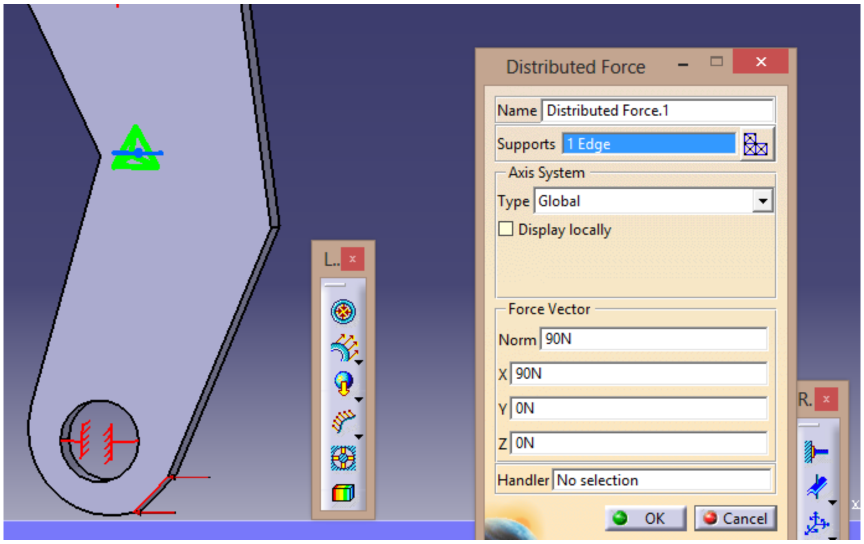

Figure 13: Application of distributed force

Then applying the distributed forces as shown on the bottom of the object which is a representative of the actual condition, deformation can be assessed.

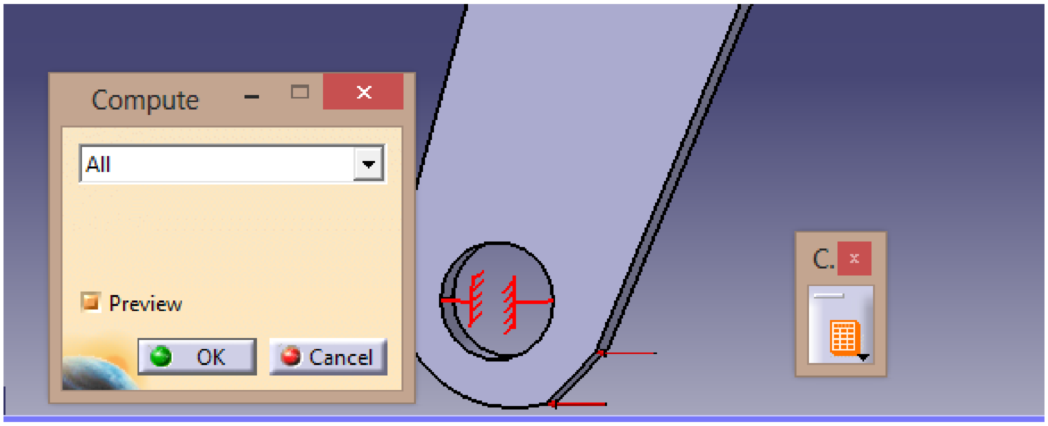

Figure 14: Compute icon

To run the analysis, Compute icon is selected. This leads to the Compute box shown to the left. The default All which means everything is computed. Upon closing this box, after a brief pause, the second box shown below appears.

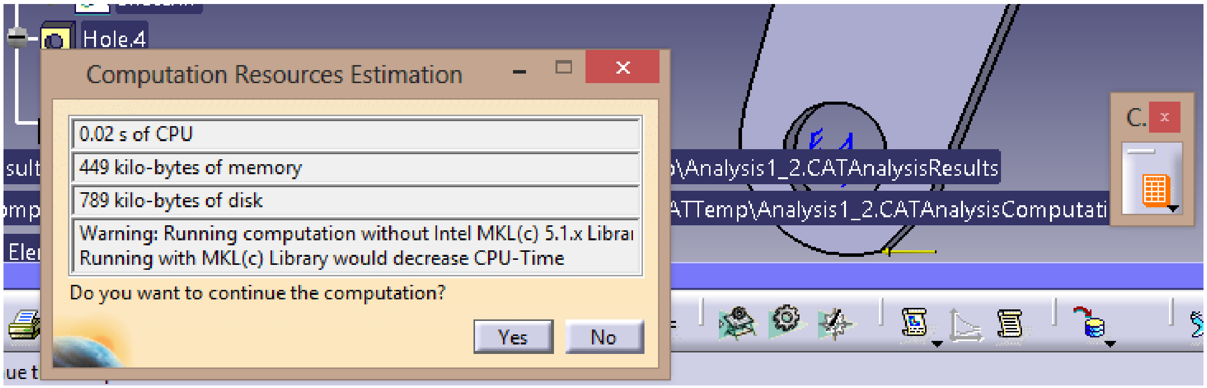

Figure 15: Completing the analysis

This box provides information on the resources needed to complete the analysis. If the estimates are zero in the listing, then there is a problem in the previous step and should be looked into. If all the numbers are zero in the box, the program may run but would not produce any useful results.

The main post processing toolbar is called Image. To view the deformed shape, the deformation icon should be selected. The resulting deformed shape is displayed on the next page. The deformation image can be very deceiving because one could have the impression that the brake actuator actually displaces to that extent. The displacements are scaled considerably so that one can observe the deformed shape.

