Development of Autonomous Mobile Robot coupled with Obstacle Avoidance, Path Planning and Localization

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Abstract

The current investigation styles the whole design, development, and testing process for an autonomous mobile robot with an acrylic base. The most significant constituents of the research are the creation of the virtual environment and testing in Gazebo, the design and simulation in SolidWorks, and the integration of cutting-edge navigation algorithms into the mobile robot. The focus has been provided on designing and simulating the physical construction of the mobile robot in the first phase using SolidWorks simulation. Due to its affordability, adaptability, and light weight, acrylic is chosen as the robot basis. In the second stage, a virtual environment is built using the robust robotics simulation package Gazebo. A thorough test and validation of the navigational skills of the robot is done by simulating actual settings and conditions. The simulated setting offers a secure and economical platform for assessing the robot's performance, spotting possible problems, and fine-tuning its navigational algorithms. In the last stage, the importance on integrating state-of-the-art navigation algorithms into the control system of the mobile robot is prioritized. The complete set of autonomous navigation, obstacle avoidance and path planning coupled with localization is made possible by induced algorithms. The efficient and autonomous operation of the robot in a variety of contexts depends on the effective integration of these algorithms.

Keywords: Gazebo, SolidWorks Simulation, Navigation algorithms, Obstacle avoidance, Path planning, Localization, Control system

1. Introduction:

The contemporary developments in robotics, particularly those involving autonomous systems, hold great potential for applications in a range of fields, including industry, healthcare, and exploration. The autonomous navigation, which enables robots to analyze their environment, create plans, and perform tasks independently, is a key element [4]. To achieve autonomy, complex components like as actuators that adapt to changing environments, perception algorithms, and decision-making frameworks must be integrated. The main challenges in autonomous navigation include perception and sensing, precise localization and mapping, effective path planning, robustness and safety, and human-robot interaction [6]. To overcome these challenges, an interdisciplinary strategy integrating expertise in mechatronics, robotics, computer vision, machine learning, and control system is essential.

The current research explores the most modern methods and technology for creating autonomous mobile robots through theoretical discussions, experimental research, and practical applications. Sensor fusion, localization, route planning, mobility control, safety measures, and human-robot communication are all given a lot of attention. With time, the potential for autonomous mobile robots that employ AI, machine learning, and cutting-edge sensing technologies to revolutionize a number of industries and enhance the quality of our everyday lives will only grow. The aim of this manuscript is to inspire researchers of all analysis capabilities to think about forthcoming customs for autonomous robots.

2. Literature Survey:

N. Herrera, J. Li et. al. [1] has presented a method to enhance the toughness of bacterial cellulose nanofibrils by sizing them with poly (ethylene glycol) to improve their tensile strength and impact strength, thereby enhancing composite applications. S. Kushwah, A. Rajpurohit, et. al. [2] has researched and summarized Essential fracture work (EWF) which is used to characterize stress resistance in ductile polymers and structures. It splits fracture-associated energy into two sections, evaluating crack propagation fractures and measuring precise fracture work based on ligament length. D. Wloch, N. Herrera, and K.-Y. Lee [3] has produced optically transparent BC/acrylic composites, with improved impact strength and morphology. Mercerisation of bacterial cellulose nanofibrils produces ductile BC nanopaper with lower tensile modulus and strength which is explained with necessary data for our testing process. W. K. Sleaman, A. A. Hameed, and A. Jamil [4] presented an internal analysis algorithm for mobile robots, combining convolutional neural network layers and hierarchical decision-making. Their system, trained on low-cost depth camera data, achieves autonomous analysis and autonomous navigation, with 77% accuracy in indoor experiments. H. Liu et al. [5] proposed an autonomous rail-road amphibious robotic system for railway inspection and maintenance tasks, offering flexible job location access, low costs, and reduced track network possession. Their system integrates hardware and software, demonstrating high technological readiness for autonomous maintenance and intelligent asset management. I. Nizar and M. Mestari [6] presented a novel approach for safe autonomous navigation and path planning for a four-wheel robot using the Decomposition-Coordination (DC) technique. The robot generates optimal paths in real-time, corrects for obstacles, and uses collision avoidance.

