Design & simulation of a Stewart Platform for Shipboard Aircraft Stabilisation.

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Abstract

The Design and Simulation of a Stewart Platform for Shipboard Aircraft Stabilisation project aims to develop a cost-effective alternative to the existing Stewart platform. Currently priced at approximately INR 40,00,000, the cost of the platform poses a significant barrier to its widespread utilization in the aerospace field. This project recognizes the immense utility of the Stewart platform in various applications, ranging from aircraft simulators to actual Navy aircraft carriers. Therefore, a more affordable and efficient solution is sought.

This research project focuses on designing and simulating a Stewart platform that can be utilized for shipboard aircraft stabilization. The primary objective is to reduce the cost associated with the platform while maintaining its functionality and performance. To achieve this, the project explores two potential avenues: developing a three-leg model or exploring a novel concept involving ball-socket joints and linear actuators, which has not been previously explored.

The optimal design model for shipboard aircraft stabilization will be determined through thorough simulation and calculations. The feasibility of both the three-leg model and the novel concept involving ball-socket joints and linear actuators will be evaluated. The results of this research project can potentially revolutionize the aerospace industry by providing a cost-effective solution for shipboard aircraft stabilization, enabling widespread adoption and enhancing operational efficiency.

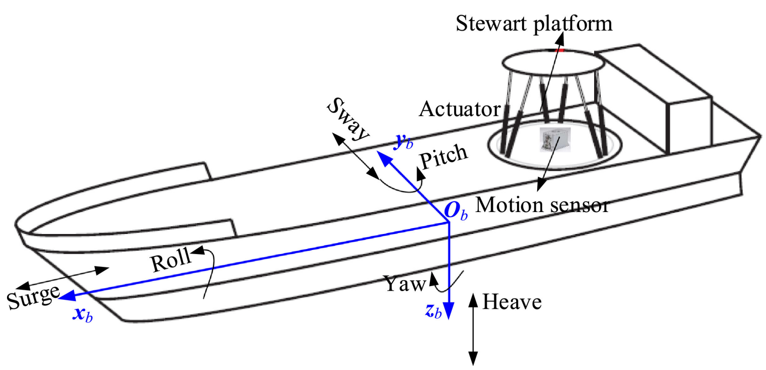

Figure 1: The general utility of the Stewart platform

Our initial goal would be to create a Non-response platform, feed already tested wave data to it and make it work on the given data so that it perfectly compensates for any effect of ship movement. This proof of concept will be tested on the basis of its utility and budget requirements, and then further changes will be made.

1 Progress Report

1.1 Strategy

Several research papers were studied to gain insights into the dynamics and kinematics of Stewart platforms. Notable works include ”Dynamic Analysis of the 3-3 Stewart Platform” by Stefan Saicu, ”Exploiting Higher Kinematic Performance” by Yong-Jin Yoon and Hassan Zohoor and ”Kinematics and Dynamics Simulation of a Stewart Platform” by Fengchao Liang. These papers present different configurations, including a 6-leg Stewart platform with linear actuators, a 6-servo Stewart platform, and a 3-servo 3-linear actuator platform. These papers were used to get a general idea of the physics behind the model and to get unique solutions from it.It was also found from *Exploiting Higher Kinematic Performance Using a 4-Legged Redundant PM Rather than Gough-Stewart platforms*, the performance of different platforms differs hugely.

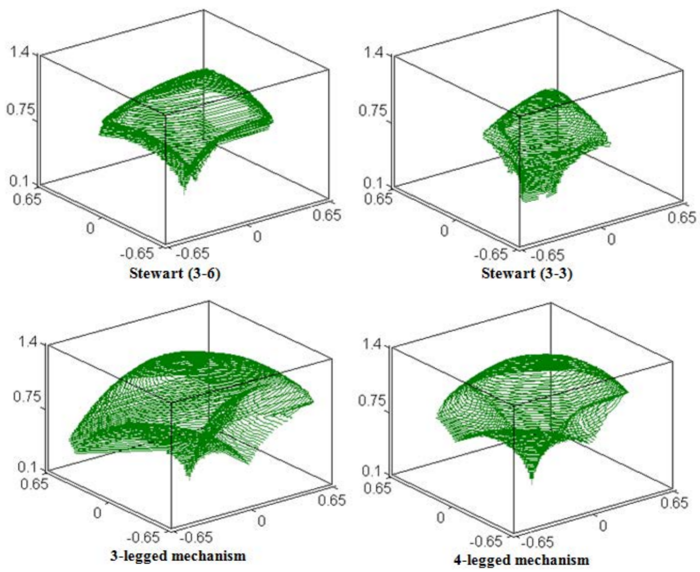

Figure 2: Workspaces of Stewart (3-6), Stewart (3-3), 3-legged and 4-legged mechanisms.