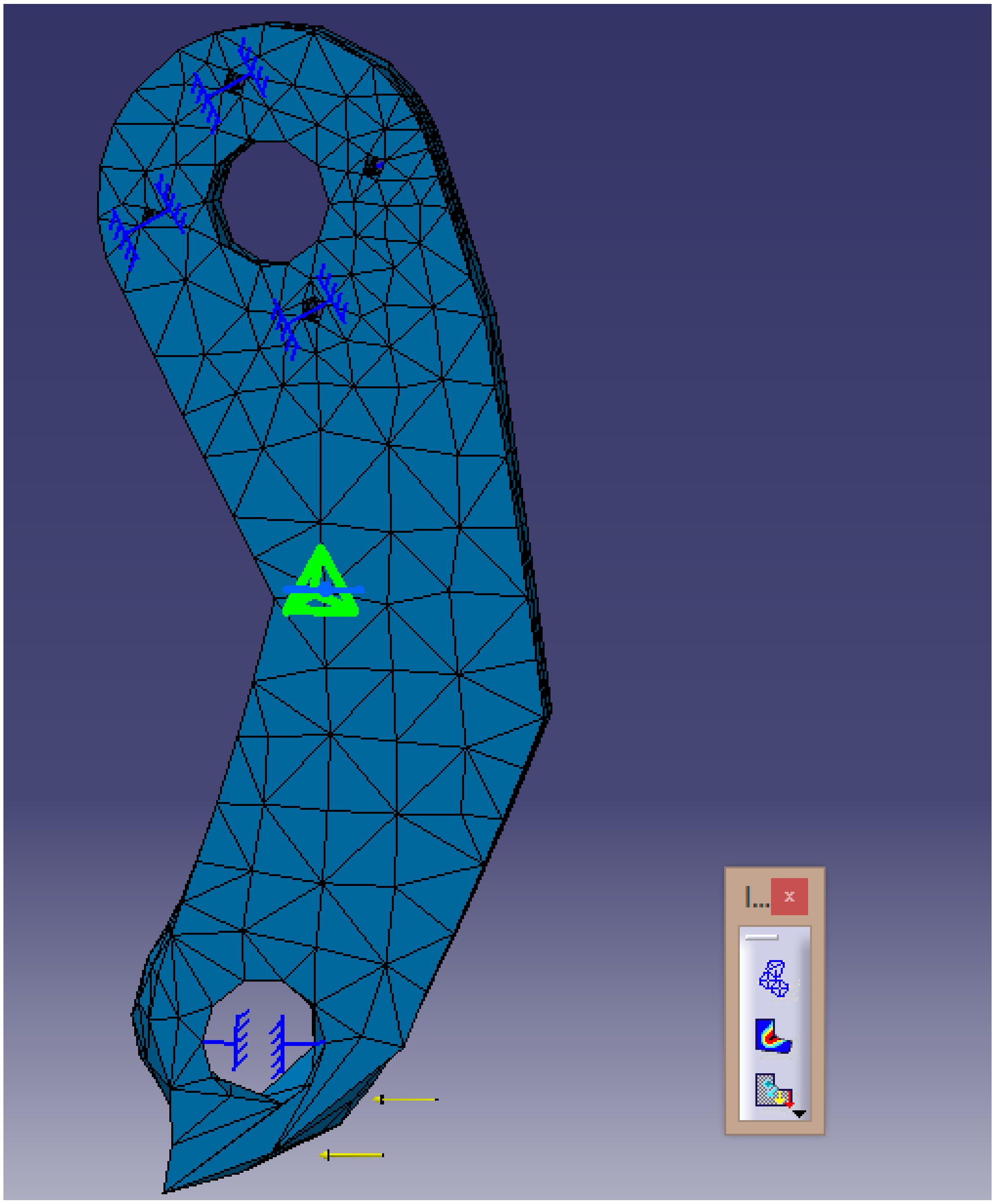

Figure 16: Possible deformation scenario

The Displacement icon in the image toolbar is used to see the displacement field. The default display is in terms of displacement arrows as shown below. The color and the length of arrows represent the size of the displacement.