S.-E. Oltean [7] proposed a low-cost mobile robot platform with a fixed four-wheel chassis, Raspberry Pi and Arduino Uno interfaces, and a DOF robotic arm for 2D environments. The Internet of Things (IIoT) aims to integrate multiple technologies to enhance business services across industries. An IoT platform with an intelligent navigational robot uses machine learning, achieving learning accuracy exceeding 0.98 which is effectively said by S. Harapanahalli, N. O. Mahony, et. al. [8]. L. C. Básaca-Preciado et.al. [9] proposed a practical autonomous mobile robot navigation system using dynamic triangulation for obstacle avoiding tasks. Their system integrates 3D laser scanning technical vision and mobile robot navigation systems, improving laser ray alignment, parasitic torque, and friction reduction. S. Raikwar, J. Fehrmann, and T. Herlitzius [10] proposed a stable navigational algorithm for an orchard robot in a GNSS-denied environment. Their model uses input driving coordinates and vehicle state from wheel and steering encoders. Verified in real and simulation environments, the model provides a realistic approach with minimal sensor interaction. Y. Bai, B. Zhang et.al. [11] reviewed the research advances in autonomous vehicle and robot navigation in agricultural environments, focusing on machine vision technology's potential for real-time and accurate navigation. They discuss key visual navigation information processing technologies, application, challenges, and future development of vision sensor technology. S. Zhao and S.-H. Hwang [12] proposed a new Complete Coverage Path Planning (CCPP) scheme for robot operating systems, improving the coverage ratio by 98% through sub-area division algorithms and dynamic tracking. M. U. Farooq et.al. [13] reviewed the energy solutions for terrain-based mobile robots, highlighting prospects and research gaps, and provides a comparison of power techniques for autonomous mobile robots which are gaining market attention for their efficient, precise, and streamlined workflow. A. Loganathan and N. S. Ahmad [14] reviewed the various path planning strategies, analyzing strengths, shortcomings, and practical implementation challenges which provides guidance for future research. S. Macenski, T. Moore, D. V. Lu et.al. [15] presented a robust navigation system for a robot, demonstrating its ability to complete 26.2 miles of autonomous navigation in an office environment using an efficient Voxel-based 3D mapping algorithm. D. McNulty, A. Hennessy et.al. [16] discussed the current and future of advanced autonomous mobile robots (AMR) specifications. AMR are crucial for smart manufacturing, providing flexible work environments. They require high power for tasks like lifting and transporting, and require lithium-ion batteries for long-term power demands. X. Li, L. Wang et.al. [17] reviewed the ant colony algorithms that combine robot grid map modeling with image processing, converting non-standard actual environment maps into standard grid maps. This method is adaptable, intuitive, and suitable for various maps. D. T. Fasiolo, L. Scalera et.al. [18] reviewed the current technologies for autonomous mapping in agriculture, focusing on ground mobile robots, sensors, localization techniques, and artificial intelligence potential.

3. Methodology:

The motive of current investigation is to develop a reliable localization and mapping system that allows the robot to accurately determine its position and orientation in real-time, even in GPS-denied or GPS-degraded environments commonly encountered in military/defines scenarios. The objectives are to enable the robot to exhibit collaborative behavior by integrating communication capabilities and coordination algorithms with other robots or human operators, facilitating team-based missions and enhancing situational awareness, optimize the robot's energy consumption and autonomy to ensure prolonged operational endurance, enabling extended missions and reducing the need for frequent recharging or refueling in remote or hostile environments with Sensor Fusion and SLAM, Communication and Coordination, Energy Efficiency and Autonomy (Low-Power Components, Battery Management, Energy Harvesting, Intelligent Path Planning), Redundancy and Robustness, Human-Robot Interface, Adaptive Algorithms.

