DESIGN AND DYNAMIC BALANCING OF MULTI LOOP SPATIAL MECHANISM

A Synopsis of the PhD Thesis

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by

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1. Title of thesis and abstract

Title of Thesis:

DESIGN AND DYNAMIC BALANCING OF MULTILOOP MECHANISM

Abstract:

Industrial uses for spatial mechanisms include parallel robot manipulators, machine positioning platforms, and more. The high stiffness, large payload capacity, and simple construction make parallel manipulator robots popular in industry. The RSSR-SS platform is a 2-dof pioneer in parallel manipulator usage. Rotary Spherical Spherical (RSSR-SS) is a spatial mechanism with rigid body control and passive degree of freedom. This study's idea is focused on linking the Rotary and Spherical pairs (Universal joint). Stepper motors drive the rotary joint. Simulate parallel manipulators using Universal joints for exact positioning. The RSSR SS parallel manipulator's forward kinematics are solved in MATLAB. A user interface is created to control the actuators The motor can be pulsed to tilt the manipulator's platform in different directions.

Experiments were carried out to determine the movable platform's position analysis and angular tilt along the x- and y-axes by actuating the manipulator linkages. Matlab was utilized to solve the kinematic difficulties involved in order to corroborate the results acquired by the experimental and analytical methods. The RSSR SS manipulators were developed in Solid Works based on the produced models. Graphs are generated by running kinematic simulations to get different parameters such as force, position, and angular tilt related to simulation time. Dimensional synthesis is a subset of kinematic synthesis that determines connection parameters for 2-DOF RSSR SS parallel manipulators. An adjustable possibility is employed to accomplish the greatest number of rigid body positions using velocity and acceleration analysis and variable input speed. The solution of a set of equations using a newly invented program using the MatLab R12018b package.

The simulation results demonstrate the efficacy of the proposed technique, the dynamic equations of the RSSR-SS manipulator, and the effects of Leg/ Actuator inertia and its components on the overall system dynamics. The RSSR-SS was modeled in Solidworks2021.

A potentiometer-based control scheme for parallel robot rotary actuators was designed and demonstrated on two cylinders. For creating control programmers, Arduino software is utilized. The displacement of the RSSR SS platform was determined using an accelerometer sensor, and the resulting graphs are shown in the thesis. Fabrication aspects were thoroughly discussed in the thesis, and prototypes were created that are adequate for manipulating low-weight items and performing industrial activities.

Finally, the research looked at dynamic difficulties with a specific RSSR-SS manipulator.

2. Brief description on the state of the art of the research topic

A mechanism is a device designed to convert input motion into the needed set of output motion and forces. The spatial mechanism is now widely employed in a variety of industrial applications, such as parallel kinematic machines as a robot manipulator[1].

Parallel kinematic machines (PKM) provide several benefits, including excellent position precision, intrinsic static / dynamic stiffness, and minimal inertia[2]. PKMs have advantages and disadvantages because to their high nominal load-to-weight ratio and remarkable dynamic efficiency are a small and complex workspace[3], often coupled position and changing platform orientation, and sophisticated forward position kinematics[4].

From 2001 to 2019, the review cover article was published in a variety of journals. The current chapter offers a comprehensive in-depth literature evaluation with a temporal line connected to spatial mechanism kinematics.

Various approaches, principles, criteria, or methods have been used to perform kinematic analysis of spatial mechanisms with single loop[5], one degree of freedom, with various methods on different kinds of Spatial mechanisms like PPSC, RSCR, RSSR, HRSR, RSSR-SC, RSSRR-SRR, RPSSPR-SPR, CSSP, RRSS, RSSP, RPSS, RSCP, 5R, 7R, 5R2P, and 4R3P[6].

According to a survey of the literature, researchers have undertaken synthesis of many types of multi spatial mechanisms to give connections with the appropriate relationship between input and output linkages[7].

Dimensional synthesis is also used to get the best force transmission for a given set of relative poses of input and output linksin RSSR SS[8]. Different techniques, concepts, criteria, or procedures are utilized to accomplish spatial mechanism synthesis[9], such as the -3R hybrid leg, P-3R hybrid modal, P-3R2R22R mechanism, parallel hybrid loop form, hybrid structure of spatial two loops with 3T, and hybrid structure of spatial seven loops with 3T2R[10].

According to a survey of the literature, dynamic analysis for open chain spatial mechanisms is often accomplished utilizing a variety of methodologies. These techniques may be used to derive recurrence relations for velocities, accelerations, and generalized forces[11].

It is also feasible to do dynamic analysis on a closed loop system by transforming it to an open loop system and then employing the same formulation techniques[12].

In comparison to other study areas, such as kinematics, synthesis, and dynamic balance of spatial mechanisms, there is very little work on dynamics of spatial mechanisms.

As a result, it is an open study topic to work on it with variable input speed in consideration.

Based on the examination of the literature, it is possible to infer that the dynamic balancing of spatial mechanisms was performed for open loop and closed loop linkages with a single degree of freedom system of a single loop[13]. As a result, it depicts the need to perform dynamic balancing of spatial links. During the examination of the literature, researchers performed dynamic balancing of several spatial processes.

- π-3R hybrid leg,
- P-3R hybrid modal,
- P-3R2R22R mechanism,
- Parallel hybrid loop form,
- Hybrid structure of spatial two loops with 3T,
- Hybrid structure of spatial seven loops with 3T2R.

Kinematic spatial mechanism assessment based on their ability to apply unique methodologies, criteria, or procedures for a certain mechanism type. The construction of a multi-loop spatial mechanism and dynamic balancing were examined by the researchers[14]. In the spatial multi-loop system, synthesis establishes many types of input and output desired relationships.

It was determined that the Kinematic analysis conducted multiple Multi-loop Spatial Mechanism settings for Kinematic geometry, topology, and displacement modelling with the use of the Jacobian matrix[15]. Kinematic Design, synthesis, and optimization were also performed using it[16].

3. Definition of the problem

- Various methodologies, ideas, criteria, or procedures are utilized to perform kinematic analysis of spatial mechanisms with a single loop and one degree of freedom. According to a literature survey, researchers have synthesized many types of multi-loop spatial mechanisms to offer linkages with desired relationships and optimum force transmission between input and output linkages.
- Very few studies have been done on Kinematic analysis of RSSR-SS spatial mechanism to develop closed from I/O relation with numerical simulation.
- Diverse techniques, concepts, criteria, or methodologies were utilized to perform synthesis of various spatial mechanisms, and literature study shows the dynamic analysis for open-chain spatial mechanisms using multiple ways. These methods may be used to derive recurrence relations for velocities, accelerations, and generalized forces on the RSSR SS mechanism.
- No study has been done by researchers on the relationship between the I/O linkages for the RSSR-SS mechanism.
- It is also feasible to do a dynamic analysis on RSSR SS closed loop by transforming it to an open-loop system and then using the same formulation techniques. In comparison to other study areas, such as kinematics and synthesis of spatial RSSR SS mechanisms with variable speed, there is very little work on dynamics of spatial mechanisms.
- No one is working on the design, development, and analysis of the RSSR-SS spatial mechanism, and no one is comparing experimental and simulation results.
- As a result, working on it with variable input speed rather than constant speed on RSSR SS is an open study topic.

4. Objectives and scope of work

4.1 Objectives of the work

1. Kinematic analyses of an RSSR-SS spatial mechanism to develop closed form input output nonlinear relation with numerical method
2. Synthesis of RSSR-SS spatial for finding out the relationship between input and output linkages.
3. Design, develop and analyze the RSSR-SS spatial mechanism.
4. Compare the Experimental results of Mechanism with SimMechanics / MatLab result.

4.2 Scope of work

The current study focuses on the construction of a physical model and mathematical modeling and real-time control system design and implementation of an RSSR SS Manipulator in MatLab.

- Using numerical simulation, the current study analyses the performance on Kinematic analysis of RSSR-SS spatial mechanism to generate closed from I/O relation.
- It is proposed to study dynamic characteristics of performance in Simulink (MatLab).
- It is also planned to evaluate the model using PLC with Modbus connection in MatLab.
- Processing 4.0 and Arduino will come in handy for creating graphical representations of Model activity.
- Using Arduino and Processing 4.0, investigate the impact of angle change on link trajectory.
- Based on the prior art and findings, investigate alternative geometric parameters such as link length and leg angle in order to suggest the best appropriate RSSR SS model design.
- Build the physical RSSR SS manipulator and confirm the computational results using experimental data.
- The model is verified using both experimental and published data from other

researchers.

- Under the section "Conclusion and Future scope," the conclusion of the complete study endeavor, as well as the physical rationale and further development of this research, have been explored.

5. Original contribution by the thesis

- The whole thesis work in the overview and thesis is unique. Extensive research on the RSSR-SS mechanism culminated in a kinematic analysis using the Jacobian matrix in MatLab. Also, create spatial systems with changing leg length and pace.
- Needs to be addressed and yet not done by the researcher to design and create a low-cost RSSR-SS multiloop spatial manipulator; therefore, it is built, and a patent for the full model is filed.
- Only a few researchers have employed the RSSR-SS mechanism up to Kinematic analysis, but dynamic analysis is still unused. As a result, the design and development of a low-cost RSSR-SS multiloop spatial manipulator has been completed.
- Compare the experimental findings of the RSSR SS Mechanism with SimMechanics / MatLab and Arduino, as well as Processing 4.0, which is used for feedback system with graph creation.
- Matlab controls and communicates with the entire system (RSSR-SS multiloop spatial manipulator).
- Design and construction of a Multi Loop- Spatial Mechanism RSSR SS is a fresh and original contribution of the current work.