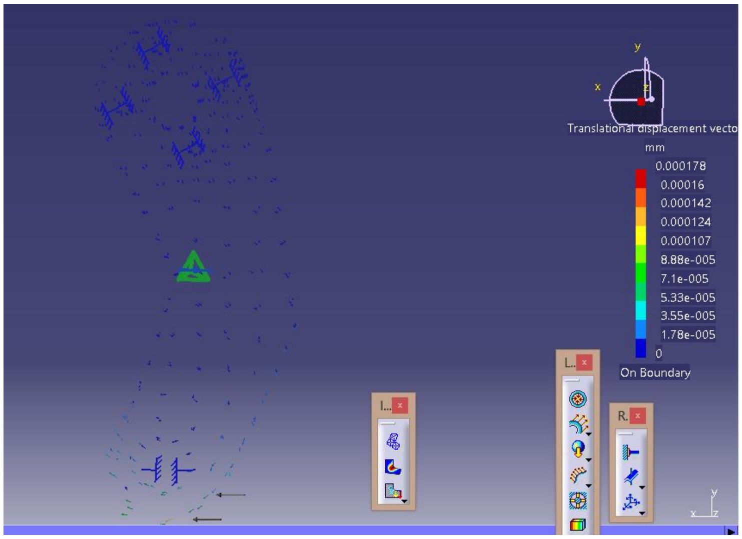

Figure 17: Translational displacement

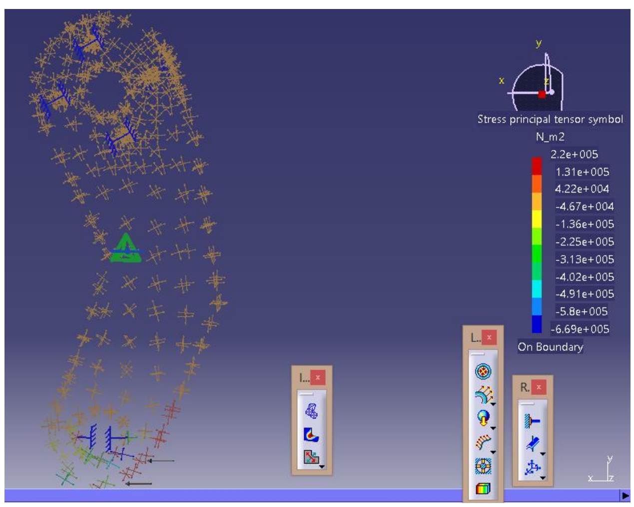

Figure 18: Stress analysis

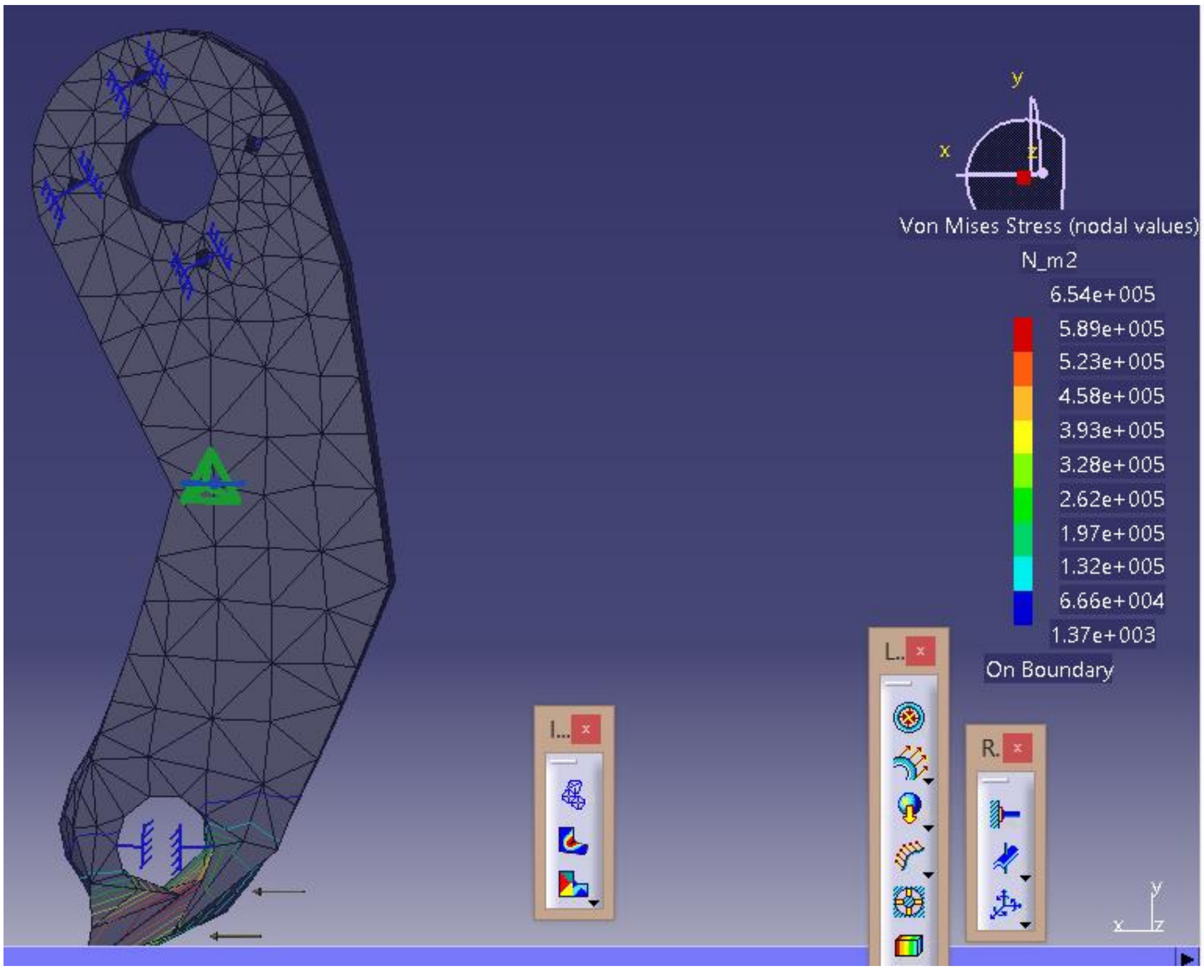

Figure 19: Stress analysis

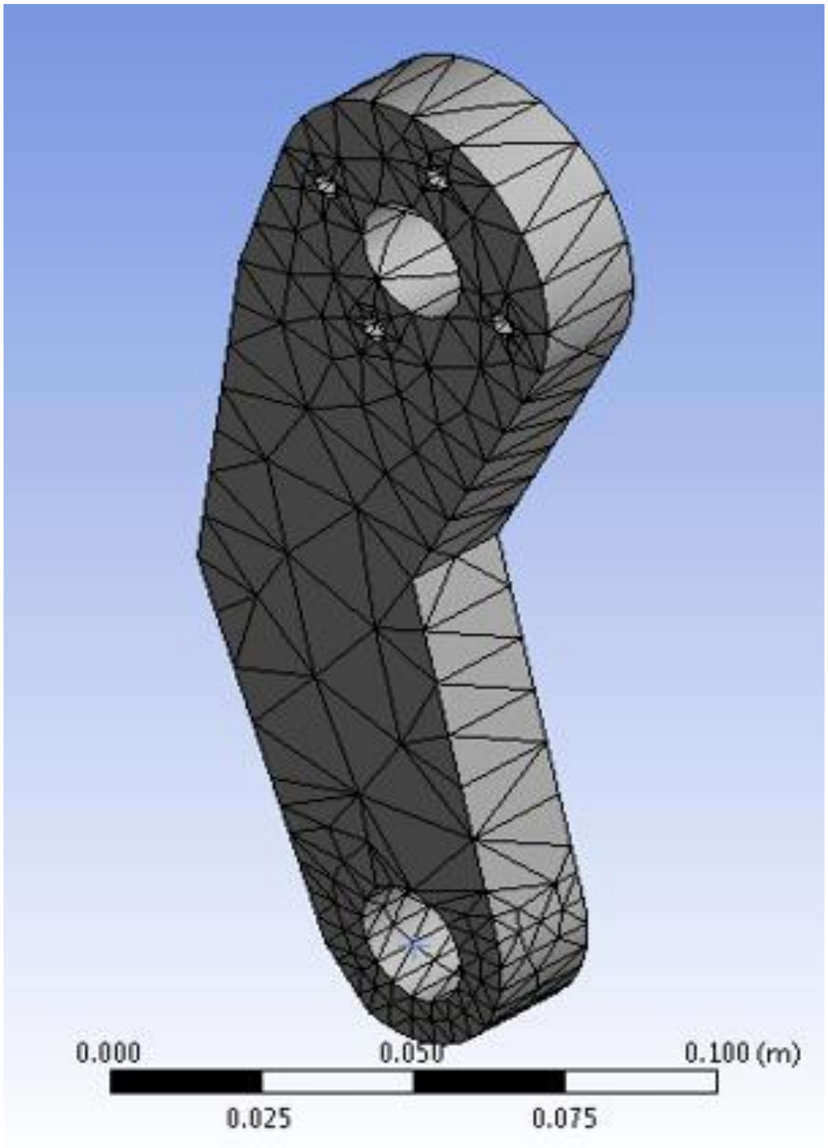

Figure 20 Mesh refinement

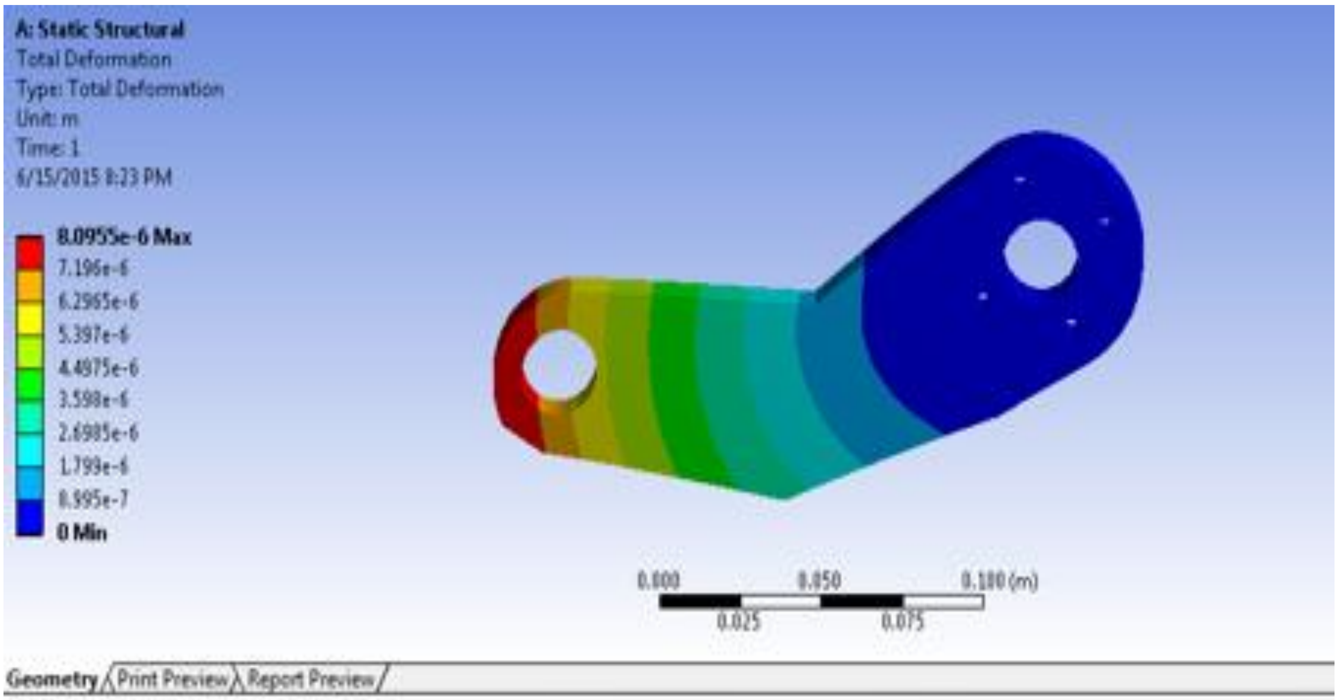

Figure 21 Total Deformation

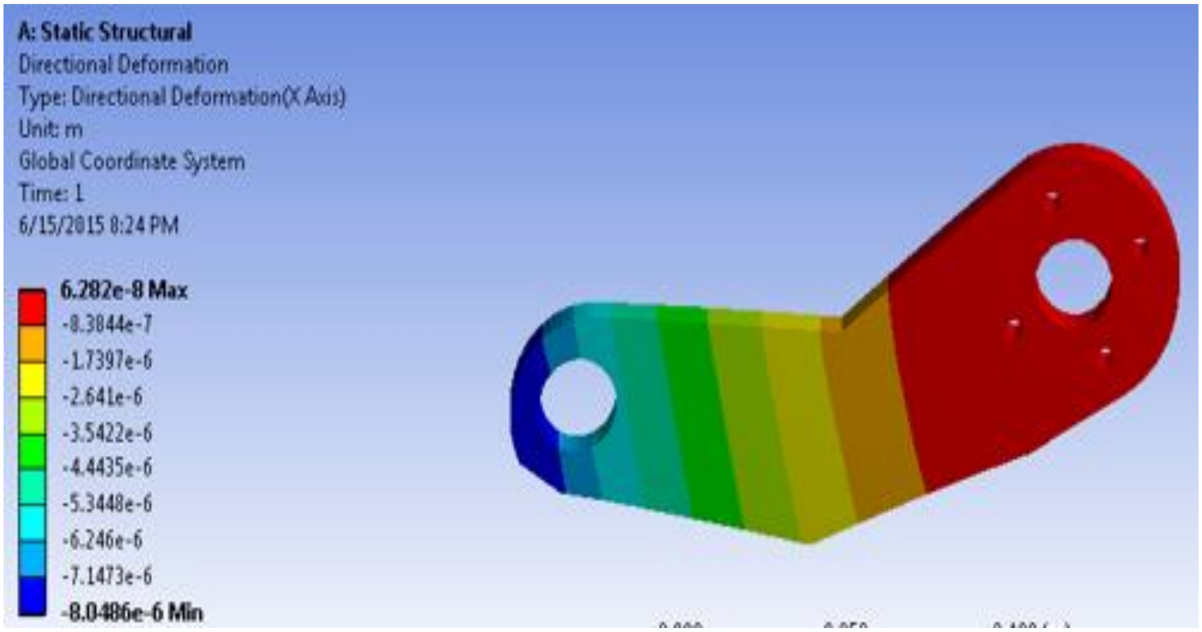

Figure 22 Directional Deformation

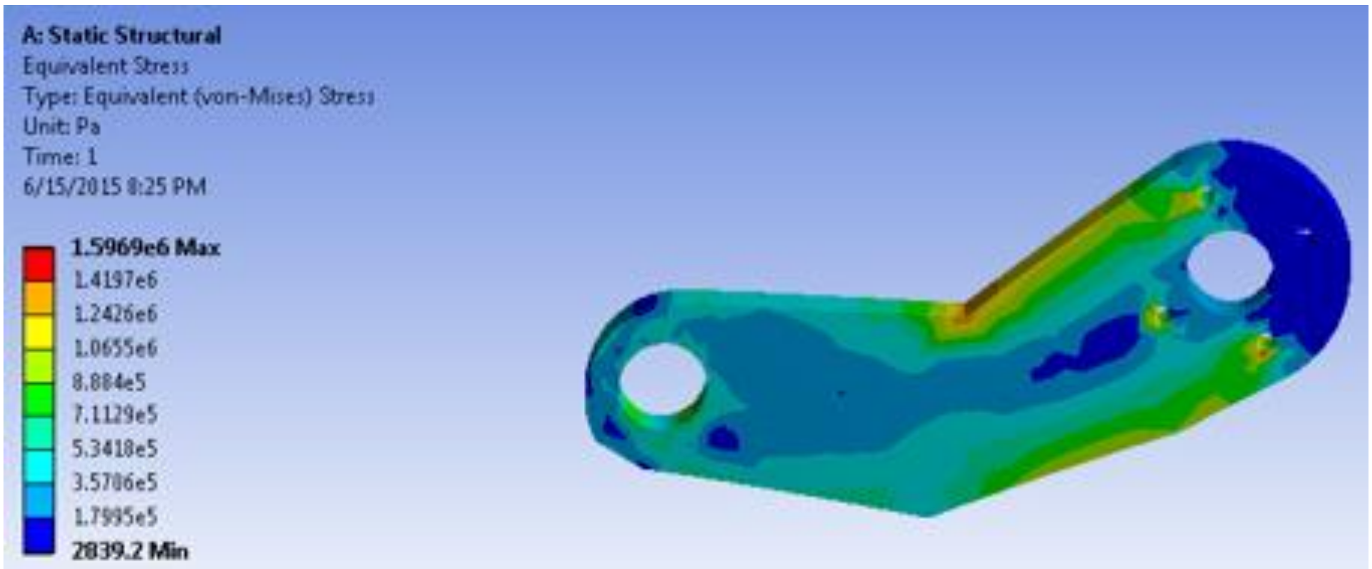

Figure 23 Directional Deformation

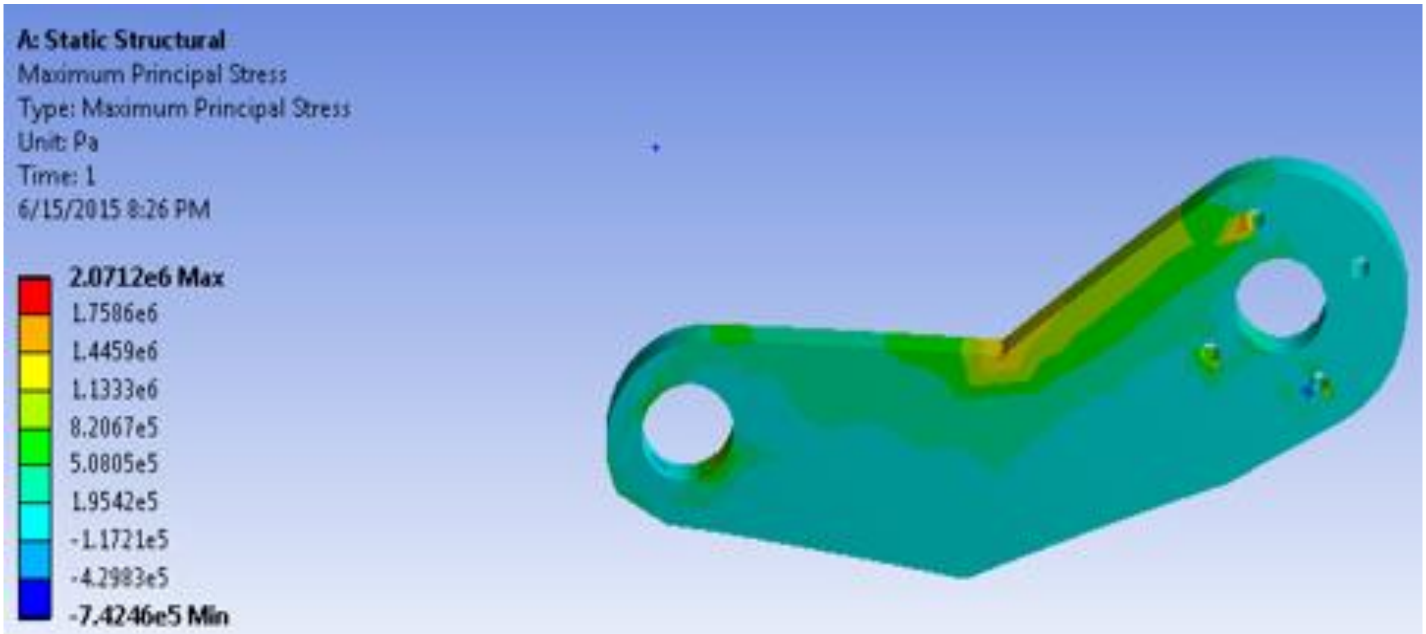

Figure 24 Maximum principal stress

Project

First Saved	Monday, June 15, 2015
Last Saved	Monday, June 15, 2015
Product Version	14.5 Release
Save Project Before Solution	No
Save Project After Solution	No

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\user\Desktop\Part2.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	8.1623e-002 m
Length Y	0.20256 m
Length Z	2.e-002 m
Properties	
Volume	1.9175e-004 m³
Mass	0.53115 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1

Nodes	4019
Elements	2192
Mesh Metric	Element Quality
Min	0.11919303043855
Max	0.998767043231672
Average	0.649191122198762
Standard Deviation	0.158286365235727