3.1 SolidWorks Analyzation

One of the stages in the design and development of a mobile robot for autonomous navigation is conceptualization. Other phases include mechanical design, electrical and electronic integration, and software development. Such a robot is mechanically designed and analyzed using SolidWorks, a well-known 3D CAD (Computer-Aided Design) application. During the idea stage, engineers and designers create rough sketches of the robot's purpose, size, shape, simulation and critical features. SolidWorks was used to create the 3D models of the robot, enabling precise visualization and design iteration. This program aids in the development of the robot's chassis, wheels, and other mechanical components. Engineers may check for stress points, structural integrity, and compliance with all relevant specifications. Stress, strain, and displacement analysis for acrylic sheets is crucial in engineering and design applications to ensure the material's structural integrity and performance under various loads and conditions. Acrylic sheets are frequently used because of their strength, clarity, and light weight.

3.2 Gazebo Testing

The goal and needs of the robot must first be established. This entails determining the area it is meant for, any obstacles it could run into, the appropriate speed and mobility, and any particular duties it must carry out on its own. Choosing the right sensors and actuators is crucial throughout the hardware design process. Cameras, lidar, ultrasonic sensors, and inertial measurement units (IMUs) are typical sensors used in autonomous navigation. Wheels and motors for mobility might be part of the actuators.

A crucial part of the project is the creation of the software stack. This involves developing algorithms for planning, perception (processing sensor data), and control (decision-making based on sensor data). For this reason, well-known frameworks and technologies like ROS (Robot Operating System) are widely employed. The software must be set in order to interact with the hardware components, which must be placed within the robot's chassis. For reliable sensor data to be obtained, calibration is essential.

3.3 Gazebo Virtual Environment Creation and Testing

The integration of hardware and software components a key component of many modern systems, particularly in the context of autonomous navigation, it is which includes applications like a self-driving cars, drones, and robots. Achieving seamless hardware and the software integration in essential for the reliable and secure functioning of these systems. Below, I will go into further detail on how this integration is carried out.

3.4 Testing and Validation

Testing and the validation are crucial stages that must be a completed before a robotic system can be a developed and deployed. In the context of the Gazebo simulation, these processes are an essential for the assessing a robot's performance, capabilities, and resilience before it is used in real-world in the situations.

4. Results and Discussion

The investigation led to involvement of testing and validation. We executed testing in SolidWorks simulation for hardware choices then for working under different condition we simulate in robot operating system using gazebo. The main factors that are responsible for testing the materials are displacement changes with respect to various factors due to stress and strain acting on the material. The minimum stress the base can handle should be 1.324e+08 as shown in Figure 1.

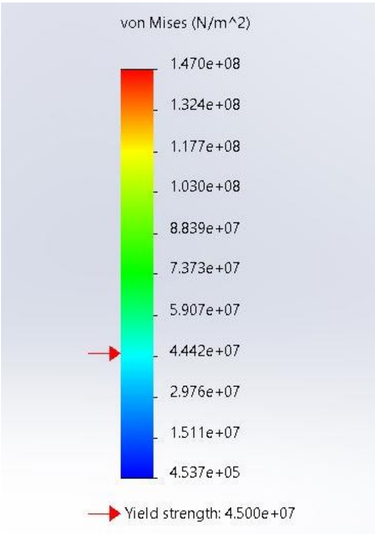

Figure 1 Yield Strength of the chosen criterion

The ability of the material under the various condition is checked and the output/ reaction of base is shown with the above indication. The results are projected in Figure 2.