It was clear that the 3-legged model would be prioritised because of the high workspace, even though it compensated for some accuracy.No one had researched on working on 3-Leg models, so it was also a new branch we would dive into, trying to do what no one has or find out that why it is never been done.

1.2 Design

Using the information gathered, two CAD models were developed. One model employed a ball socket joint to hold the fixed actuators placed on the edges of an imaginary equilateral triangle, while the other utilized three linear actuators with six universal joints. SolidWorks was utilized for the CAD modelling and giving constraints to the models.

Figure 3: Universal joint model

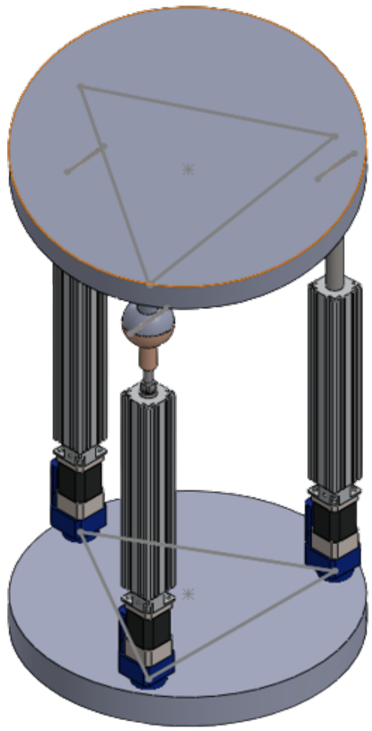

Figure 4: Ball-socket model

The model was simulated on MATLAB to get the proof of concept and to calculate individual leg motion range. The simulation kept failing in terms of "Constraint Issues" and stated that the CAD was underdefined. We concluded that no unique solution was possible for the given systems and hence it was not practical.

1.3 Inspiration from Swashplate

To look out for more solutions, we came across the research paper of Dr Abhishek, *Prediction of UH-60A Structural Loads Using Multibody Analysis and Swashplate Dynamics*. Swashplate is a mechanical component that converts input from the helicopter's flight controls into the motion of the main rotor blades. It has similar motions of pitch and roll as a Stewart Platform. Following are the diagrams for the concept. Notice that in our case, pitch links are not required, so it has no use here.

$$R_f = \frac{F_z}{2} + \frac{M_x + M_y}{2r_s}\sin\phi + \frac{M_x - M_y}{2r_s}\cos\phi$$

$$R_l = \frac{M_y\cos\phi - M_x\sin\phi}{r_s}$$

$$R_a = \frac{F_z}{2} + \frac{M_x - M_y}{2r_s}\sin\phi - \frac{M_x + M_y}{2r_s}\cos\phi$$

Figure 5: Force calculations of the swashplate model

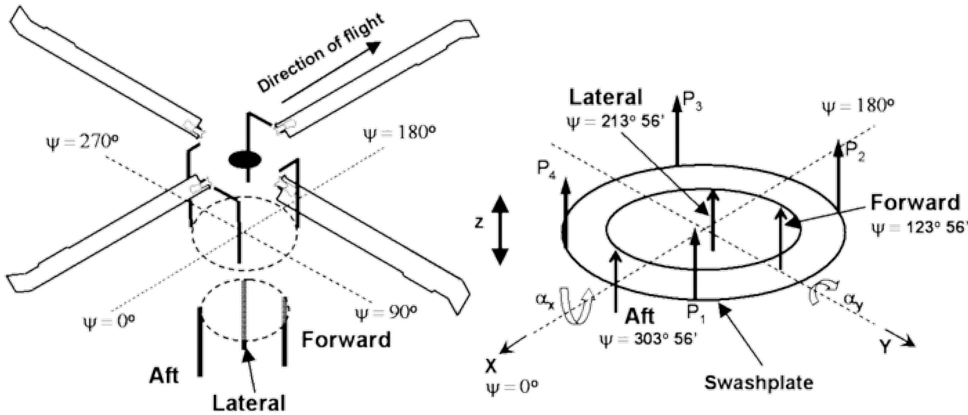

Figure 6: UH-60 Swashplate model

A cad model on this concept was built to carefully put Aft, Lateral and Forward to be perpendicular to each other. Again pitch links are not added, and a **Scissor joint** is to be added opposite to the actuator, which is perpendicular to both(**Lateral**). The scissor joint was not added because of the complexity of the object and its rare availability,a normal hinge would be used in practice.