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\user\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*PartBody*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Aluminum Alloy
Nonlinear Effects	Yes

Thermal Strain Effects	Yes
Bounding Box	
Length X	8.1623e-002 m
Length Y	0.20256 m
Length Z	2.e-002 m
Properties	
Volume	1.9175e-004 m³
Mass	0.53115 kg
Centroid X	-1.131e-002 m
Centroid Y	-6.3785e-002 m
Centroid Z	1.e-002 m
Moment of Inertia Ip1	1.5027e-003 kg·m²
Moment of Inertia Ip2	1.8826e-004 kg·m²
Moment of Inertia Ip3	1.6556e-003 kg·m²
Statistics	
Nodes	4019
Elements	2192
Mesh Metric	Element Quality
Min	0.11919303043855
Max	0.998767043231672
Average	0.649191122198762
Standard Deviation	0.158286365235727

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 5
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	7.854e-003 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	4019
Elements	2192

Mesh Metric	Element Quality
Min	0.11919303043855
Max	0.998767043231672
Average	0.649191122198762
Standard Deviation	0.158286365235727

TABLE 6
Model (A4) > Mesh > Mesh Controls

Object Name	*Refinement*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Refinement	1

Static Structural (A5)

TABLE 7
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 8
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled

Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Max Number of Result Sets	Program Controlled
Analysis Data Management	
Solver Files Directory	C:\Users\user\Desktop\ted folder\Tedy st ana_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 9
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	4 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		-90. N (ramped)

Y Component		0. N (ramped)
Z Component		0. N (ramped)

Solution (A6)

TABLE 10
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 11
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 12
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Equivalent Stress*	*Maximum Principal Stress*
State	Solved			
Scope				
Scoping Method	Geometry Selection			
Geometry	All Bodies			
Definition				

Type	Total Deformation	Directional Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress
By	Time			
Display Time	Last			
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Orientation		X Axis		
Coordinate System		Global Coordinate System		
Results				
Minimum	0. m	-8.0486e-006 m	2839.2 Pa	-7.4246e+005 Pa
Maximum	8.0955e-006 m	6.282e-008 m	1.5969e+006 Pa	2.0712e+006 Pa
Information				
Time	1. s			
Load Step	1			
Substep	1			
Iteration Number	1			
Integration Point Results				
Display Option			Averaged	

