ME 224 Course Project

Making of a Stewart Platform

Date

Iyer Akash Seshan
230103041

by

Jaden Joseph Moncy
230103042

Department of Mechanical Engineering
Indian Institute of Technology Guwahati

Motivation and Application

MOTIVATION:

This project was motivated by:

•Desire to explore real-world mechanisms that go beyond basics taught in class.

•Learning how to model complex assemblies in SolidWorks using mates and motion studies.

APPLICATIONS:

1. Flight and Driving Simulators

•Used to mimic realistic aircraft or vehicle motion.

•Offers pilots or drivers physical feedback corresponding to visual scenes.

2. Robotic Surgery

•Provides ultra-precise motion control in robotic-assisted surgeries.

•Enhances accuracy in delicate procedures (e.g., eye or brain surgery).

3. Aerospace and Satellite Testing

•Simulates motion, vibrations, and forces experienced during launch and orbit.

•Tests components under dynamic conditions.

Originality beyond class assignments or teaching notes

What makes this project unique is that the Stewart platform is not a typical textbook mechanism. We had to base our design on an understanding of how parallel manipulators work. This meant researching actuator placement, joint behaviour, and carefully aligning all components in CAD to mimic real-world motion

Kinematic Analysis

Gruebler's Formula (for 3D spatial mechanisms):

$$\boldsymbol{DOF} = \boldsymbol{6}(\boldsymbol{n} - \boldsymbol{j} - \boldsymbol{1}) + \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{j}} \boldsymbol{f}_{\boldsymbol{i}}$$

Where:

•$\boldsymbol{n}$ = Number of **links** (including the base)

•$\boldsymbol{j}$ = Number of **joints**

•$\boldsymbol{f}_{\boldsymbol{i}}$ = DOF of the **i-th joint** (for example, a revolute joint has 1 DOF, a spherical joint has 3 DOF)

Applying this to the Stewart Mechanism:

Assumptions:

•1 base + 1 moving platform + 6 links = **8 links**

•Each of the 6 legs connects the base and platform using **2 spherical joints** (top and bottom), so:

- j=12 joints
- Each **spherical joint** has 3 DOF: f_i=3

DOF = 6(8 – 12 – 1) + 12 X 3

DOF=6(−5)+36=−30+36 = 6

Kinematic Analysis

Inverse Kinematics

Given a desired platform pose (p, R) (position vector $P \in \mathcal{R}^3$, rotation matrix $\mathrm{R} \in SO(3)$), **find** the six leg lengths L_i .

1.Frame & Notation

- Fix a base frame OOO.
- Let a_i be the coordinates of the i-th base attachment (in base frame).
- Let b_i be the coordinates of the i-th platform attachment expressed in the platform's local frame.

2.Leg Vector

$$d_i = (p + Rb_i) - a_i$$

3.Leg Length

The vector from base to platform joint is

$L_i = \ \|d_i\|$, I = 1,…,6.

Each actuator must simply extend/retract to match L_i .
This solution is **closed-form** and computationally trivial, making inverse kinematics extremely efficient.

Kinematic Synthesis

Platform Architecture:

- The base and moving platform are typically circular for symmetry.
- Each contains six joints (three joint pairs).
- Joints are connected by six independently actuated struts.

Joint Design:

- Ball-and-socket joints are used at both ends of each actuator.
- These provide the necessary angular freedom to accommodate platform movement.