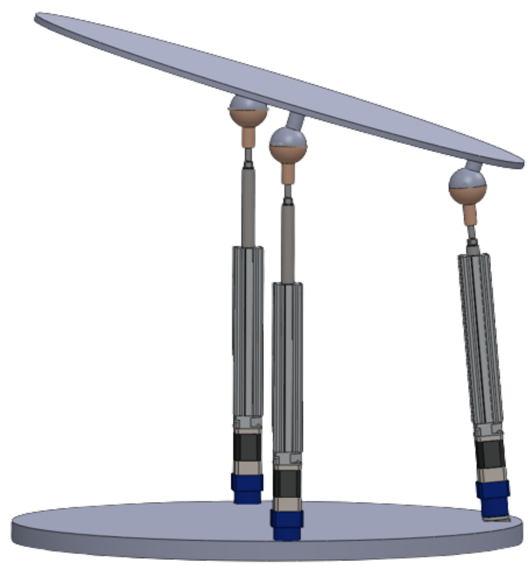

Figure 7: Swashplate based model

The calculation for individual actuator was performed in accordance with the research paper; the absence of pitch links are compensated by putting the azimuthal angle $\phi = 33'56$

$$v_f = z + \alpha_x r_s \cos\phi + \alpha_y r_s \sin\phi$$
$$v_l = z - \alpha_x r_s \sin\phi + \alpha_y r_s \cos\phi$$
$$v_a = z - \alpha_x r_s \cos\phi - \alpha_y r_s \sin\phi$$

Figure 8: Swashplate based model

1.4 Simulation

SolidWorks was utilized for the CAD modelling and MATLAB with Simscape Multibody were chosen for simulation purposes. Every Joint was added to Matlab, and constraints were added. In theory, the Matlab model will help us get the real-time simulation of the platform with details of the positions of every leg but sending in exactly perfect constraints was not possible after many attempts. However, we did get a simulation of the desired movements through it. This simulation was an important step in getting a proof of concept. The already done research on swashplate almost made it certain to work.

