Dual Operated Firefighting Robot

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Research Article

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Abstract

In this study, a dual operated firefighting robot was designed, fabricated and analyzed. The robot can be operated in both RC and automatic modes. The robot consists of three different types of system units- fire detection system, extinguishing system and communication system. The fire detection system uses flame sensors for detection of fire. The extinguishing unit consists of fire extinguisher cylinder mounted on the robot which can be controlled by the user through a remote. . The fire extinguisher is operated with the help of a relay circuit. The whole set up is controlled and monitored by the main controller or microprocessor. Using a belt drive enables the robot to climb stairs. The main chassis consists of 400mm*390mm aluminum profile. Four motors, each of 60 rpm, are used which provides adequate thrust for motion. The power supply for the functioning of robot is provided by a 12V, 7 AH battery. The compact design of the firefighting robot enables it to enter small or narrow space with ease. More over the dual operation ability of the robot helps to increase the overall efficiency of the robot.

Introduction

Fire incident is a disaster that can potentially cause the loss of life, property damage and permanent disability to the affected victim. They can also suffer from prolonged psychological and trauma. Fire fighters are primarily tasked to handle fire incidents, but they are often exposed to higher risks when extinguishing fire, especially in hazardous environments such as in nuclear power plant, petroleum refineries and gas tanks. They are also faced with other difficulties, particularly if fire occurs in narrow and restricted places, as it is necessary to explore the ruins of buildings and obstacles to extinguish the fire and save the victim.

Casualties and property damage from fire continue to exist in fire disasters and new measures are continuously introduced. One of the major hazards associated with firefighting operations is the toxic environment created by combustible materials. The four major risks are smoke, oxygen deficiency, elevated temperatures, and poisonous atmospheres. Additional hazards include falls and structural collapse that can exacerbate the problems encountered in a toxic environment. To combat some of these risks, fire fighters carry self-contained breathing apparatus.

The first step in a fire fighting operation is reconnaissance to search for the origin of the fire and to identify the specific risks. Yoshihiro et Al. [1] compared the firefighting skills of experts and novices. For the comparison, two sets of evaluation items are created on the basis of the fundamental tactics of firefighting- evaluating the reconnaissance activity and determining the water discharge point. It was concluded that the experts evaluate the reconnaissance areas in a multifaceted way whereas novices evaluate only a limited range of reconnaissance area as they cannot follow a multifaceted approach similar to experts. Several mobile robots have been implemented to carry out reconnaissance and dexterity operations in remote environments comprising of unstructured obstacles. Karo, a mobile robot, has been designed and implemented that exhibits high degree of mobility at the side of maintaining required dexterity and exploration capabilities for urban search and rescue (USAR) missions. It exhibits superior properties when compared to its counter parts [2]. Intelligent firefighting robots are an area of active research to reduce casualties. Several autonomous systems were developed for fire suppression with closed loop control. The advantages of autonomous systems are that they increase the effectiveness of firefighting tasks through advanced vision systems and image feedback support in low visibility environments [3]. An advanced version of this system involves an infrared image- based feedback control system, whose aims are to realize automatic aiming of the fire site and continuous fire tracking in the process of fire extinguishing through adjusting of the yaw angle of the fire monitor[4].

While a range of fire-fighting robots have been developed and put in action worldwide, they have not yet contributed greatly to the fight. Most robots assist only in small ways, helping fight fires from a distance or monitoring outside fire scenes. With high barriers and risks in fire extinguishment operations, technological innovations can be utilized to assist firefighting.

Material And Methods

Material selection and Design of Firefighting Robot

The robot was designed using SOLIDWORKS 2020.At this stage; the various limitations faced by the existing firefighting robot were taken into consideration such as limitation over transportation due to enormous size and weight of the robot, the need for external supply of fire extinguishing fluids and cost of manufacturing. The materials were selected so as to reduce the overall weight and improve the efficiency of the robot. Aluminium Bronze was selected for the fabrication of chassis of the robot, because of its high strength to weight ratio, high durability and anti-corrosive property. Bakelite sheet was chosen for the base of the robot, because of its high temperature withstanding capacity. The wheel of the robot was made using stainless steel.