6. Chapter Wise Description of the Thesis

6.1 Chapter 1: Introduction

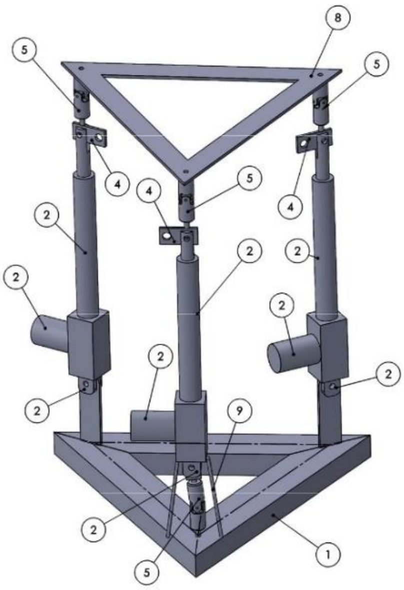
This chapter provides a brief description of the current research field, the rationale for the current study, and an outline of the thesis format.

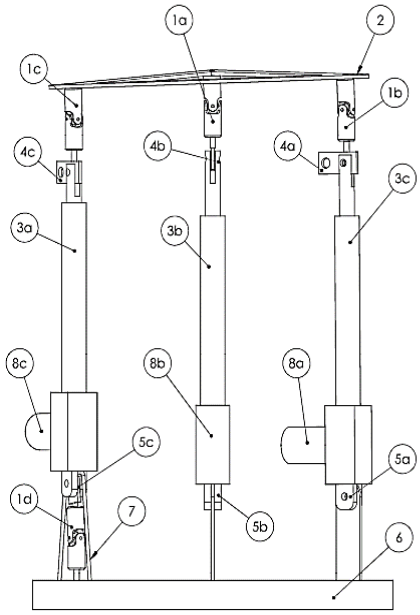
6.2 Chapter 2: Literature Review

This chapter describes in short the literature review that led to the identification of research gaps and the research objectives, as well as the thesis hypothesis and overall design process.

The majority of research works rely only on the kinematic study of the RSSR-SS mechanism[17], with very little work based on experimental work. Based on the identified research need, the primary goal of this work is to investigate the behavior of RSSR SS manipulators under various experimental parameter settings.

6.3 Chapter 3: Modeling & Kinematic Analysis of RSSR SS Manipulator





Linear Actuator/Lag (3a/3b/3c)	Top platform (8),
Drive member (2a/2b/2c),	Rotary joint (5a/5b/5c),
Universal joint (1a/1b/1c/1d)),	“U” shape round bar (7)
Sensor mounting plate (4a/4b/4c),	Bottom platform (6)

A robot manipulator is a multi-segmented electronically controlled apparatus that accomplishes tasks by interacting with its surroundings. They are also known as robotic end effectors or platforms. Robot manipulators are widely utilized in the industrial production sector, but they also have a wide range of specialized applications. The study of robot manipulators deals with the locations and orientations of the various elements of manipulators. This lesson presents the fundamental ideas needed to describe rigid body locations and orientations in space and coordinate transformations.

The majority of the cited literature and patented work were focused to kinematics and workspace analysis of parallel mechanisms produced from the RSSR SS platform (Figure 1 & 2). Work on Kinematic modelling and simulation from a single link to three links was presented. Jacobian Matrix was used to do position kinematic analysis[18].

6.3 Chapter 4: Synthesis of RSSR SS Manipulator

The difficulty of modifying a mechanism to achieve the desired movement is known as a kinematic synthesis of the mechanism. Four bars is a frequent mechanism. In this case, the synthesis challenge is to determine the size of the articulated link mechanism necessary to generate a specified functional connection between the input and output angles. The purpose of this chapter is to give an overview of the velocity and acceleration analyses [19]. The Programme (Figure 3) below illustrates the notion of tracing and tracking the trajectory and motion of different precision points.

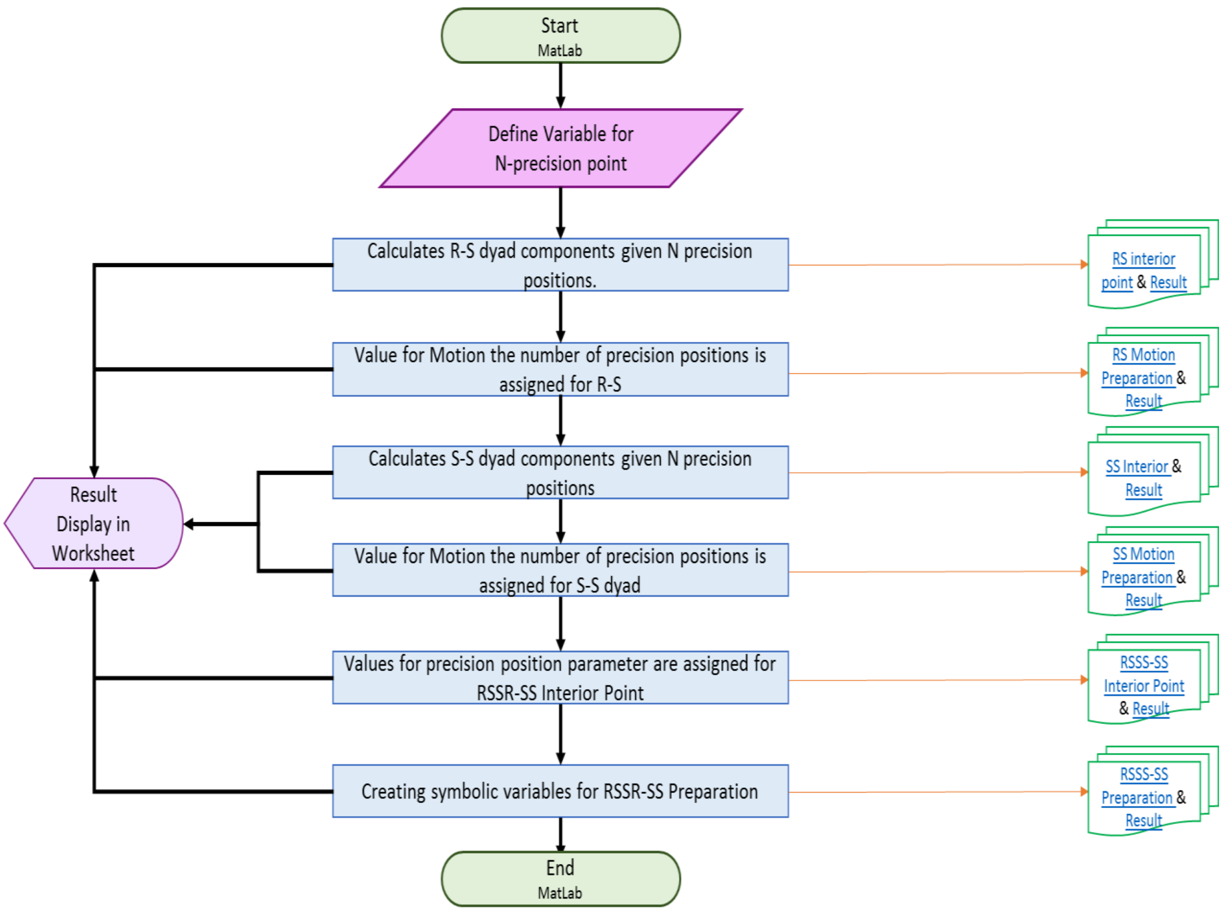


Figure: 3 Algorithm for trajectory and motion of RSSR SS manipulator

6.4 Chapter 5: Simulation of RSSR_SS Spatial Mechanism

SimMechanics is a block diagram (Figure: 4) modelling framework for modelling and

Simulating RSSR SS mechanical systems that use Newtonian dynamics of forces and torques[20]. The creation of a mechanism's kinematic model is not required for SimMechanics-based kinematic investigations. Machine parts may be easily represented graphically using linked block diagrams (Figure: 5), saving time and effort while modelling[21]. The block set comprises body, joint, sensor, and actuator libraries, constraints and controllers, and force components (Figure:6)[22]. SimMechanics models may be seamlessly combined with conventional Simulink modular components[23].