Material Data

Aluminum Alloy

TABLE 13
Aluminum Alloy > Constants

Density	2770 kg m^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

TABLE 14
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0

TABLE 15
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength Pa
2.8e+008

TABLE 16
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength Pa
2.8e+008

TABLE 17
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3.1e+008

TABLE 18
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 19
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity W m^-1 C^-1	Temperature C
114	-100
144	0
165	100
175	200

TABLE 20
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress Pa	Cycles	R-Ratio
2.758e+008	1700	-1
2.413e+008	5000	-1
2.068e+008	34000	-1
1.724e+008	1.4e+005	-1
1.379e+008	8.e+005	-1
1.172e+008	2.4e+006	-1
8.963e+007	5.5e+007	-1
8.274e+007	1.e+008	-1
1.706e+008	50000	-0.5
1.396e+008	3.5e+005	-0.5
1.086e+008	3.7e+006	-0.5
8.791e+007	1.4e+007	-0.5
7.757e+007	5.e+007	-0.5
7.239e+007	1.e+008	-0.5

1.448e+008	50000	0
1.207e+008	1.9e+005	0
1.034e+008	1.3e+006	0
9.308e+007	4.4e+006	0
8.618e+007	1.2e+007	0
7.239e+007	1.e+008	0
7.412e+007	3.e+005	0.5
7.067e+007	1.5e+006	0.5
6.636e+007	1.2e+007	0.5
6.205e+007	1.e+008	0.5

TABLE 21
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm m	Temperature C
2.43e-008	0
2.67e-008	20
3.63e-008	100

TABLE 22
Aluminum Alloy > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7.1e+010	0.33	6.9608e+010	2.6692e+010