Hardware Components involved

The ESP-32 microprocessor is used for controlling the various operations of the robot. It has lower power consumption and higher efficiency. The flame sensor module consists of a flame sensor (IR receiver), resistor, capacitor, potentiometer, and comparator LM393 in an integrated circuit. It can detect infrared light with a wavelength ranging from 700nm to 1000nm. The far-infrared flame probe converts the light detected in the form of infrared light into current changes. Sensitivity is adjusted through the onboard variable resistor with a detection angle of 60 degrees. The working voltage is between 3.3v and 5.2v DC, with a digital output to indicate the presence of a signal. Sensing is conditioned by an LM393 comparator. L298N motor driver unit is used to control the motors. It consists of an L298 Motor Driver IC, 78M05 Voltage Regulator, resistors, capacitor, Power LED, 5V jumper in an integrated circuit.12V Johnson motor of 60 rpm was used which is mechanically commutated electric motor powered from direct current (DC). It gives a massive torque of 25kgcm. It has a metal gearbox with 6mm shaft diameter and gearbox of diameter 37mm.The motor used for actuating the extinguisher is MG995 metal gear servo motor.

Working of the Robot

The robot consists of three different types of system units- fire detection system, extinguishing system and communication system. The fire detection system uses thermal sensors for detection of fire. The extinguishing unit consists of fire extinguisher cylinder mounted on the robot. According to the type of fire, the fire extinguisher can be changed. The Flame sensors are used by the robot to sense the temperature of its environment and move to the area of higher temperature. The robot is able to operate in two mode that is RC and Automatic mode. In RC mode, the robot can be controlled by using a remote. Remote is provided with a joystick and a switch, which is connected to a Wi-Fi module (ESP-32). Joystick can be used to control the movement of the robot and switch is used to actuate the fire extinguisher manually. Whereas, in Automatic mode the robot turns 360 direction and when it detects the flame, it moves in that particular direction to extinguish the flame.

Discussing about the connections in the Robot, main controller (Microprocessor) is used to control the four motors through a motor driver. The power supply for the entire robot is provided by a 12V 7AH Battery

Fabrication of the Prototype

The chassis of the prototype is made using the aluminium bronze. The aluminium bronze tube is cut into required dimension (400mm x 390mm) to form a rectangular frame and it is fastened by using screws. Also, L brackets are used to provide structural rigidity to the rectangular frame. The motor mount is fixed to the rectangular aluminium frame using screws. The motors are assembled on the chassis with the help of motor mounts. Wheels are then attached to the motor shaft. Bakelite sheet is attached to the top of the rectangular frame and all the hardware components including microprocessor, motor driver and flame detector sensor and are attached on it and connections are made. A covering, using Bakelite sheet, is given to the hardware components for its safety. The Fire Extinguisher is placed in a tilted position thereby the spot of its action can be varied. The belt drive of the robot is fixed and a pair of dummy wheels are attached in order to provide structural stability for the belt drive.

Module Development of Remote Controller

The joystick which is used to control the direction of motion of the robot and the control switch for actuating the extinguisher is soldered to a PCB along with the ESP-32 microprocessor. A cover is developed using 3D printing technology for the safety of the PCB and the components.

Development of Extinguisher Actuator

The actuator is made by combining 3D printed parts and is controlled by servo motor. The servo motor used is MG995 which can provide 10kg/cm at 4.8V, and 12kgcm at 6V. This servo motor can rotate approximately 180 degrees (60 in each direction).

Results And Discussion

Structural Analysis

The analysis is performed in ANSYS 2020 R1. The equivalent stress distribution diagram when a load of 60N is applied is shown in Fig. 8. Stress Concentration was found to be more active at the sides and at the junction of wheel and motor shaft. The maximum stress was found to be 2.487MPa at which the part fails. The minimum stress was found to be 1.4215×10^{-3}MPa.

From the stress analysis, it is seen that the maximum stress that the part can withstand was 2.487MPa whereas the tensile yield strength of aluminium bronze is 49.7MPa. Therefore, we can conclude that the aluminium bronze used for fabrication is completely safe as it is found to be within the elastic limit. The tensile ultimate strength was found to be 414MPa at which it fails. Also, the tensile strength of Bakelite and Stainless Steel was found to be 50MPa and 243MPa respectively (Table 2 and Table 3). Thus, it can be concluded that both Bakelite and Stainless Steel are within the elastic limits and is completely safe. Both the Bakelite and Stainless Steel has ultimate tensile strength of 62.1MPa and 46MPa respectively at which they fail.

When a load of 60N was applied, the maximum equivalent elastic strain was found to be 5.6752×10^{-4}. The minimum was found to be 1.3741×10^{-8} and the average stress was1.898×10^{-6}.

Deformation when a load of 60N was applied is shown in the Fig. 10. The deformation was found to be more at the centre and the maximum deformation was found to be 0.94088 mm. The minimum deformation was 0 mm and the average deformation was 1.357×10^{-3} mm.