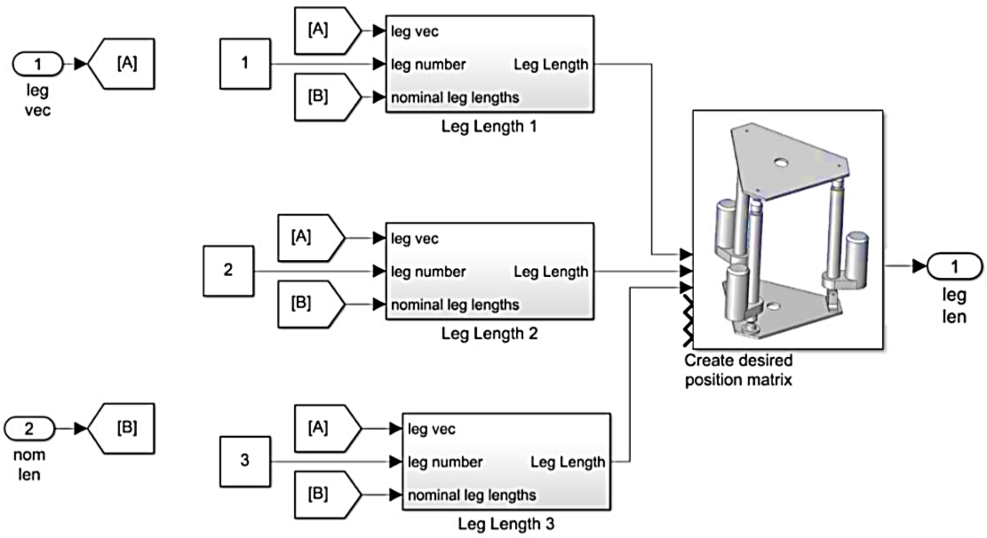


Figure: 4 Block Diagram for Position Matrix

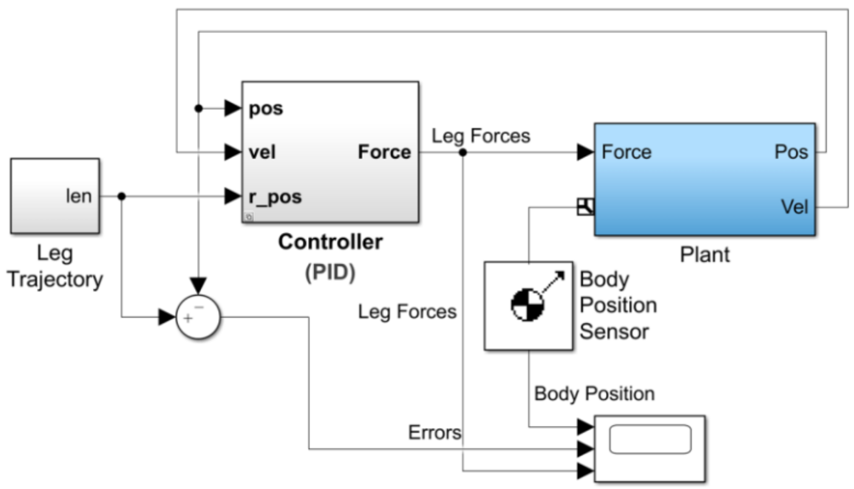


Figure: 5 Leg Trajectory and Force controller

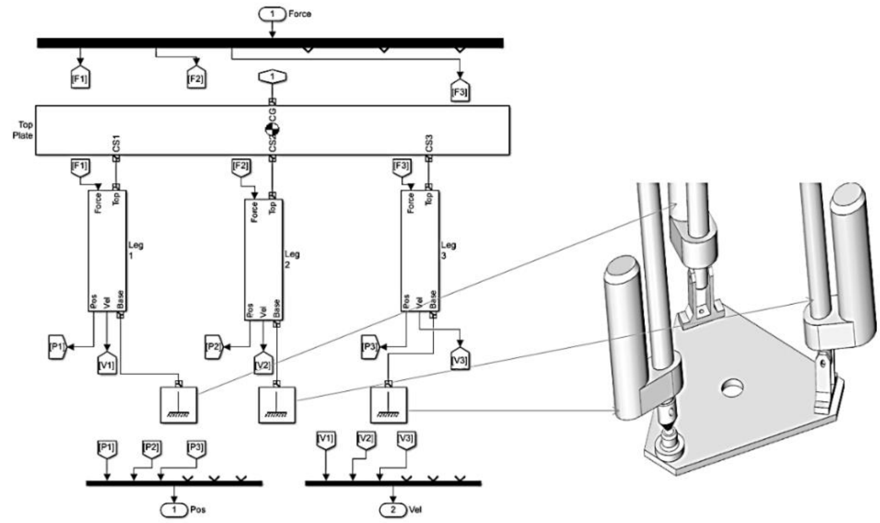


Figure: 6 Force control model for RSSR SS manipulator

6.5 Chapter 6: Model Development & Experimental Setup

- To provide the RSSR SS platform's moving plate with the necessary motion, all connections at the joints are bonded relationships with the flexibility seen in Rotary and flexible joints. Also, This chapter discusses the fabrication of the different components, construction of the model, and experimental setup with test results. Each item is meticulously crafted using a variety of processes. The test is conducted using an experimental setup for interaction with Mat Lab and feedback to Arduino. The orientation of the top plat and leg angle in relation to time is predicted using data. The accelerometer and potentiometer readings are converted to a graphical representation using Processing4.0 and MatLab.
- Solid Works software is used in this chapter to model several parts and assemble the RSSR SS platform model. Each component is well-designed and has superb architecture. Additionally, the modal analysis demonstrated how the spring reacts dynamically. To determine the optimal Universal joint profile. The RSSR SS platform's assembly and complete model are built in the Solid Works application (Figure: 7) using unique assembly techniques. Numerous connections have been established in the Solid Works application to see the top plate's motion.
- All connections at the joints are bonded connections and flexible joints to give the appropriate motion to the RSSR SS platform's moving plate. Also, This chapter details the production of the model's many components, its assembly, and an experimental setup (Figure: 8) with test results. All components are manufactured with extreme

precision employing a variety of procedures. The connection with Mat Lab and feedback to Arduino are tested using an experimental setup. The orientation of the top plat and leg angle is predicted in relation to time using data. The data is turned into a graphical representation for analysis using Processing4.0 and MatLab using the Arduino software with an accelerometer and a potentiometer.

6.6 Chapter 7: Interfacing of Experimental Setup with MatLab

- Modbus servers[24] are used to connect with one another, to operate a PLC, to transfer data to a DSP, and to read bulk memory from a controller. Configure a Connection in the Modbus Explorer allows you to connect with a PLC's read inputs and holding registers[25].

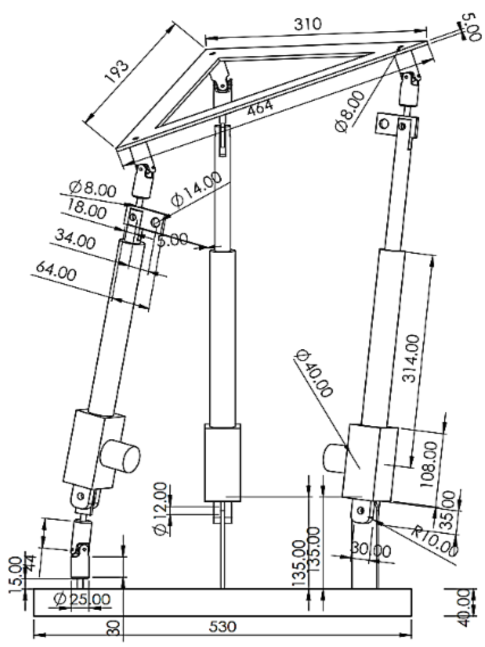


Figure :7 RSSR Model with Dimension

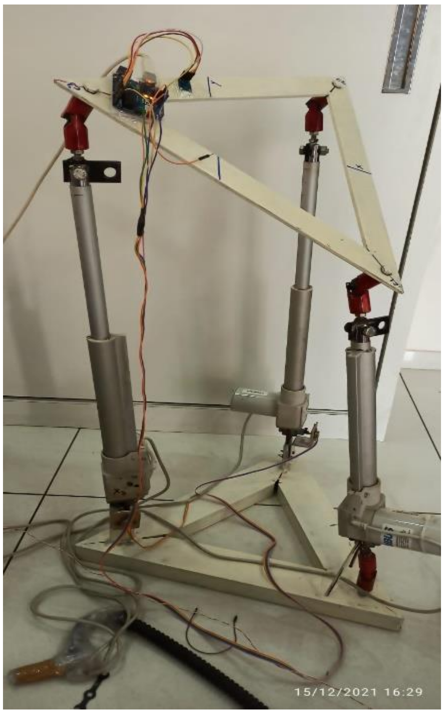


Figure : 8 Actual Model with sensor

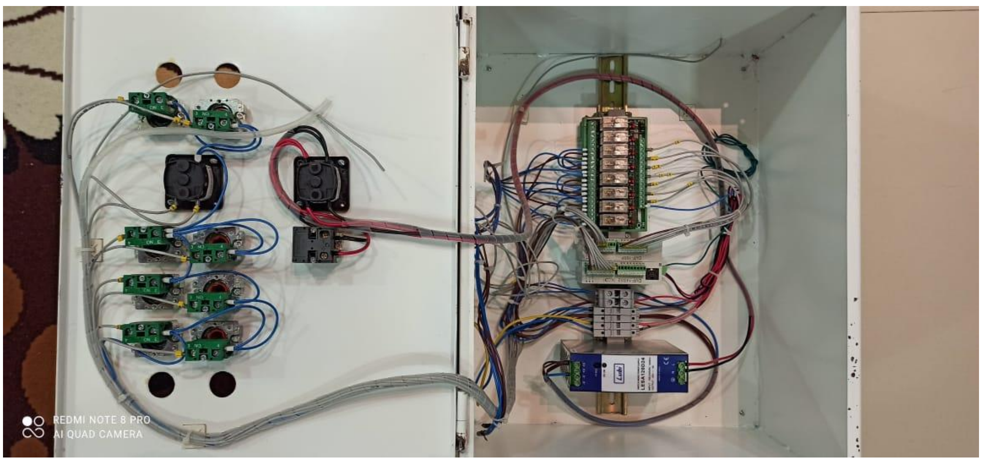


Figure : 9 Control Penal with PLC for RSSR SS Manipulator

- Create a MATLAB script using Modbus Explorer and execute it through the Instrument Control Toolbox's Modbus capabilities.
- Communication in Real Time The connection between MATLAB and the PLC was accomplished via MODBUS communication to MatLab through ISP Soft for the Delt PLC models DVP-14SS2 and Ex. DVP-16SP (Figure: 10)[24].
- ISPSoft supports Delta's programmable logic controllers (PLCs) that match the requirements for project management integration[26]. Delta's self-developed function blocks simplify the process of meeting a wide range of control