TABLE 23
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1

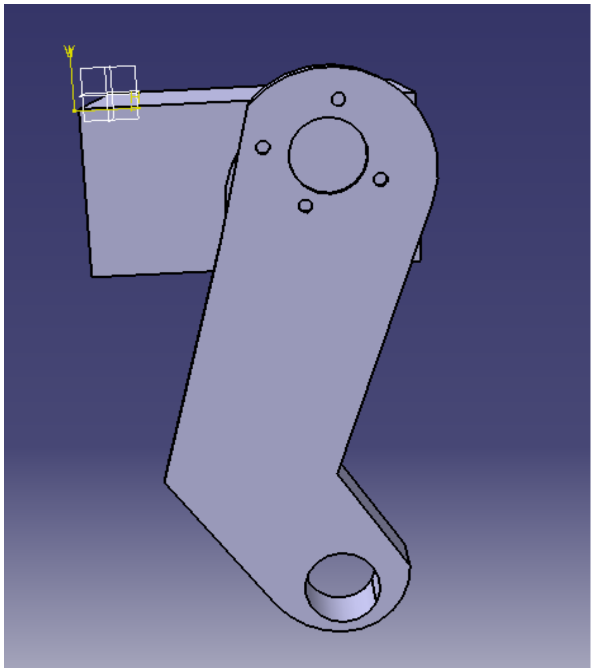

Figure 25: Brake actuator fitted to Servo Motor

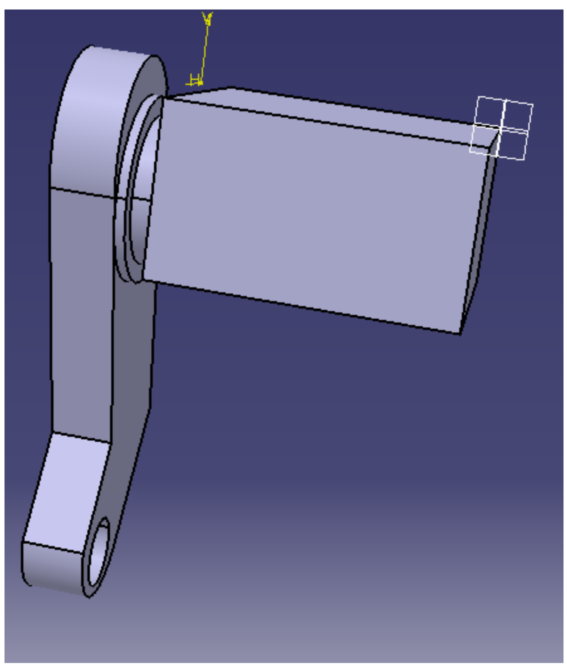

Figure 26: Brake actuator backside view

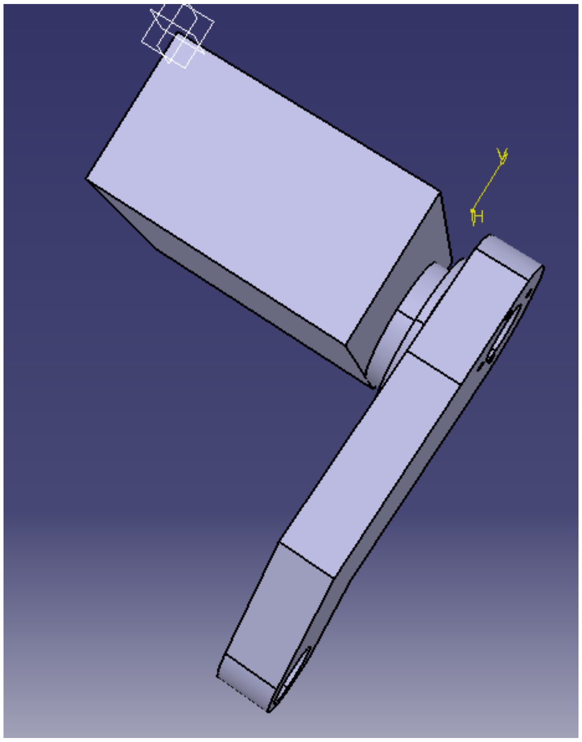

Figure 27: Brake actuator top view

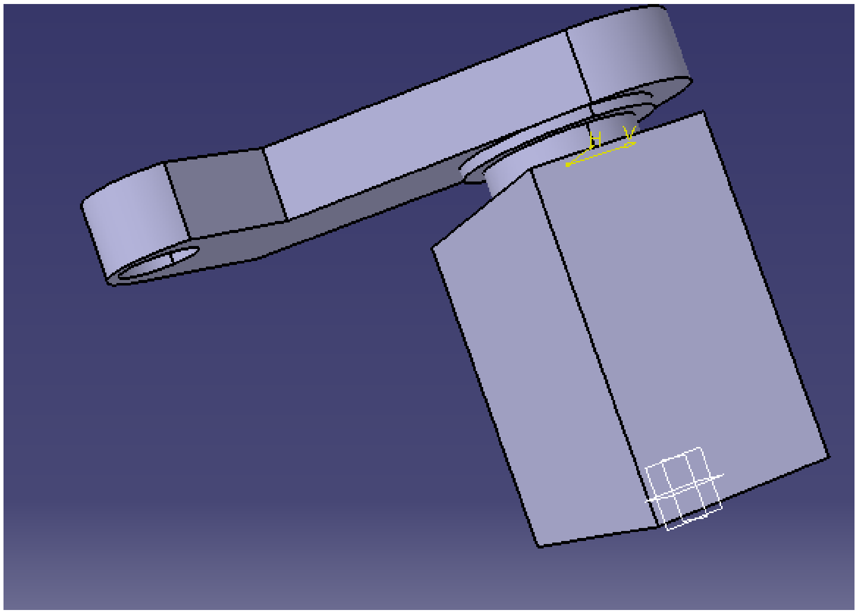

Figure 28: Brake actuator top and side view

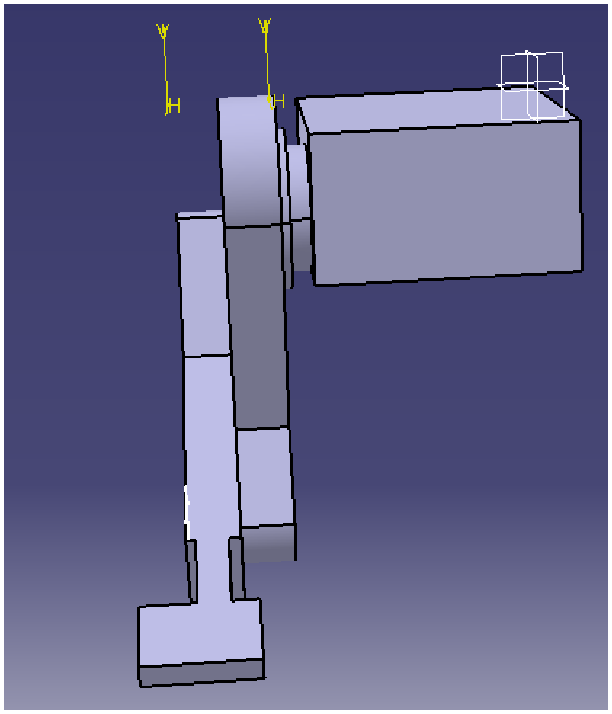

Figure 29: Brake actuator fitted to the brake pedal

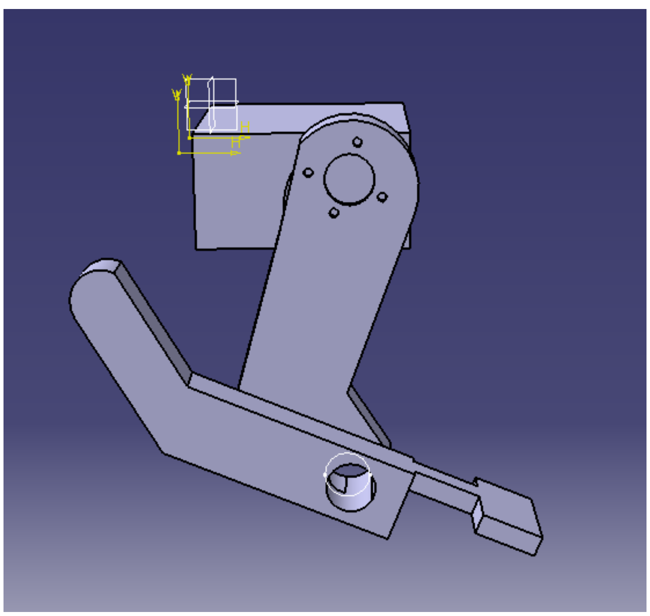