Thermal Analysis

The normal building fire temperature is in the range of 534° C to 815° C. The Aluminium Bronze used here has a melting point of 1190° C - 1215° C. The Aluminium Bronze profile has the ability to withstand the temperature caused by the building fire. Moreover, the whole system will be covered by the material Bakelite which is high resistant to heat and has a melting point 1800° C.

From Fig.11,the maximum total heat flux was found to be 7.8208×10^{-12} W/mm^2 and the minimum total heat flux was found to be 1.147×10^{-17} W/mm^2.

The figure 12 shows the temperature plot in steady state, when a maximum temperature of 820° C wss applied. Aluminium Bronze,Bakelite, and Stainless Steel was found to withstand the normal building fire, since these materials have a melting point of 1190° C, 1800° C, 1510° C respectively which is greater than the normal building fire temperature, ranging from 534° C to 820° C. It indicates that the part is thermally stable.

Material Properties

Table 1Aluminium Bronze Properties

Properties	Values
Density	2.77x10-6 Kgmm3
Thermal Conductivity	0.157 Wmm-1C-1
Coefficient of Thermal Expansion	2.38x10-5 C-1
Tensile Yield Strength	49.7 MPa
Tensile Ultimate Strength	414 MPa

Table 2 Bakelite Properties

Properties	Values
Density	1.3x10-6 Kgmm-3
Thermal Conductivity	1.4x10-3 Wmm-1C-1
Coefficient of Thermal Expansion	125 μstrain/°C
Tensile Yield Strength	50 MPa

Table 3Stainless Steel, Austenitic Properties

Properties	Values
Density	7.9x10-6 Kgmm-3
Thermal Conductivity	1.5x10-2 Wmm-1C-1
Coefficient of Thermal Expansion	1.7x10-5 C-1
Tensile Yield Strength	243 MPa
Tensile Ultimate Strength 546 MPa	

Also the tensile strength of Bakelite and Stainless Steel was found to be 50MPa and 243MPa respectively (Table 2 and Table 3). Thus, it can be concluded that both Bakelite and Stainless Steel are within the elastic limits and is completely safe. Both the Bakelite and Stainless Steel has ultimate tensile strength of 62.1MPa and 46MPa respectively at which they fail.

Aluminium Bronze, Bakelite, and Stainless Steel was found to withstand the normal building fire, since these materials have a melting point of 1190° C, 1800° C, 1510° C respectively which is greater than the normal building fire temperature, ranging from 534° C to 820° C.

Conclusion

The dual operated firefighting robot was designed and analysed. This proposes a great chance for automation and will be useful at places where humans cannot reach or is dangerous. The operator is able to extinguish fire using remote control from longer distances. Also, the robot can be switched to automatic mode. The robot can sense fire accurately in a short time. This robot can be used at a place that has a small entrance or in small spaces since it has a compact structure. The operator is able to extinguish fire using remote control from longer distance thus it ensures the safety of the operator who operates the robot.

The current design overcomes the limitations of transportation of robot from one place to another that is faced by most of the robots available now.

The structural stability of the robot was found to be in good condition. The von Misses Stress for the entire system is found to be minimum of 1.4215x10-3MPa and a maximum of 2.487MPa. The deformation was at the centre of the structure and maximum deformation was found to be 0.94088mm and a minimum of 0mm. And the strain acting on the robot is minimum 1.3741x10-8 to a maximum 5.6752x10-4. The entire robot was found to be thermally stable and will not get damaged in a fire incident.

Actuation Delay Time (ADT) of the extinguisher was found out to be less than 1 second. The slope of extinguisher various spraying position was found out by trial and error method and a slope of 50° was selected. The robot was tested to climb slopes, and it was found to climb a maximum slope of 40°.

Abbreviations

USAR: Urban Search and Rescue; ADT: Actuation Delay Time .

Declarations

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Authors' contributions

All the authors contributed equally in the fabrication ,design and analysis of the robot.

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Availability of data and materials

The data and source code used to support the findings of this study are avail- able from the corresponding author upon request.

Competing interests

The authors declare that they have no competing interests.