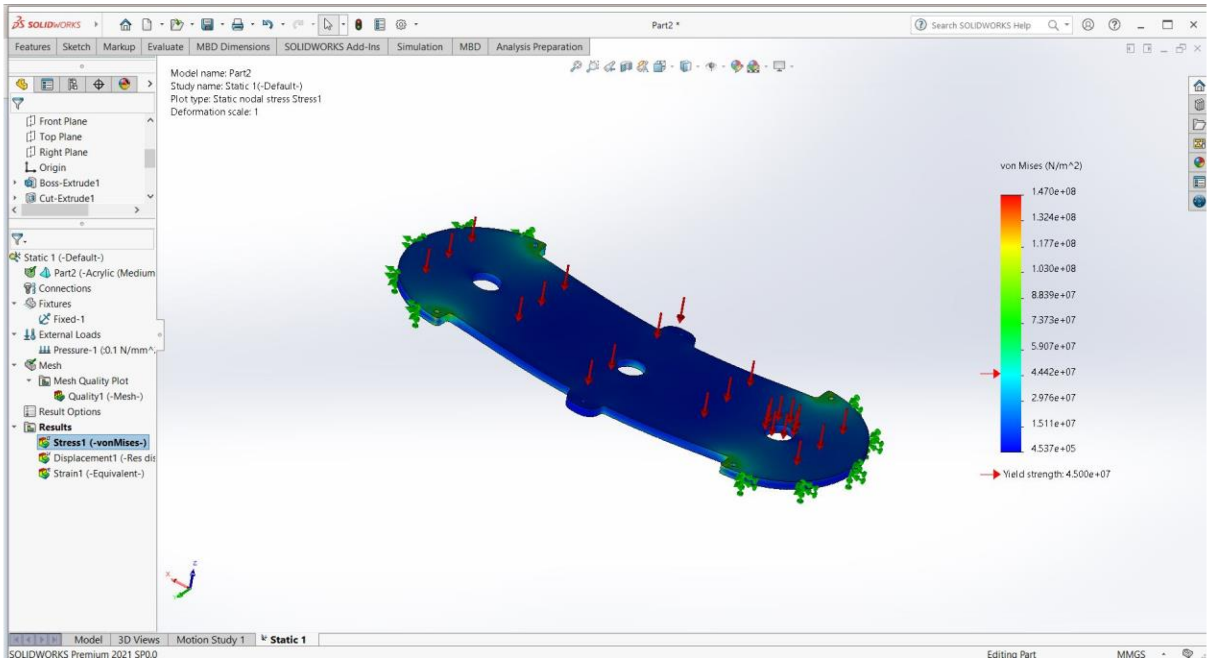

Figure 2.1 Stress acting on acrylic sheet

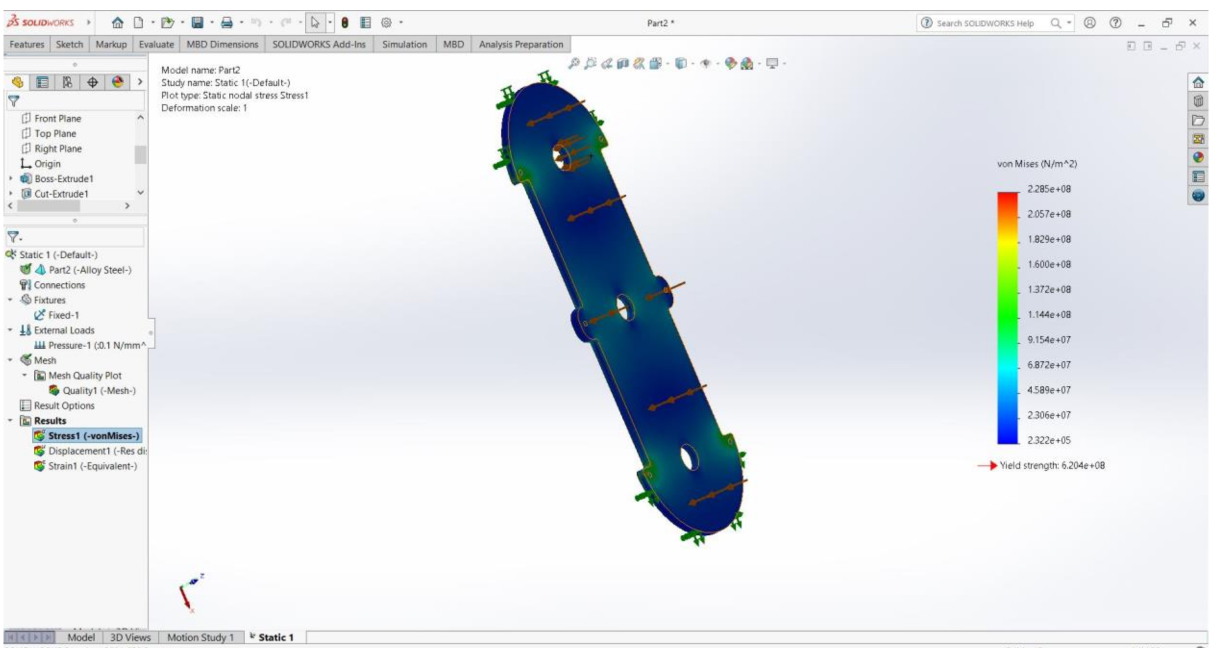

Figure 2.2 Stress acting on Alloy Steel

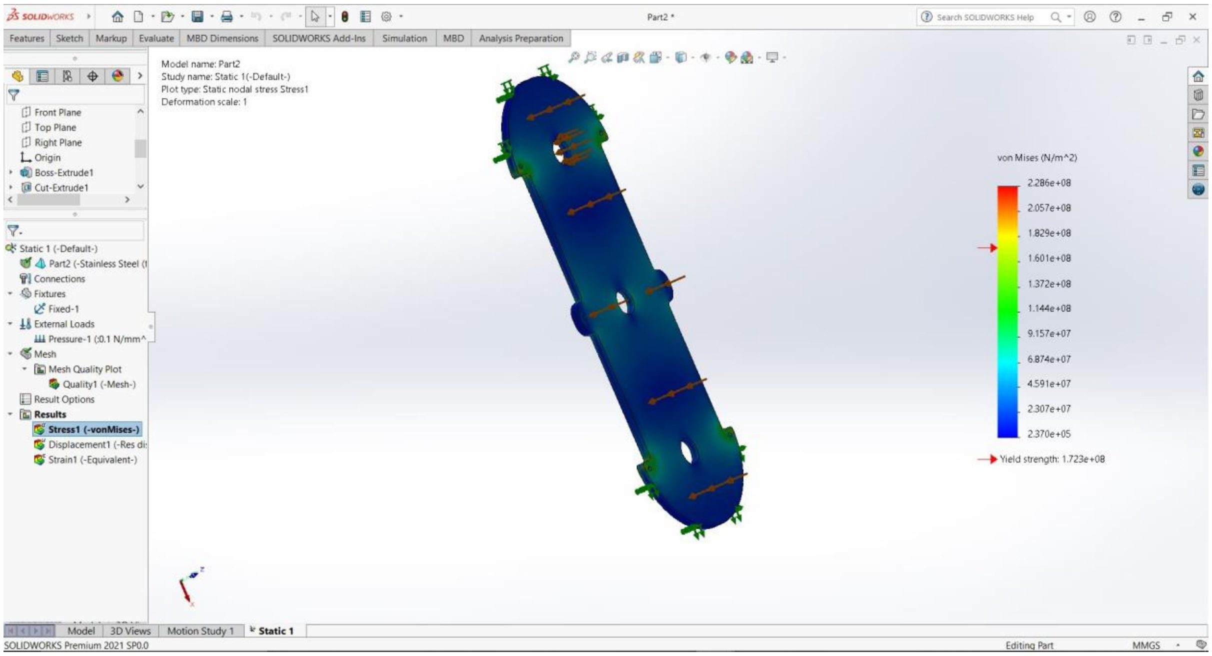

Figure 2.3 Stress acting on Stainless steel

From the choice of components, the minimum stress the base can handle should be 1.324e+08. For this condition acrylic sheet, alloy steel, stainless steel comes under this need, with the respective maximum stress carrying capacities of 1.470e+08, 2.285e+08, 2. 286e+08.The minimum strain the base can handle should be 2.817-02.