Figure 30: Front view of Brake actuator fitted to the brake pedal

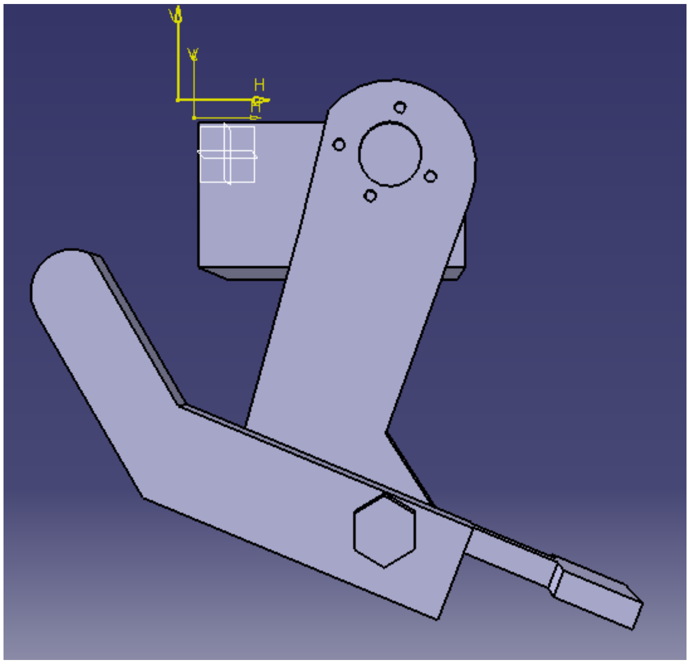

Figure 31: Front view of Brake actuator fitted to the brake pedal with a bolt

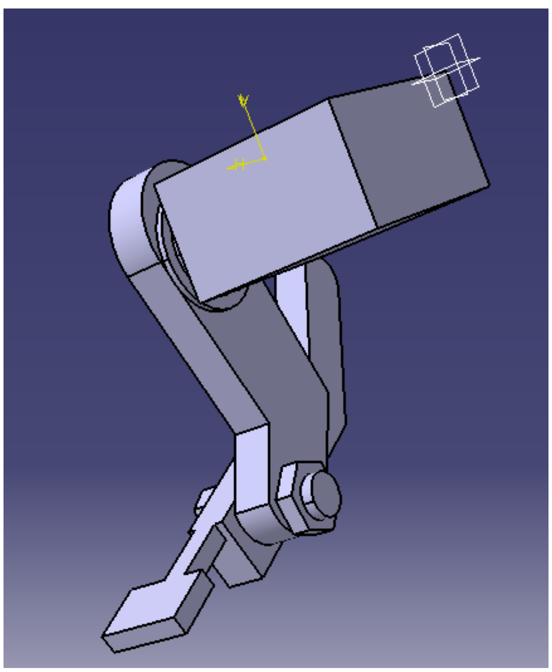

Figure 32: Backside view of Brake actuator fitted to the brake pedal with a bolt

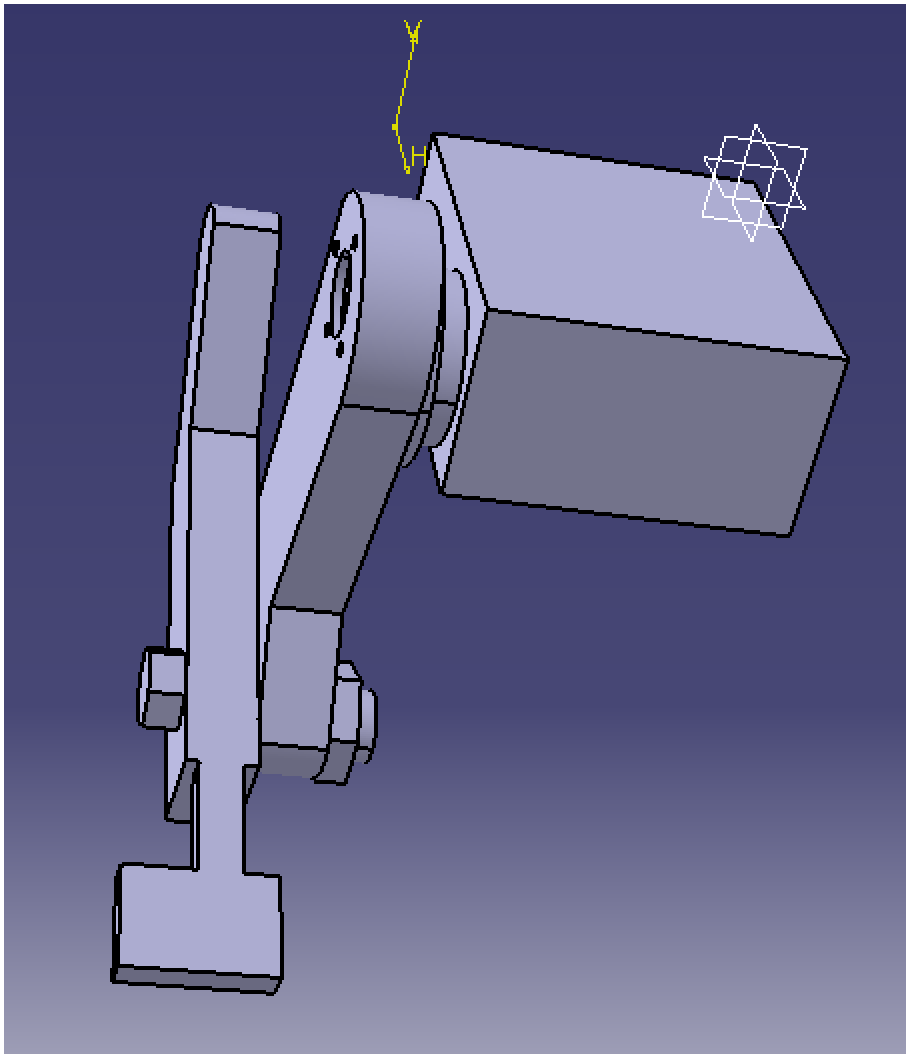

Figure 33: Side view of Brake actuator fitted to the brake pedal with a bolt

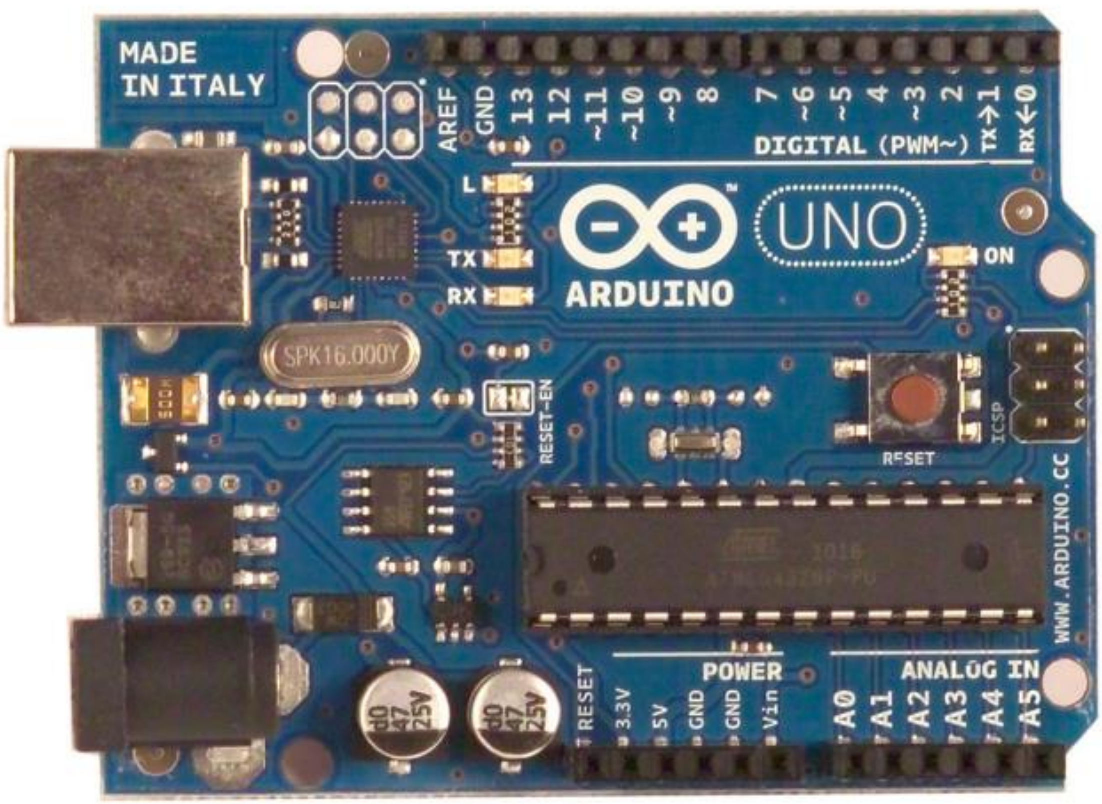

Figure 34: Arduino Uno microcontroller