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Figures

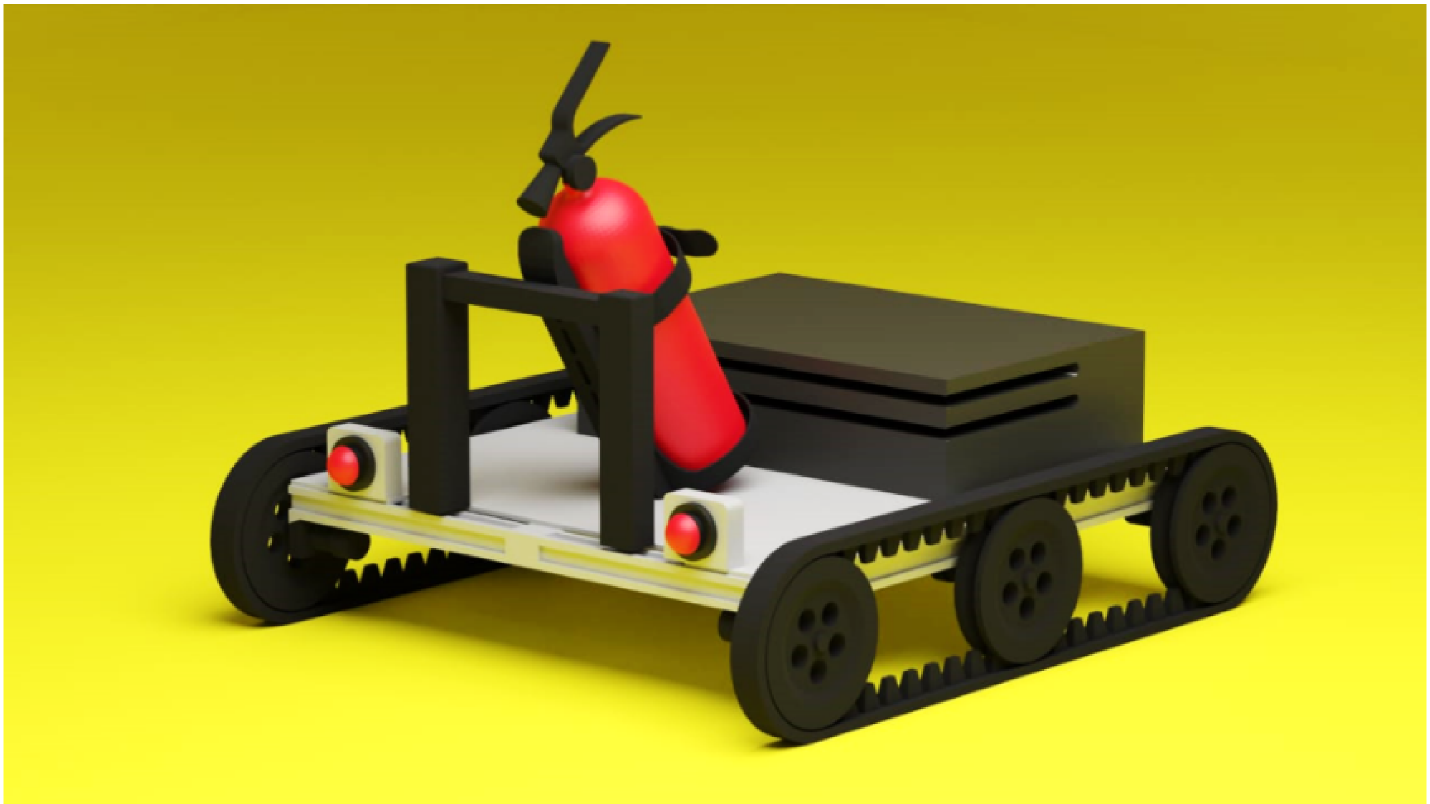

Figure 1

3D model of the Robot

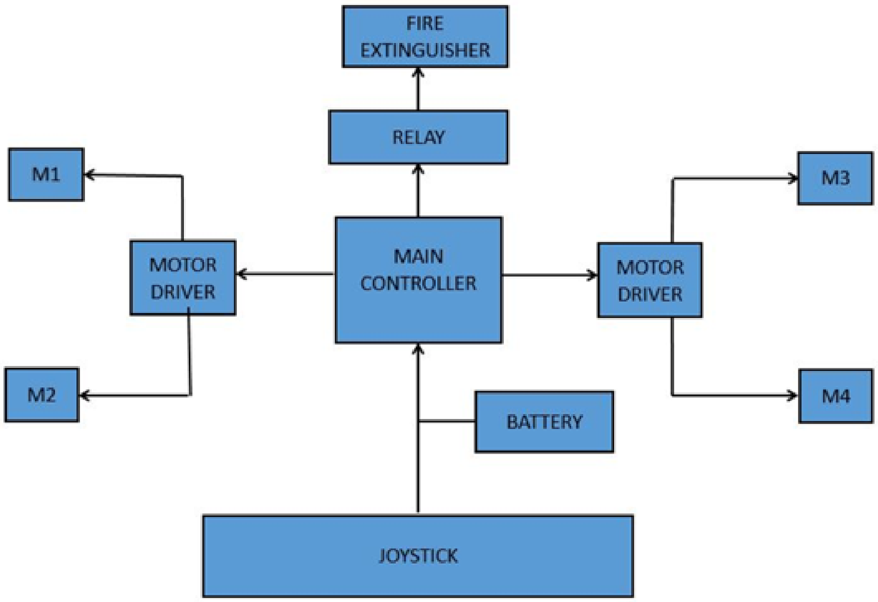