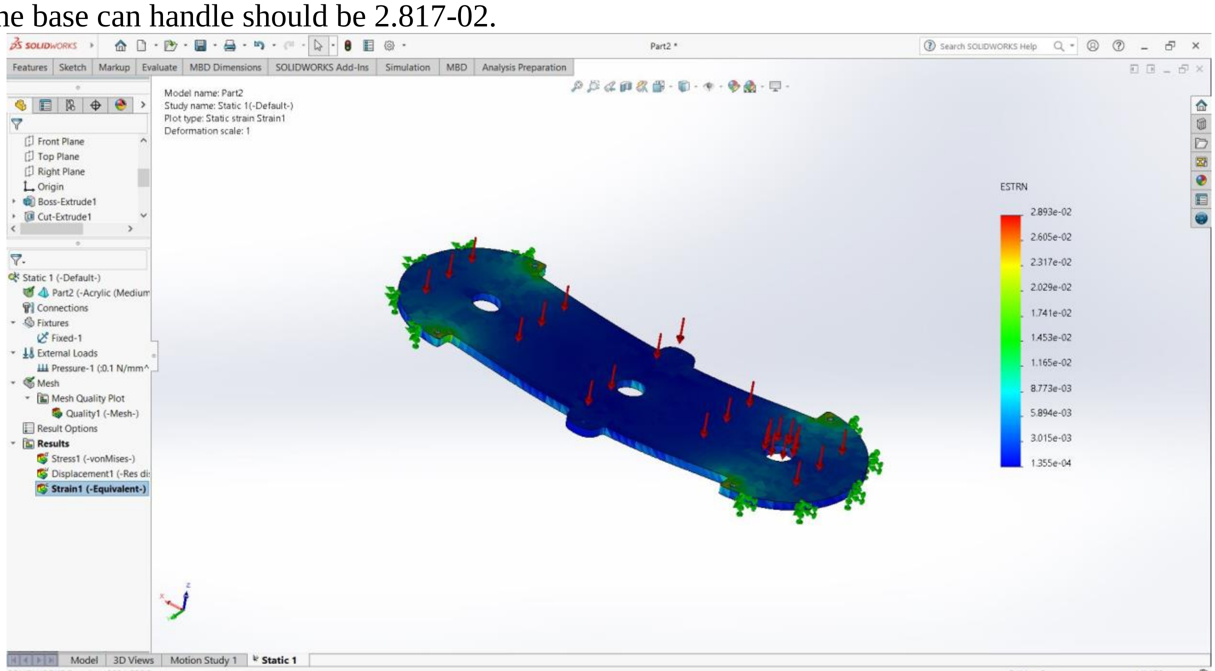

Figure 2.4 Strain acting on acrylic sheet

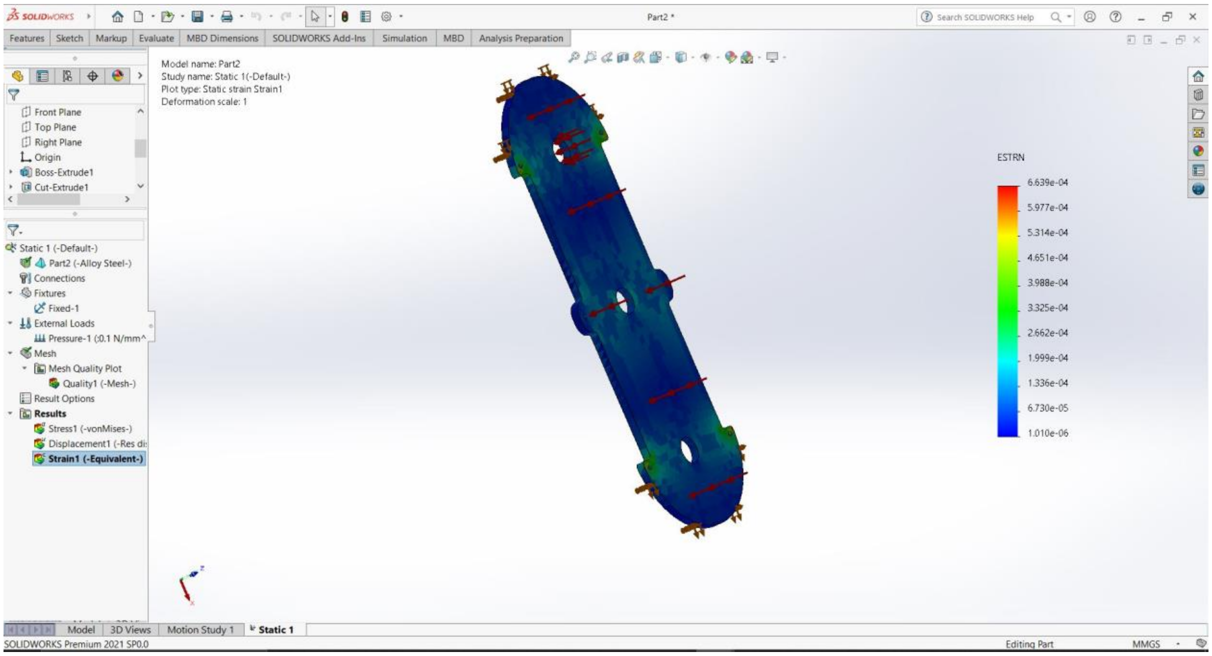

Figure 2.5 Strain acting on Alloy steel

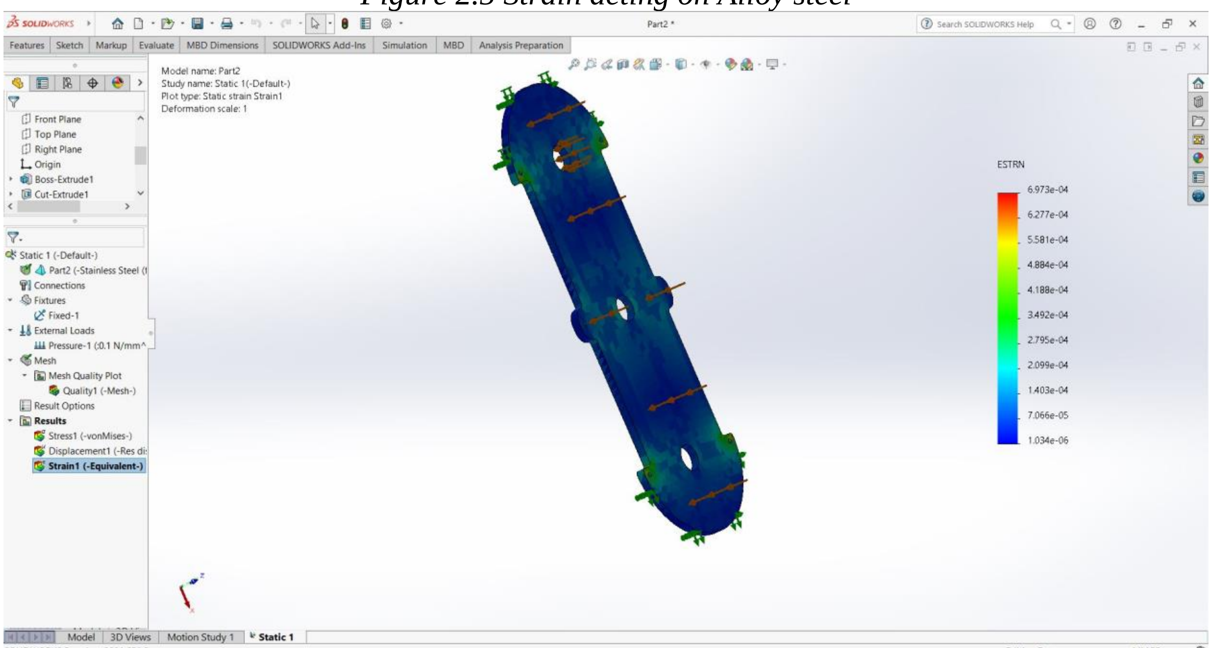

Figure 2.6 Strain acting on Stainless steel

From the choice of components, the minimum strain the base can handle should be 2.817-02. For this condition acrylic sheet, alloy steel, stainless steel comes under this need, with the respective maximum stress carrying capacities of 2.893e-02, 6.639e-04, 6.973e-04.