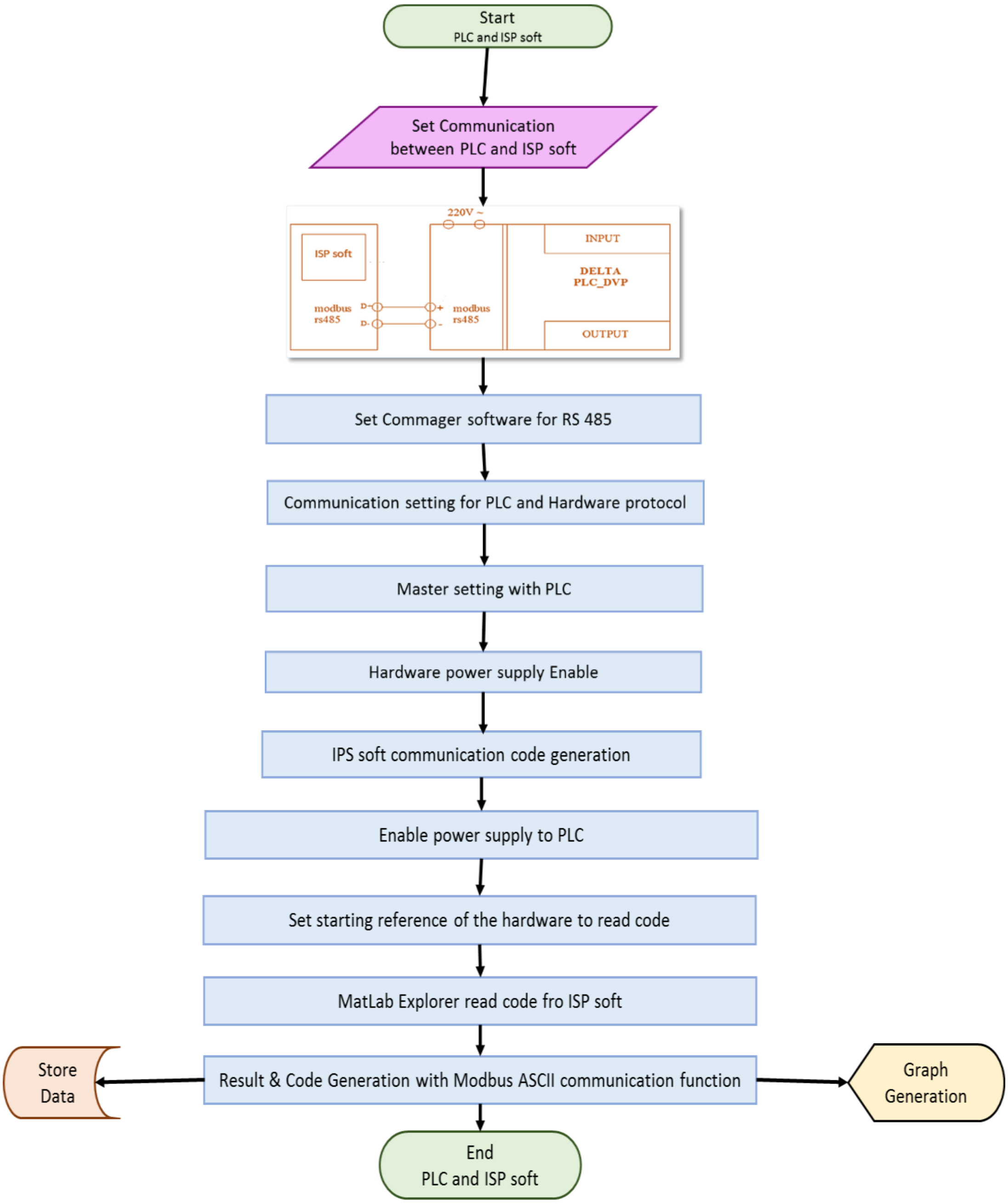


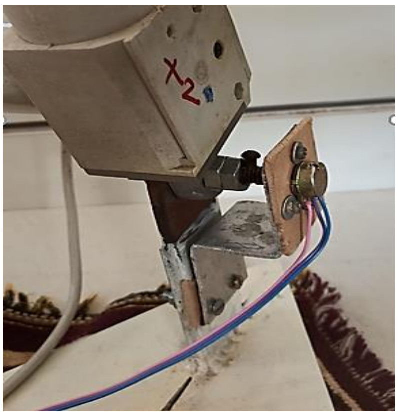
Figure : 10 Flow Chart for Modbus to MatLab Communication using PLC requirements. ISPSoft's development environment is both efficient and user-friendly, making it suitable for both small and sophisticated control systems.

6.7 Chapter 8: Feed Back & Validation of Experimental Setup

This section discusses the installation of Arduino is a popular prototyping platform. MATLAB, on the other hand, is a professional numerical calculation Programme. Interfacing Arduino with MATLAB is fascinating since one attempts to control a very complex instrument [27]. Arduino provides serial data to Processing through a serial library (in Processing). It permits the use of data from various sensors and the operation of Processing 4.0 designs through a serial connection with the Arduino [28]. Potentiometers are a kind of analog sensor that is used to measure a mechanism's absolute angular rotation or linear motion.

Accelerometers are used as inertia sensors to determine tilt angles. When the platform is stationary and not moving, it can reliably perform this function. Typically, it is connected to one or more gyros to acquire a precise tilt angle to combine data to calculate the angle.

This research may also be used to the Arduino for the creation of feedback and communication with Matlab (Figure 13), as well as to Processing 4:0 for the development of live graphs and communication with Matlab.



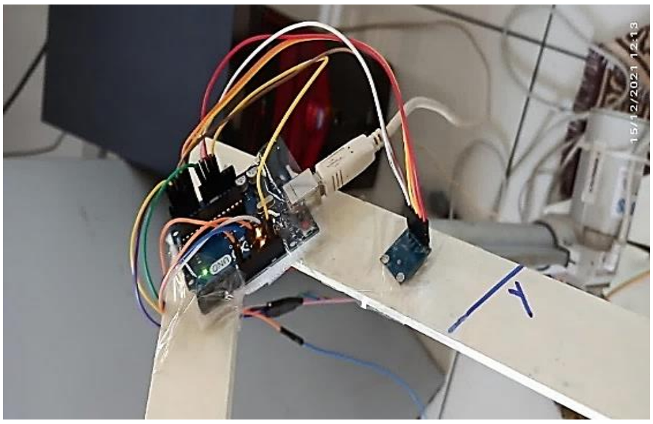
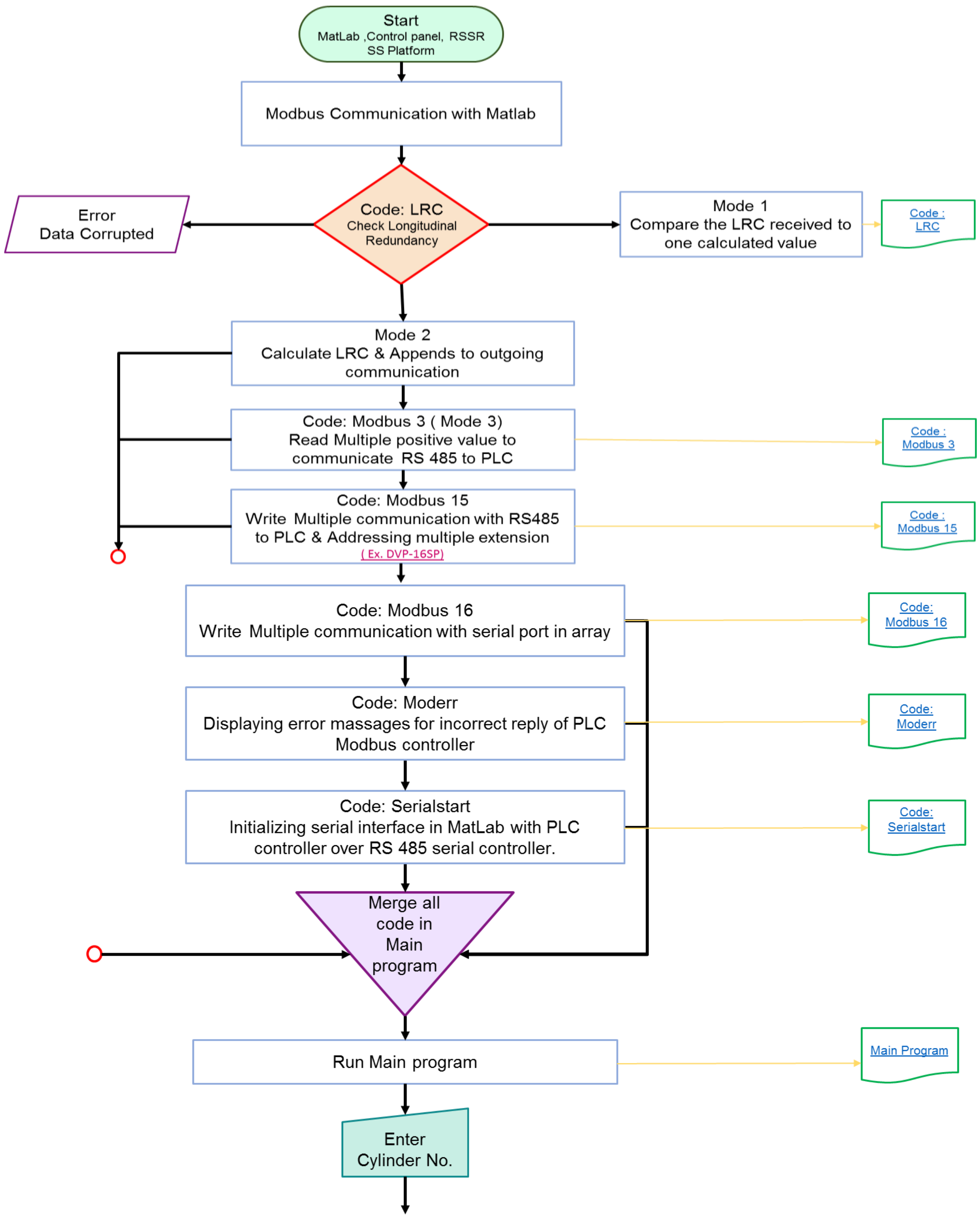