Figure 2

Block Diagram of Working

Figure 3

Assembly with Belt

Figure 4

Assembly without Belt

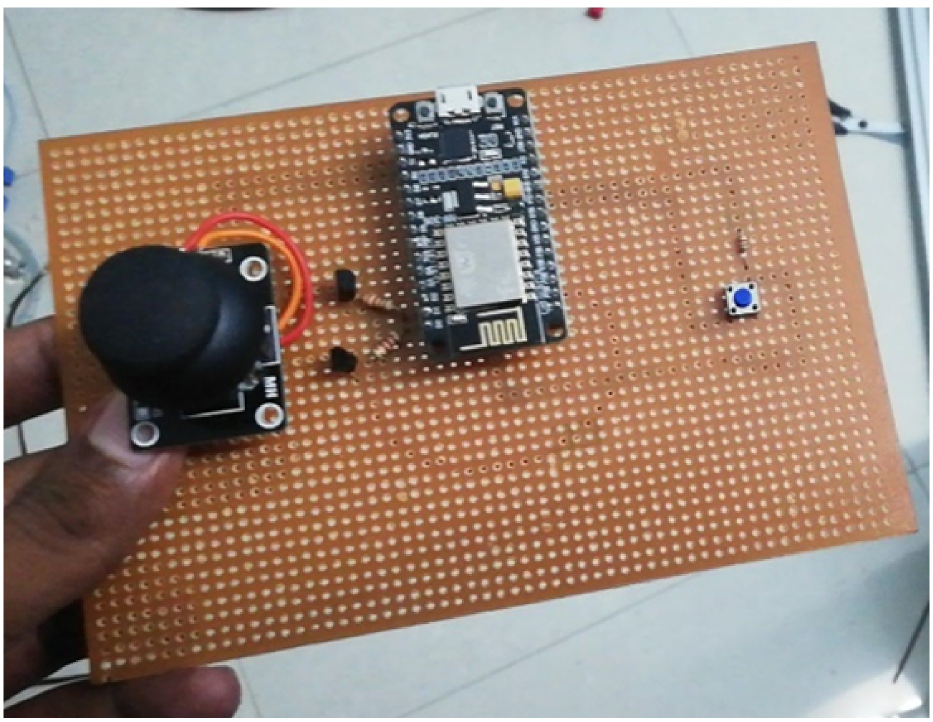

Figure 5