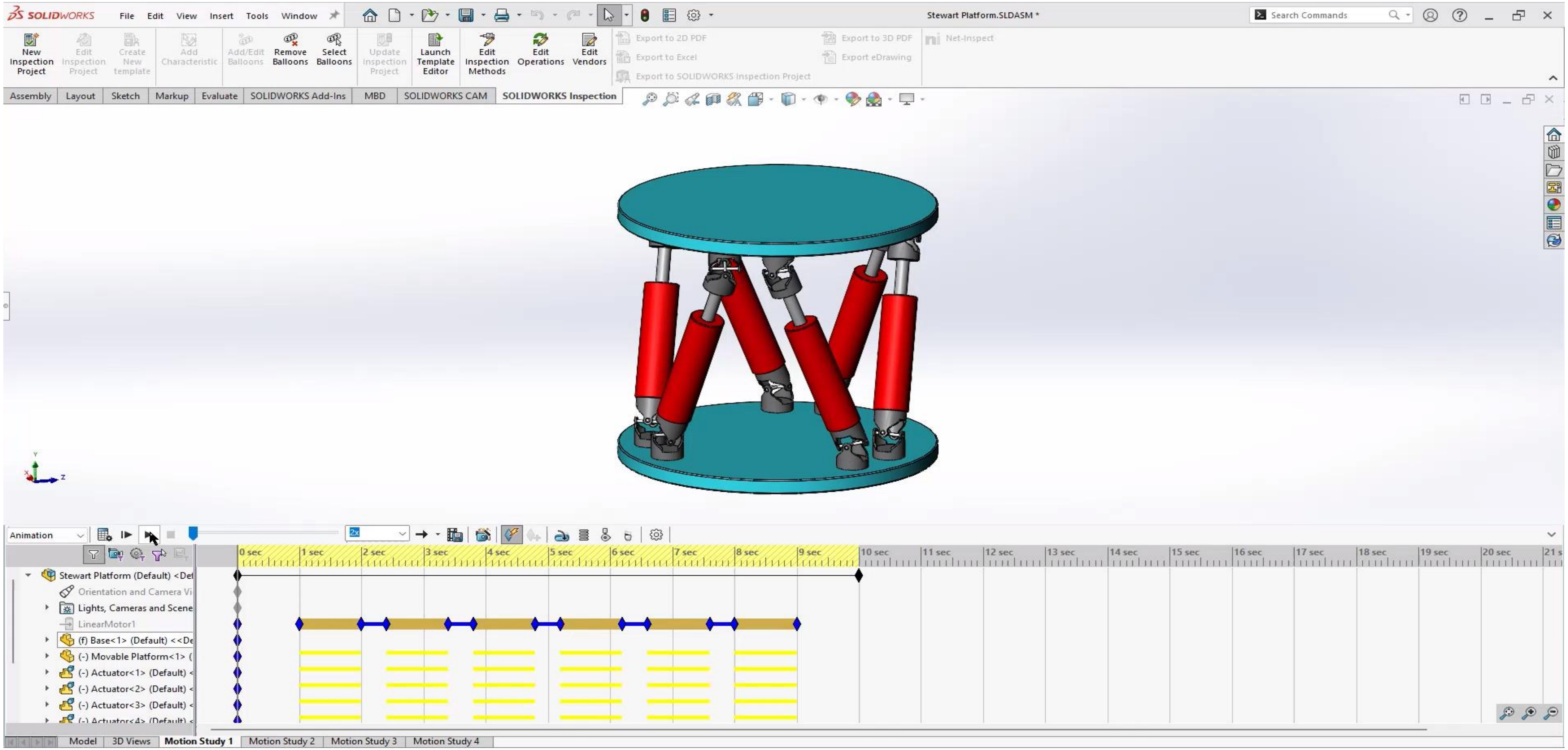
Actuator Configuration:

- Actuator lengths are chosen based on workspace requirements and mechanical limits.
- Proper placement ensures collision-free motion and full positional coverage.
- Actuator stroke must support both translational and rotational movements.

Geometric Considerations:

- The platform radius is generally smaller than the base radius to enhance stability.
- Joint angles and positions are selected to avoid singular configurations and maximize dexterity.

Computer Aided Design



Motion Analysis / Study

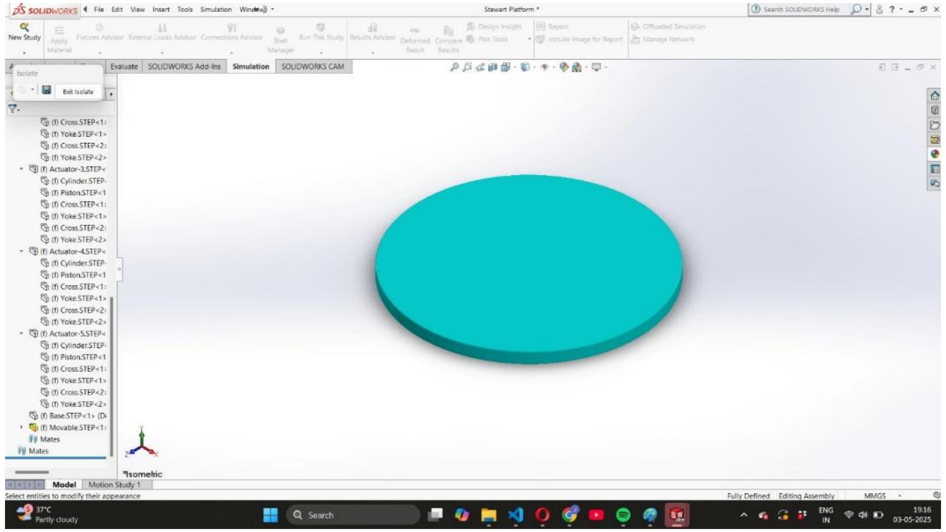
Degrees of Freedom (DoF)

A Stewart platform typically has **6 DoF**:

•**3 translational**: movement along X, Y, and Z axes

•**3 rotational**: roll (rotation about X), pitch (about Y), and yaw (about Z)

This full spatial freedom is why it's called a **6-DOF parallel manipulator**.