Figure : 11 Potensiometer   Figure : 12 Acclerometer with Ardunio



Algorithm for MatLab Program: RSSR-SS mechanism

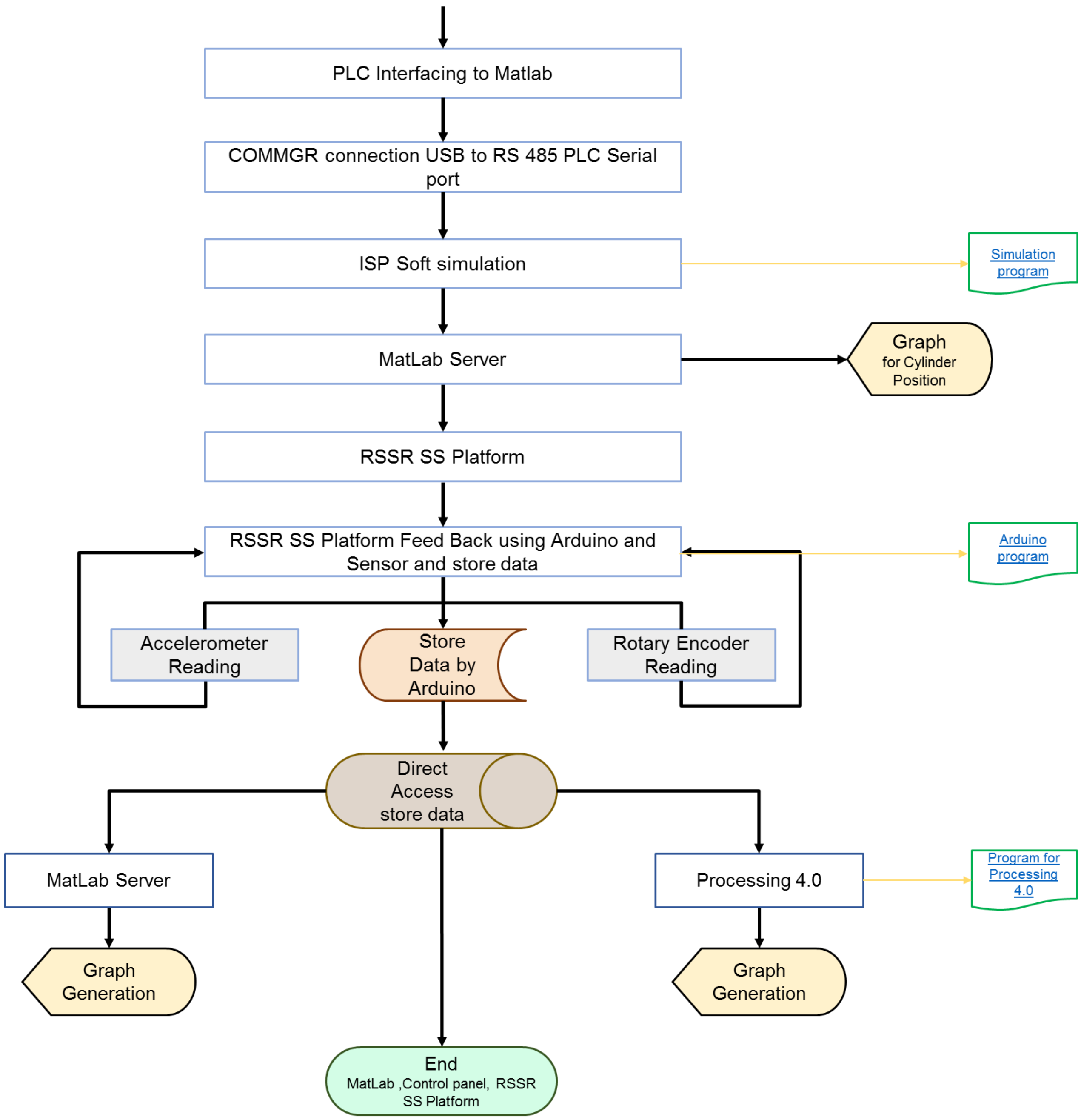


Figure : 13 Flowchat for Communication between Matlab, PLC , Modbus Arduino and Proccessing 4.0

6.8 Chapter 9: Conclusion

- This chapter concludes the complete work of the thesis. The sources consulted for this work have been cited and mentioned in the 'References' section.

6.9 Chapter 10: Scope for Future Work

- This chapter concludes the future work of the thesis.

7. Methodology of research, Results / Comparisons

7.1 Methodology

- This study is separated into two sections: I Kinematic Modeling and Simulation of Physical Models; and (ii) Model Interfacing and Feedback. The kinematic analysis was performed using the Jacobi matrix, and the simulation was performed using the Simulink Programme. MatLab was used to interface the Experimental Setup. Feedback and validation were conducted utilizing an experimental setup comprised of Arduino / Processing 4.0 and MatLab.
  - Kinematic analysis to establish kinematic equations using Jacobian matrix techniques proposed:
  - Simulation-based investigation of the feasibility of a spatial mechanism. Additionally, construct recurrence relationships for velocity, acceleration, and generalized forces.
  - MatLab/Experimental Setup Interface & Reading
  - To conduct experiments to determine the model's stability behavior.
  - To collect feedback and validate the experimental setup using Arduino / Processing 4.0 and MatLab.
  - Validation of the proposed model using experimental data and published findings from other researchers.
  - Conclusions and discussion.

7.2 Experimentation and results:

The RSSR SS was evaluated using the experimental configuration shown in Figure 14. The experimentation was divided into three stages: the first stage involved kinematic analysis of the RSSR SS mechanism using MatLab Result shown in figure 15-23; the second stage involved manual reading of observer behavior for the model shown in Figure: 24-30; and the third stage involved feedback and validation of the experimental setup (Figure: 14) using

Arduino / Processing 4.0 and MatLab. The result is shown in Figures 31 to 44.

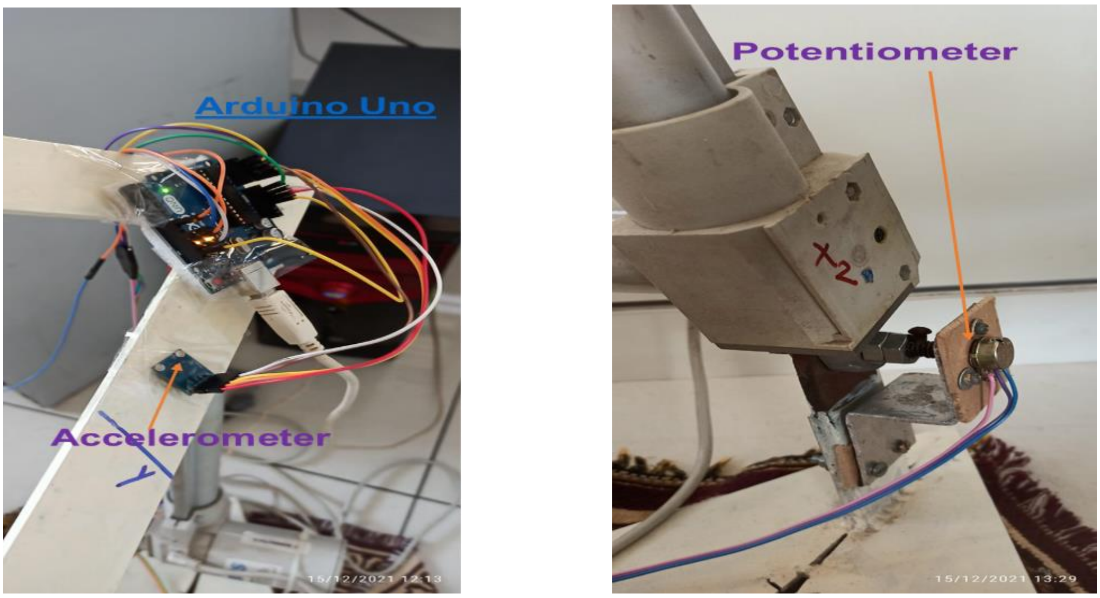


Figure: 14 Experimental Setup for RSSR SS manipulator with Potentiometer and Accelerometer using Arduino as feed back