PCB and Components

Figure 6

Remote Controller

Figure 7

Actuator of Extinguisher

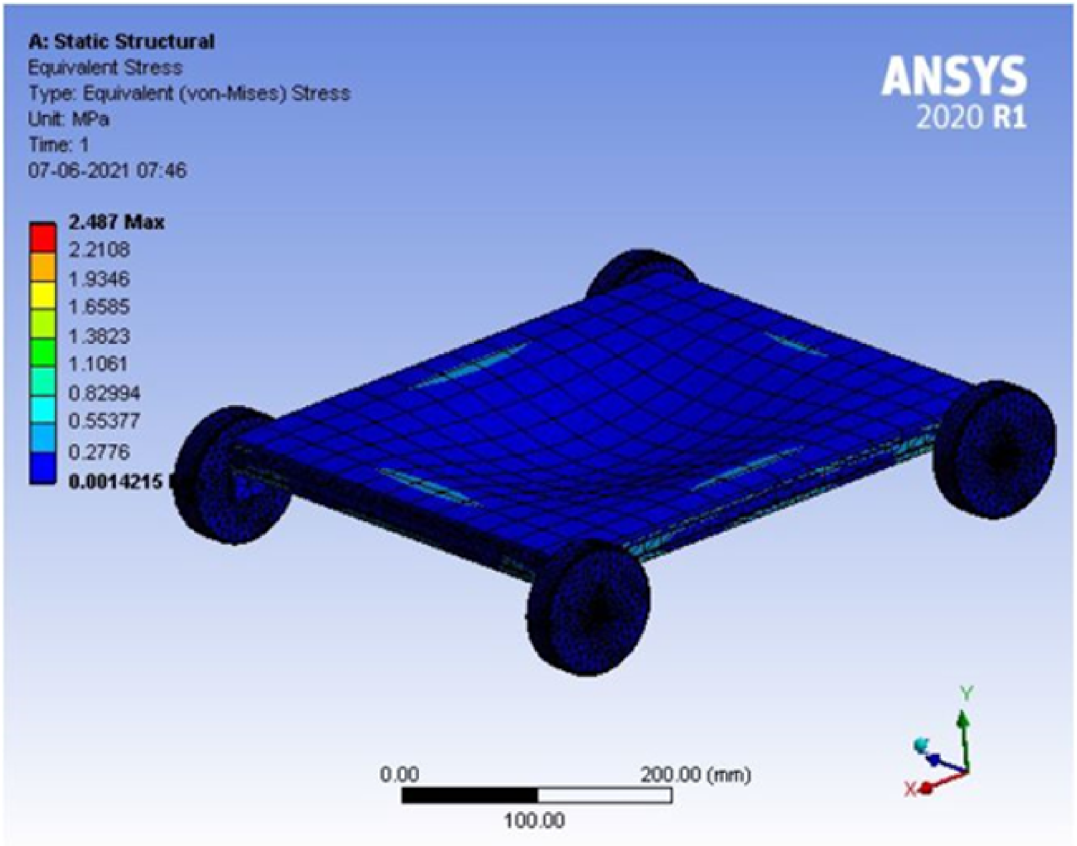

Figure 8

Equivalent Stress Diagram