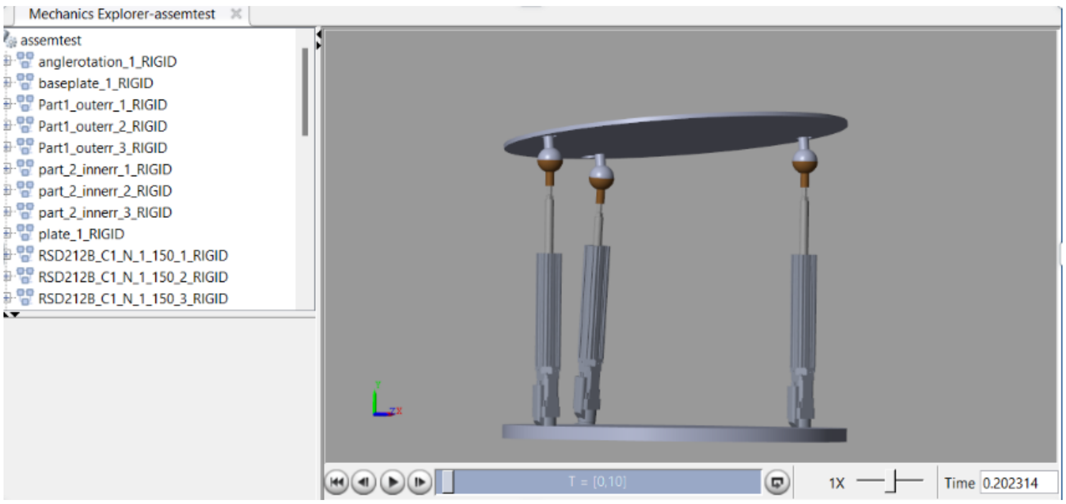

Figure 9: Screenshot of Matlab simulation

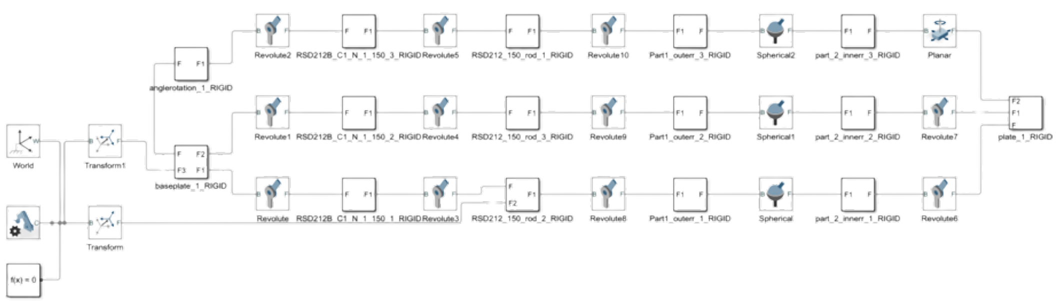

Figure 10: Simulink Structure for the model

The Above Simulink model has all the required constraints in the joints so that the whole model works smoothly.

1.5 Waveform data as feed mechanism

Simultaneously I had to get the ocean waveform data to feed it to the platform for it to work. After reading notable papers like *Simulation of Ship Motions in a Seaway*, we read about the type of Ocean data that is available and found out that at stable conditions, it can be assumed that the net ocean waves are a combination of multiple 3D sine and cosine waves. Ocean waves were brought down to individual sine and cosine waveforms to test this hypothesis. A 2D visualisation is shown below.

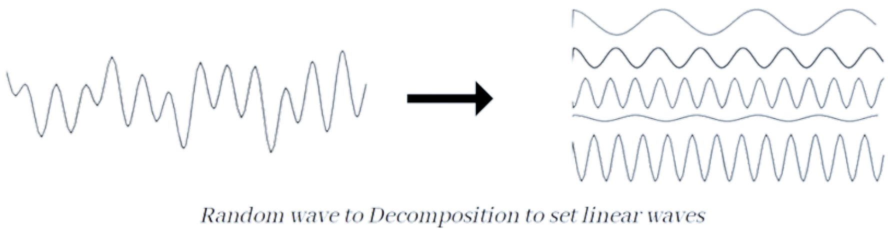

Figure 11: Similar to Fourier analysis

A 3D Matlab plot was also developed by using very small blue-gradient triangles to simulate ocean waves with the help of various articles and in-built Matlab functions.

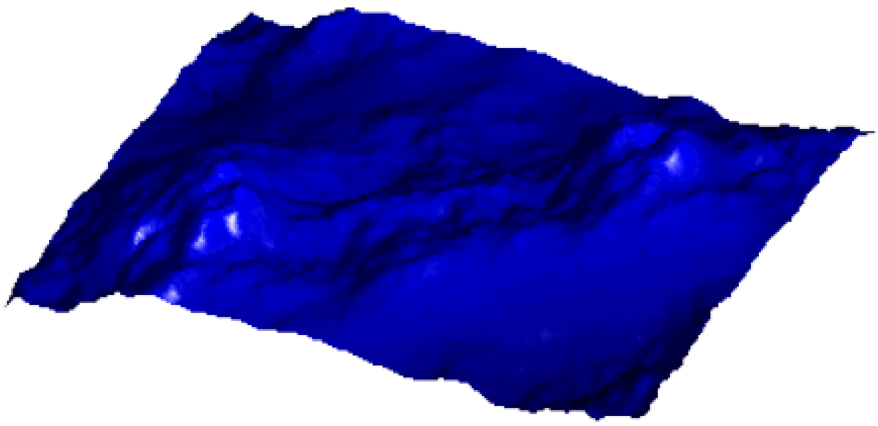

Figure 12: 3D plot on combination of many 3D waves

The wave data and functions were taken from *"Simulating Ocean Water"* article by Jerry Tessendorf. From the research paper of Harald Böttcher, *Simulation of Ship Motions in a Seaway*, we learned different methods to calculate forces on a ship acted by waves. The method used here is **Strip Method**.In the linear strip method, the response for irregular seas is obtained by using the superposition of responses for regular waves of different frequencies. Being a linear method, the strip theory has its limitations. While the prediction of heave and pitch is very good, the results for the highly nonlinear phenomenon of the rolling motion are very poor.