Actuation and Motion Generation

•The motion is generated by **changing the lengths of the six legs (actuators)**.

•Each actuator controls a direction in space, and together, the six define a **moving constraint system** that determines the pose of the platform.

•The platform's pose is fully defined by the **intersection of the six spheres** defined by each actuator (leg).

Inverse Kinematics for Motion Execution

•Given a desired pose (p,R), we calculate each leg length l_i.

•This allows **precise motion control**, essential for applications like simulators and precision machining.

Motion Analysis / Study

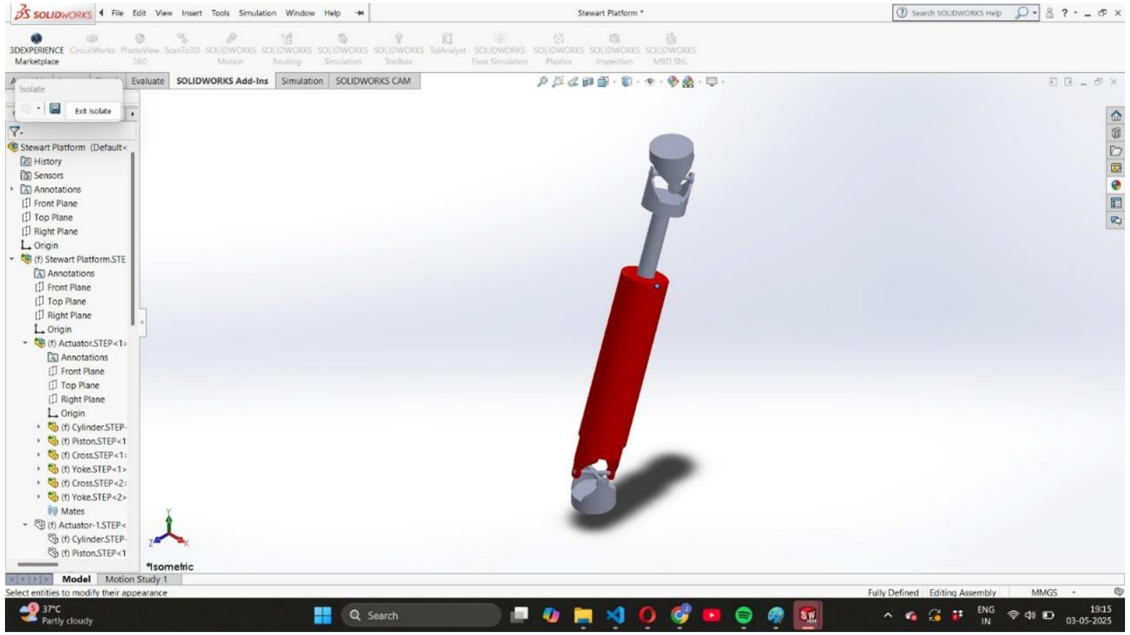
Velocity and Jacobian Matrix

•The **Jacobian matrix J** relates **platform velocity** to **actuator velocity**:

$dl/dt = Jx$, where x is $\begin{bmatrix} dp/dt \\ w \end{bmatrix}$

•This is key for:

- **Controlling speed**
- **Dynamic analysis**
- **Force transmission**



Workspace and Motion Limits

•The **workspace** is the set of all possible platform poses achievable without violating:

- Joint limits
- Actuator stroke limits
- Collisions

•The shape is typically **nonlinear and constrained**.

•Often evaluated numerically by simulating motions across different poses.

Fabrication Details

Fabrication Status and Design Considerations

A physical prototype has not yet been fabricated; however, a detailed CAD model has been developed with a focus on physical realizability. The legs have been modeled as extendable links to represent the functionality of real-life actuators. Joint types and placements have been selected to accurately replicate the motion constraints typical of a real Stewart platform. For potential fabrication, materials such as aluminum or 3D-printed polymers are considered suitable—particularly for prototyping purposes—offering a balance of strength, weight, and manufacturability.

Conclusions

The Stewart platform mechanism was successfully modeled and animated, accurately capturing its six degrees of freedom and complex kinematic behavior. This project provided a deeper understanding of parallel kinematic systems, particularly how constrained motion and actuator coordination govern platform movement. Through the use of SolidWorks, we were able to effectively visualize and analyze the interactions between components, the motion paths, and the structural dependencies of the mechanism. The process also reinforced the importance of precise geometric design, proper joint selection, and realistic modeling techniques for physically realizable systems. Overall, the project served as a comprehensive exercise in the synthesis, analysis, and simulation of a high-DOF mechanical system.

Thank You