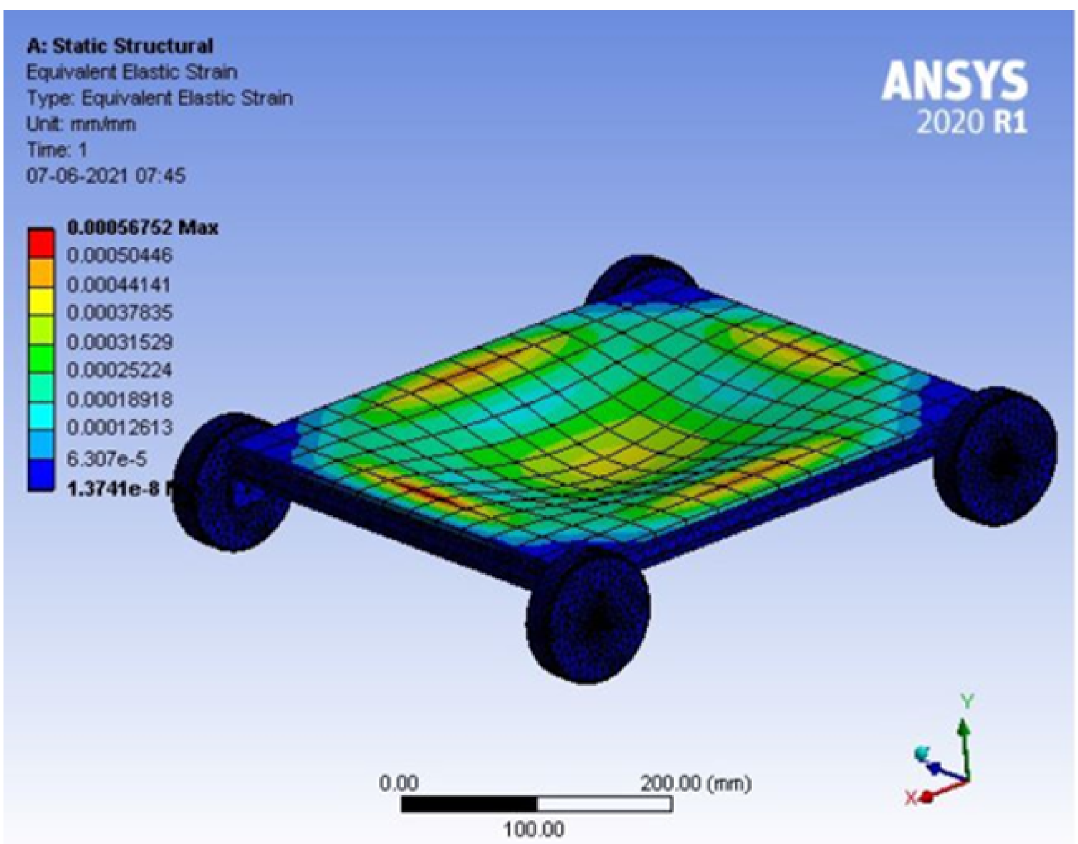

Figure 9

Equivalent Elastic Strain Diagram

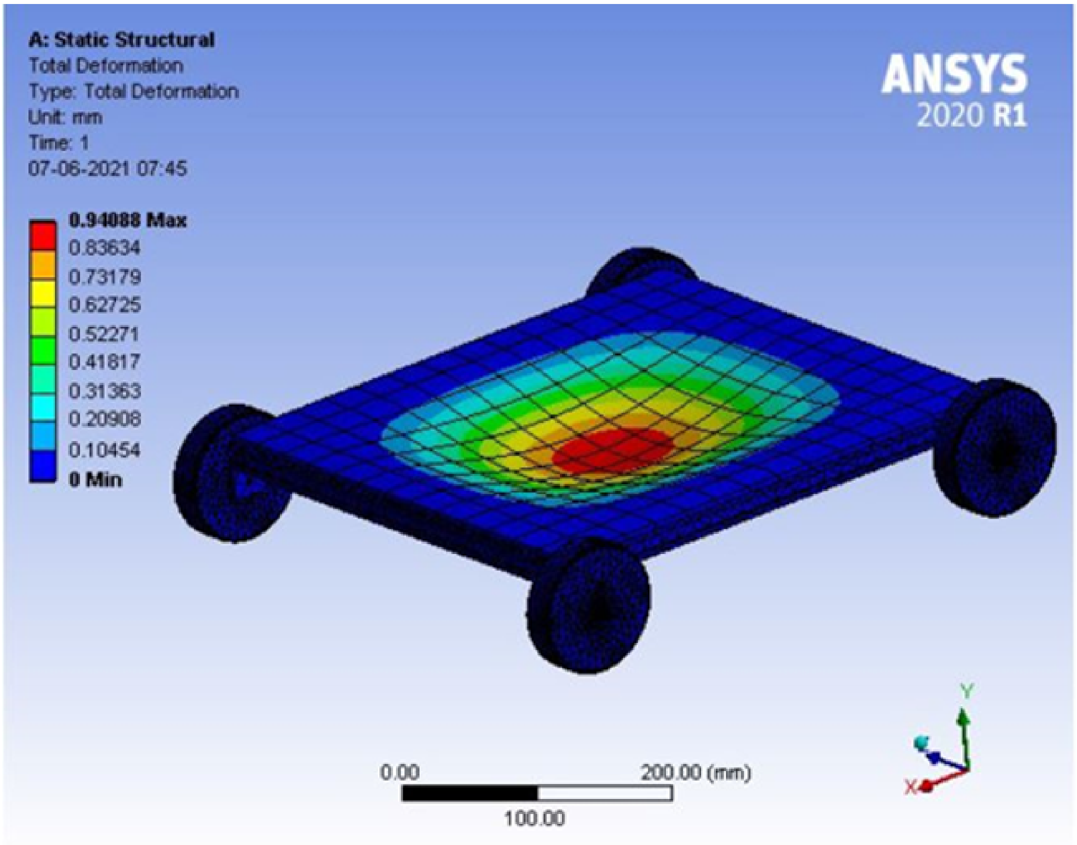

Figure 10

Deformation Diagram