7.2.1 *Kinematic analysis of RSSR SS mechanism using MatLab*

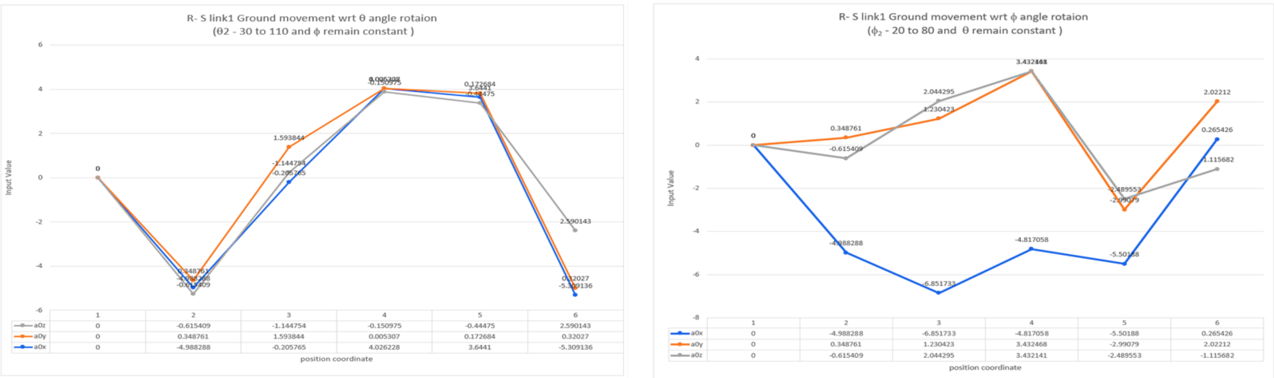


Figure: 15 R-S Link1 (Ground) with rotation angle ϕ and θ

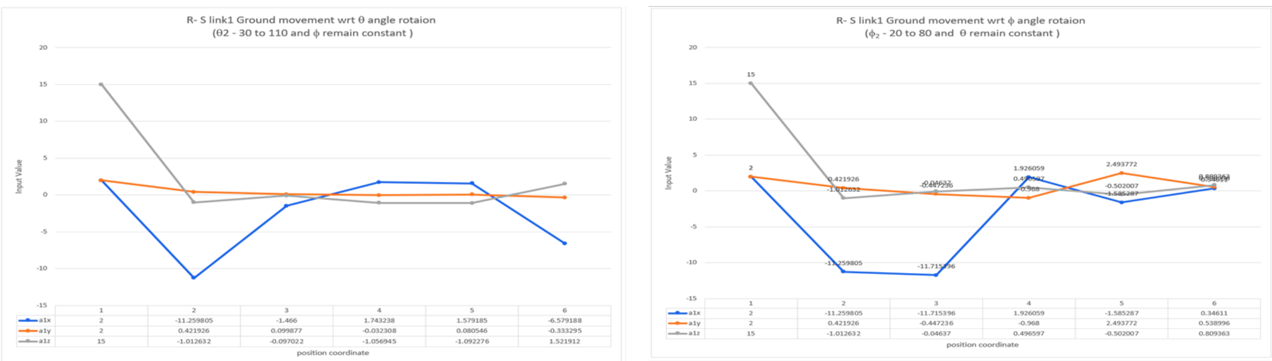


Figure: 16 R-S Link 1 (Output) with rotation angle ϕ and θ

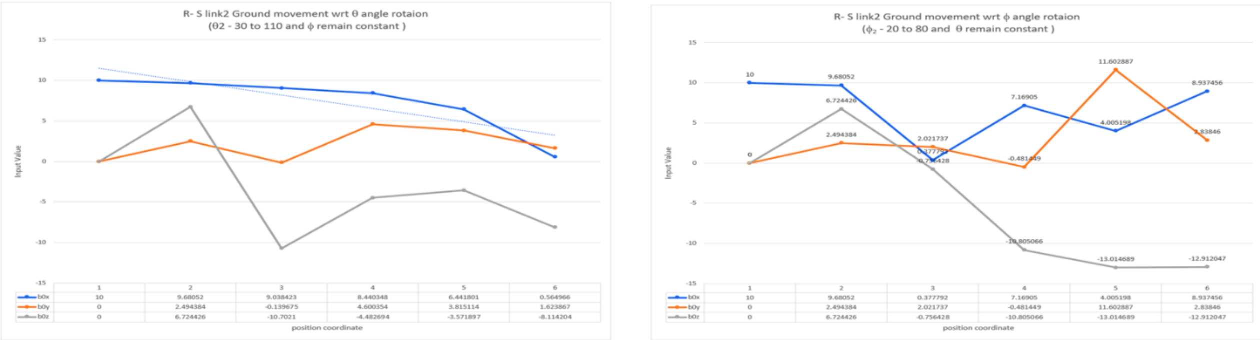


Figure: 17 R-S Link 2 (Ground) with rotation angle ϕ and θ

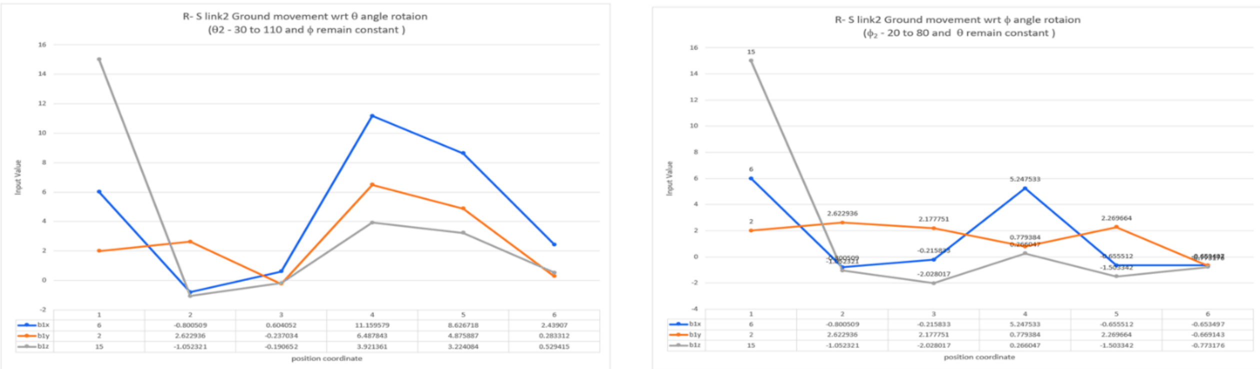


Figure: 18 R-S Link 2 (output) with rotation angle ϕ and θ