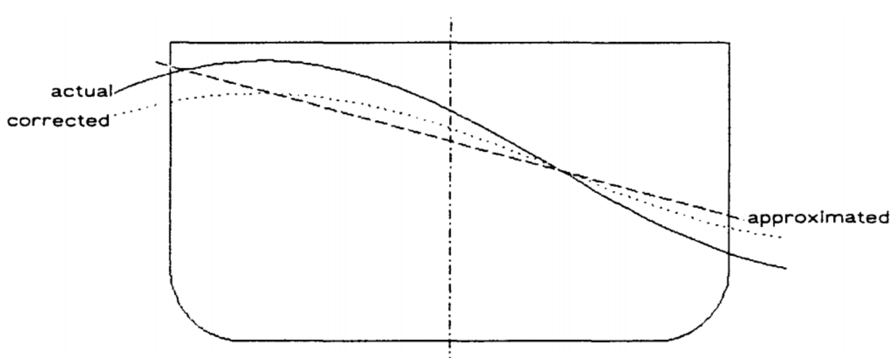

Figure 13: Actual, corrected and approximated waterlines at a section

The experimental transfer function of heave and pitch are given below of a model ship, with head wave, v=5 m/s.

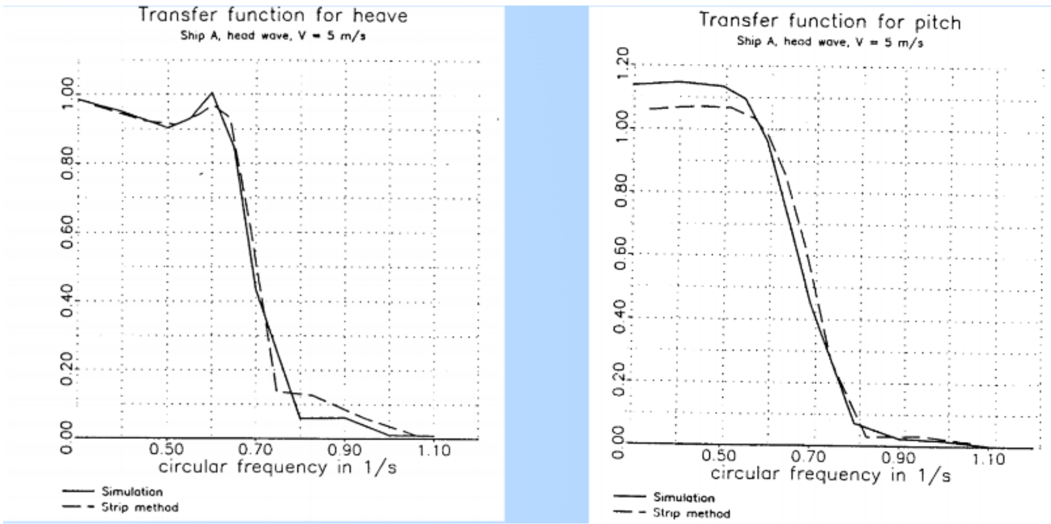

Figure 14: Functions useful to send feed data to the platform and tests the utility of Strip Method

1.6 Fabrication and Optimisation

Linear actuators were ordered with dual modules relay to power them, and Arduino uno was used as a controller. The linear actuator's specifications are as follows:

Stroke:20mm	**Speed:7mm/s**	**Load Capacity:1500**N	**Voltage:12V**	**Current Ratings:2A**

Figure 15: Linear Actuator

According to this actuator, a base plate is ordered to be constructed of metal and a top plate of carbon fibre. A relay is a device used to pass currents in both directions to the actuator to expand and contract without any physical change of wiring. Its connection is given below.