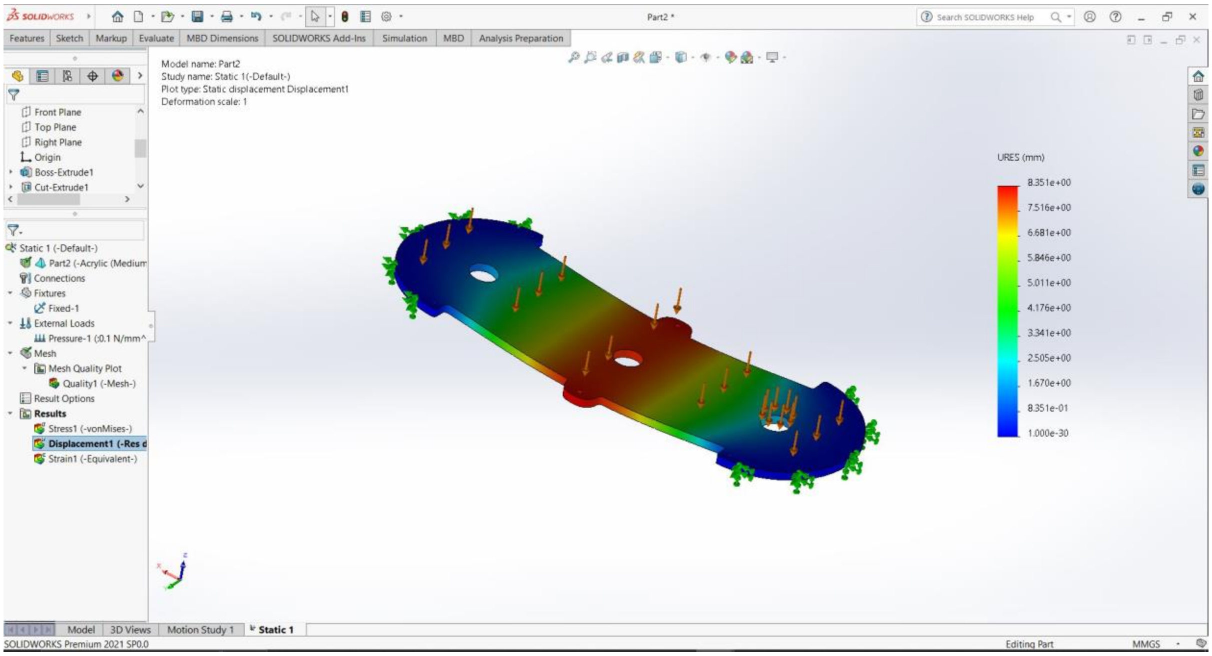

Figure 2.7 Displacement acting on Acrylic sheet

The overall weight the base should carry is 700grams in pressure its under 70 Pa approximately. To build the mobile robot in light weight we choose acrylic sheet for checking its capability lets calculate,

We know that stress=force/area
Force going to act on board approximately = 70Pa
The area of board = 280mm x 100mm =2800mm
1m^2=1,000,000mm^2
So, area=0.0028m^2
Stress= 70Pa/0.0028m^2
=25,000 Pa
The acrylic sheet has capacity of till 10.4 MPa.
1MPa=1,000,000Pa
Stress acting on base (acrylic sheet) = 0.025MPa

From this we observed acrylic sheet has capability to take the load of components and helps us for further testing process. which is cost efficient, helps in effective weight balance which helps in delivery more performance. The displacement change at this material is not possible with components and the acrylic sheet doesn't react with the components even when the components get heat due to excessive load compared to alloy or stainless steel. Acrylic is known for its elasticity, which means it can undergo deformation under stress and return to its original shape when the stress is removed. The strain will be predominantly elastic if the material is not pushed beyond its yield point. The components are assembled successfully we are in the progress of testing various components in robot operating system using gazebo simulation for real time testing process for various components like camera module with feedback sensor, Lidar sensor etc. for further development.

5. Conclusion:

Based on the investigation results, the following observations have been confirmed.

- The acrylic sheet experienced a uniform stress distribution. It did not exceed its yield point, including that it remained within its elastic deformation range. It exhibited strain as a result of the applied pressure.
- The exact magnitude of strain would depend on elastic deformation range. Acrylic elastic properties make it suitable for applications requiring resilience to stress.
- Automation navigation is successfully integrated with basic sensors. These sensors provide essential input for the robot to perceive its environment and make decisions.
- The inclusion of DC motor with L298N motor drive provide precise control of robot's movement which is crucial for achieving accurate navigation.
- The development of algorithm for obstacle avoidance and decision making is a crucial part which takes place after testing in virtual environment.

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