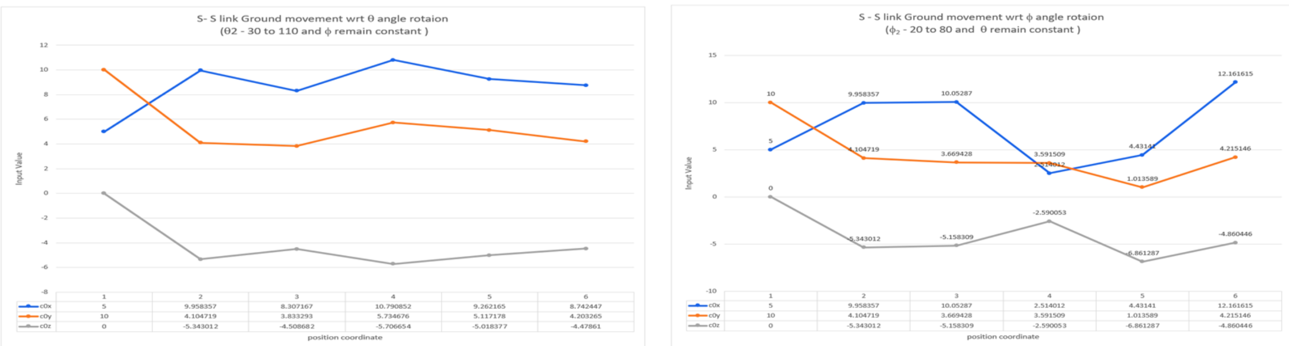


Figure: 19 S-S Link (Ground) with rotation angle ϕ and θ

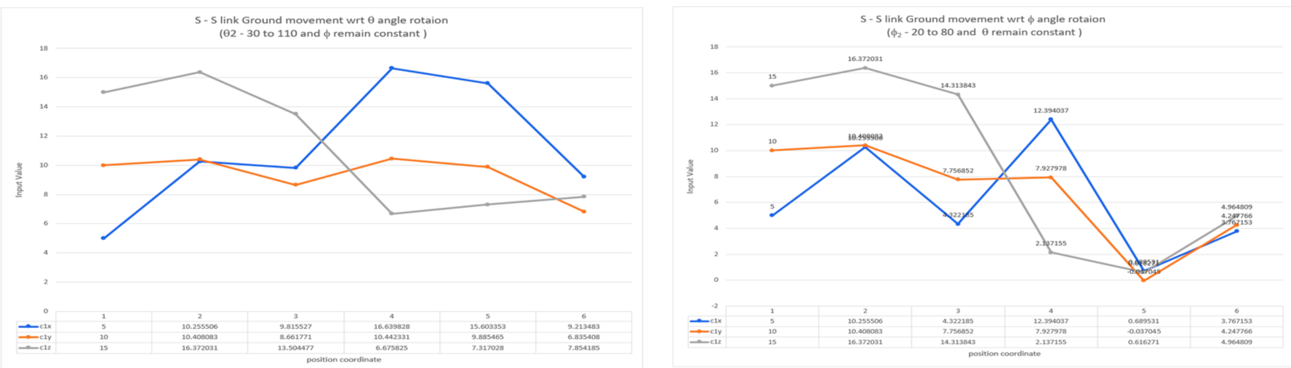


Figure: 20 S-S Link (output) with rotation angle ϕ and θ

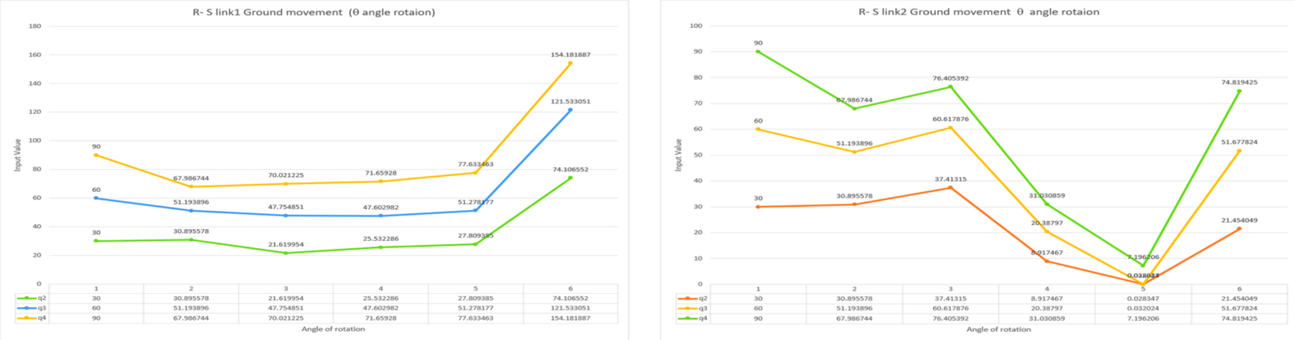


Figure: 21 Link rotation trajectory angle ϕ (Const.) and θ

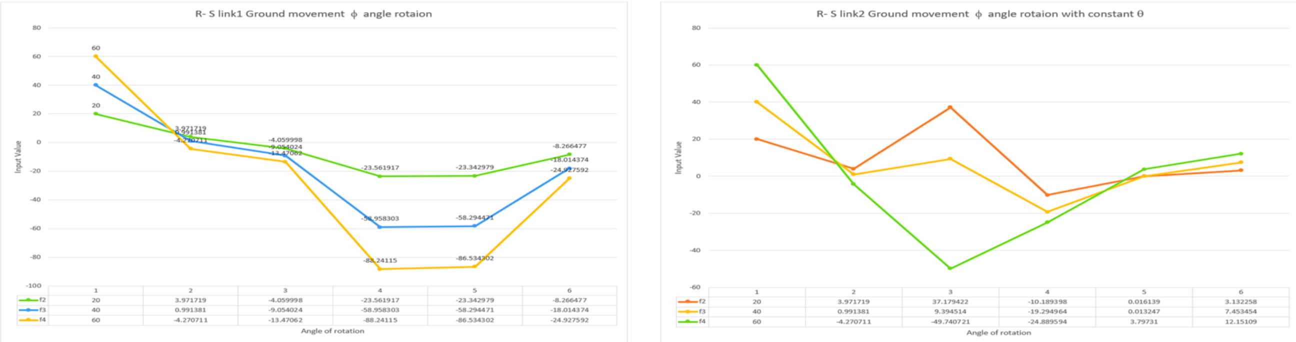


Figure: 22 Link rotation trajectory angle ϕ and θ (Const.)

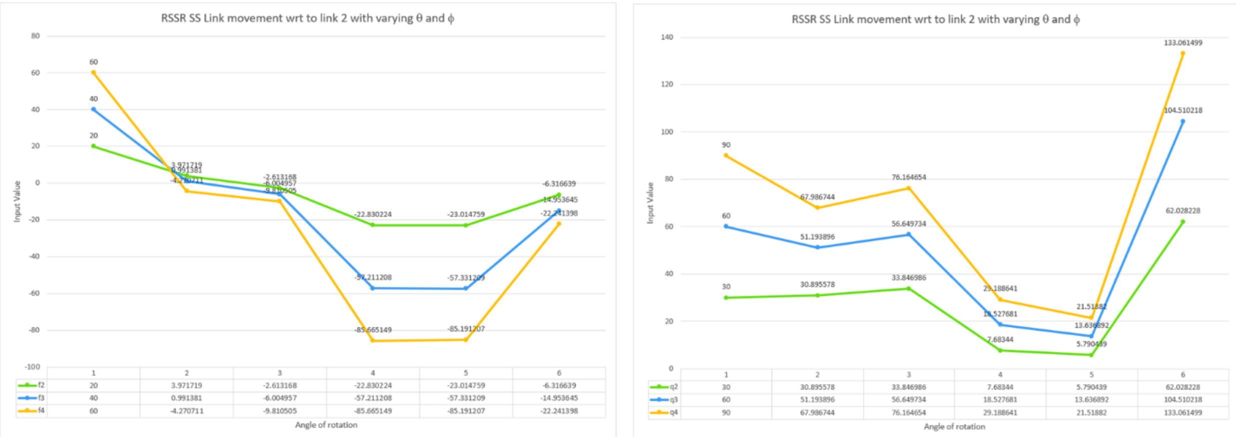
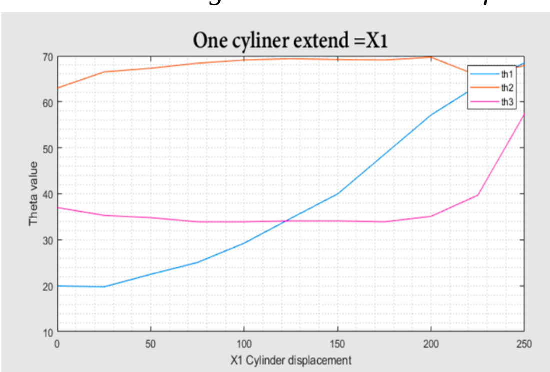