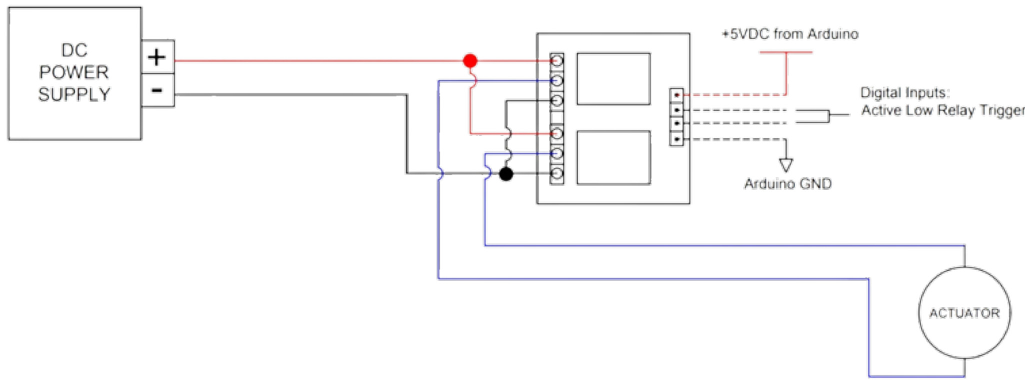

Figure 16: Normal Relay connection with 12V DC and Arduino

We went with assembling all the connections to first test out the exact speed of the actuators because a high level of time commands have to be given for exact movement. A normal 12V adapter was used to power the relay modules.

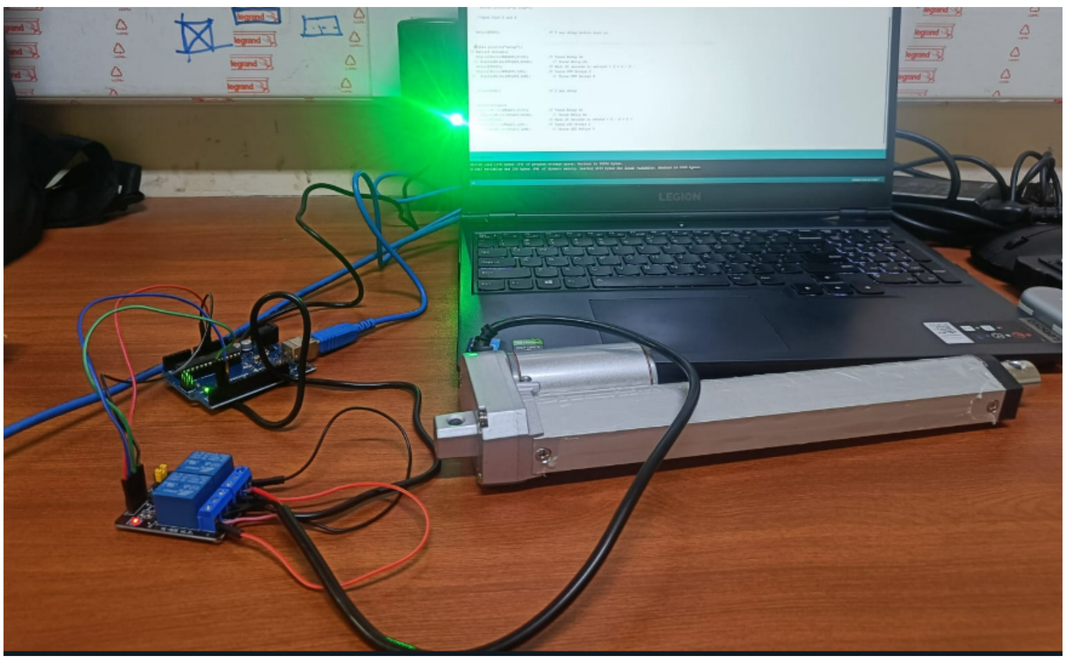

Figure 17: Connections of our model

1.7 Work to be done:

- Side by side, my project partner worked on calculations of the swashplate model to get individual displacements so as to move to a particular position.
- As soon as the plates are built, the model will be assembled, and we will get into the testing phase, where we try to increase the quality of commands given to it by Arduino.
- Moving forward, the platform's functionality and effectiveness will be thoroughly tested using simulated wave data to evaluate its utility and stability in real-world scenarios
- Current budget spend is around INR 17,000, which includes 3+1 actuators,8-channel relay, Arduino and some connecting wires. The plates are being constructed in-house.

1.8 Conclusion

- Special Thanks to my mentor Dr Abhishek who regularly guided me this far & my partner Mr Tushar Kumar for the smooth functioning of this project.
- Please note that the links to my work are accessible through clickable MODEL subsections and also on my git repository s-ritwik.