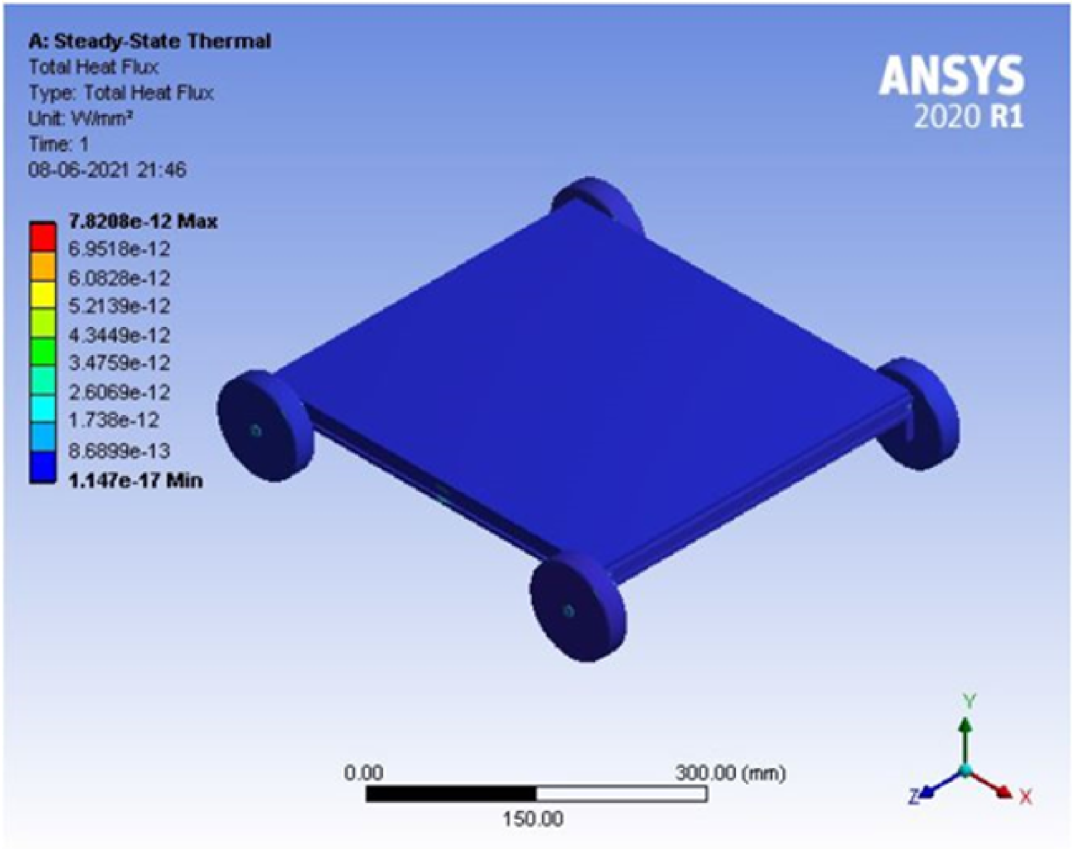

Figure 11

Total Heat Flux in Steady State

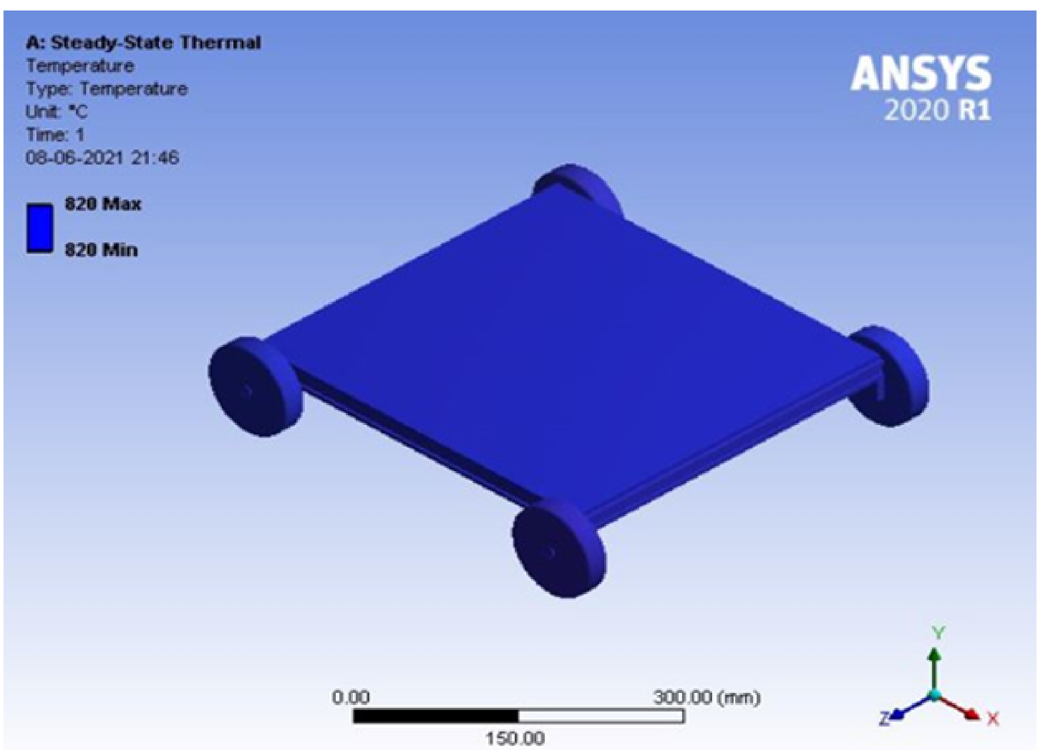

Figure 12

Steady State Temperature Plot