Figure: 23 RSSR SS full body - Link rotation trajectory with both angle ϕ and θ

7.2.2 *Manual Reading to observer behavior for Model using MatLab*



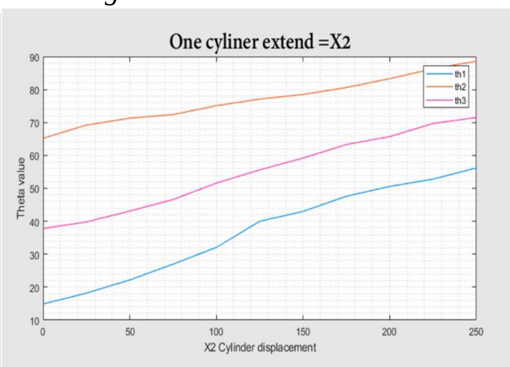


Figure: 24 for Cylinder No.1 Extend

Figure: 25 for Cylinder No.2 Extend

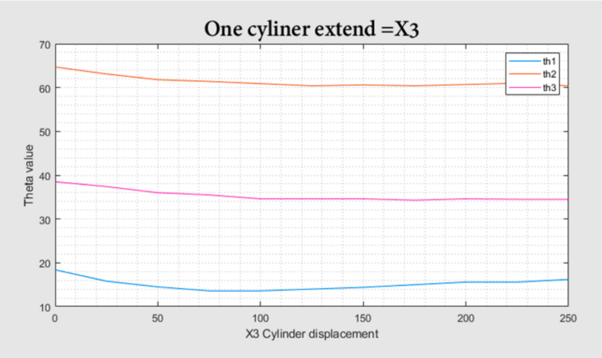


Figure: 26 for Cylinder No.3 Extend

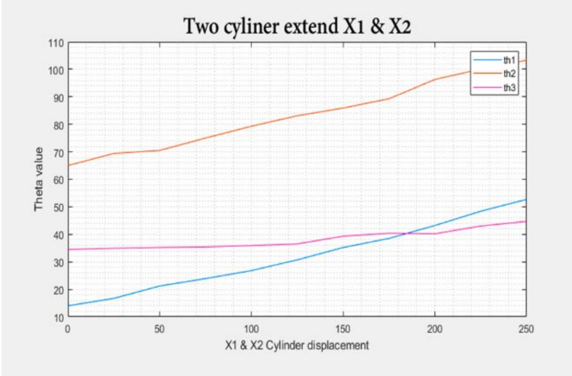


Figure: 27 for Cylinder No.1 & 2 Extend

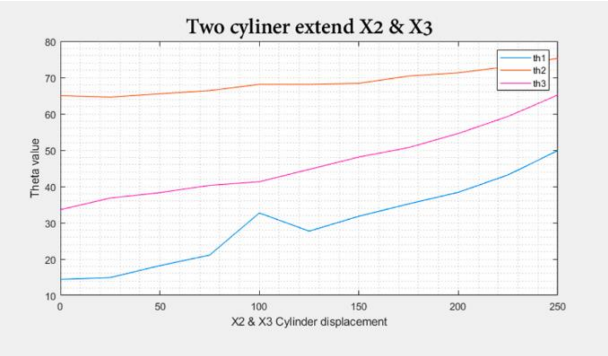


Figure: 28 for Cylinder No.2 & 3 Extend

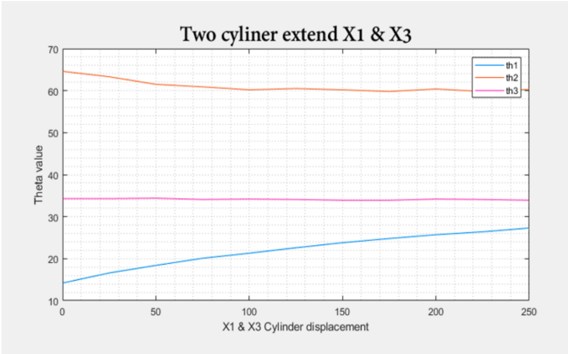


Figure: 29 for Cylinder No.1 & 3 Extend

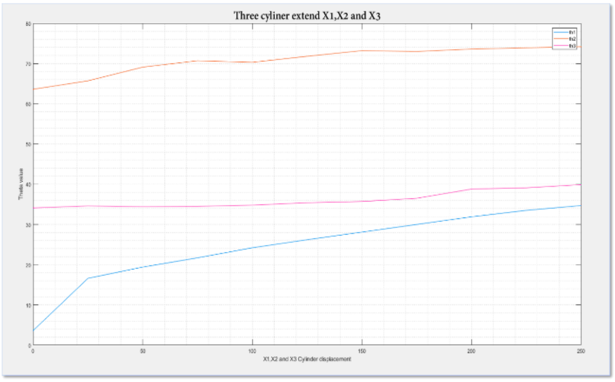


Figure: 30 for Cylinder No.1 & 2, 3 Extend

7.2.3 Feed Back & Validation of Experimental Setup using MatLab/ Arduino / Processing 4.0

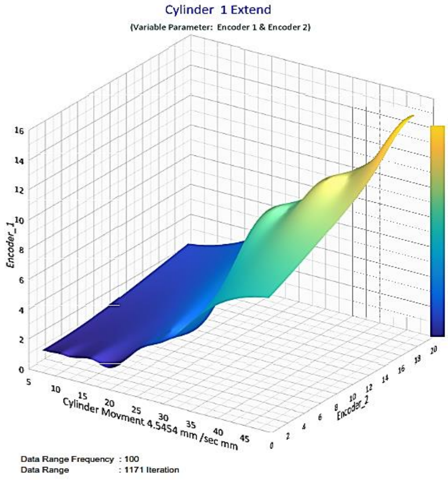


Figure:31 Encoder 1 &2 postion for Cylinder 1 Extend

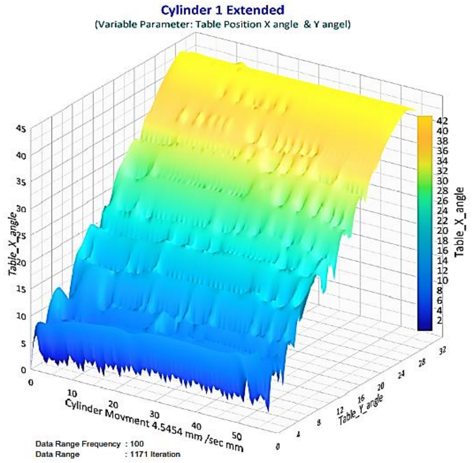


Figure:32 Table position for Cylinder 1 Extend

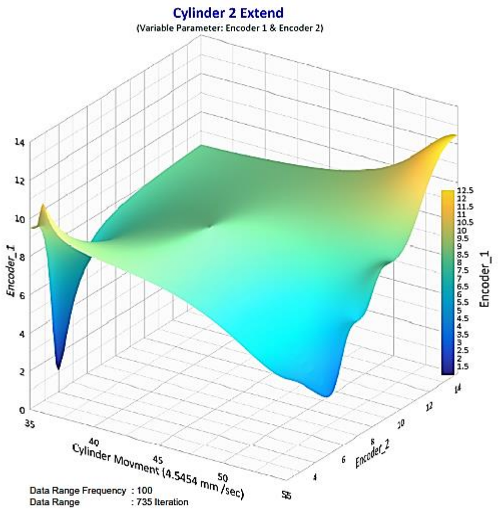


Figure:33 Encoder 1 &2 postion for Cylinder 2 Extend

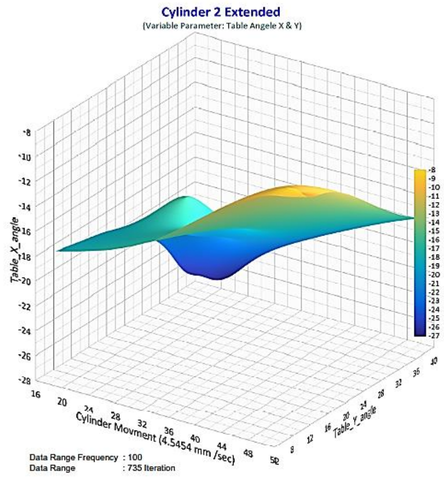


Figure:34 Table position for Cylinder 2 Extend

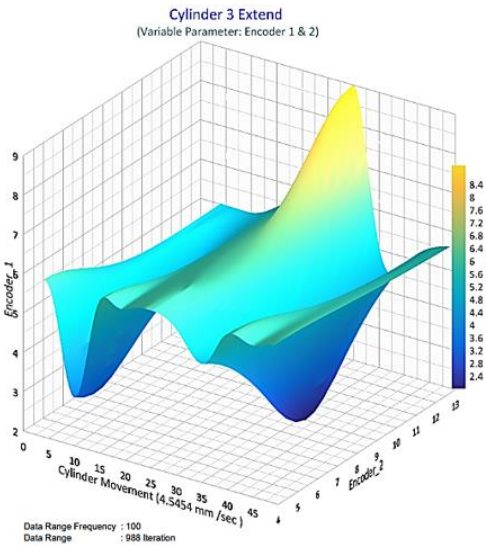


Figure:35 Encoder 1 &2 postion for Cylinder 3 Extend

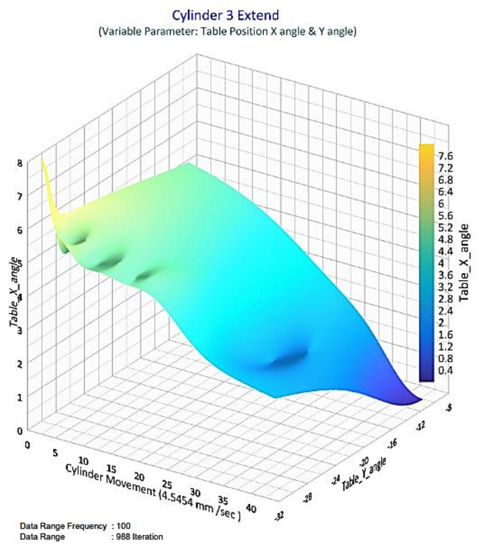
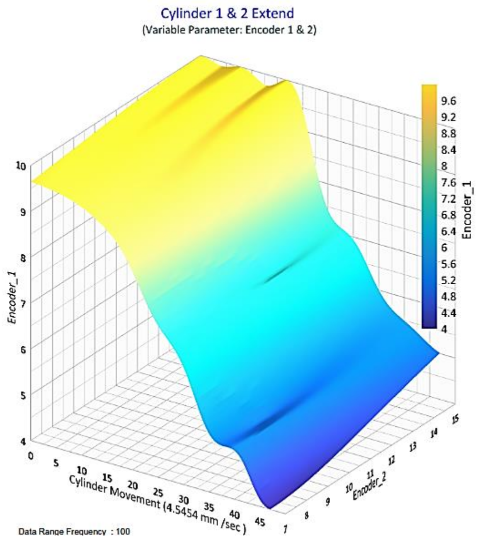


Figure:36 Table position for Cylinder 3 Extend



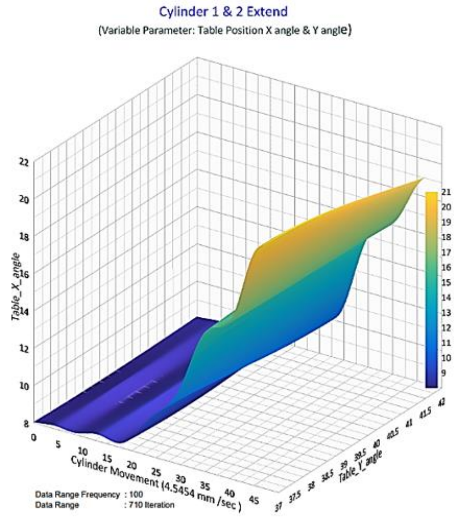
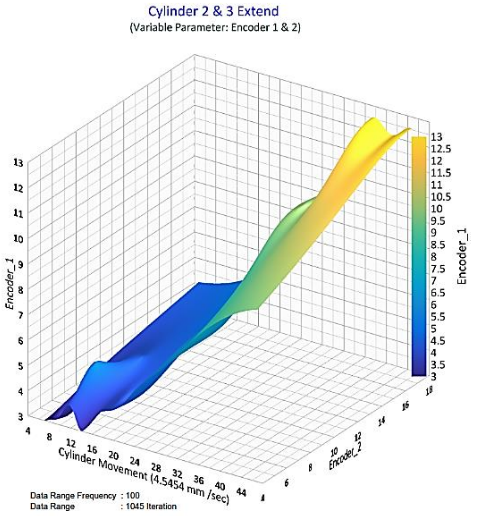


Figure:37 Encoder 1 &2 postion for Cylinder 1&2 Extend

Figure:38 Table position for Cylinder 1&2
Extend



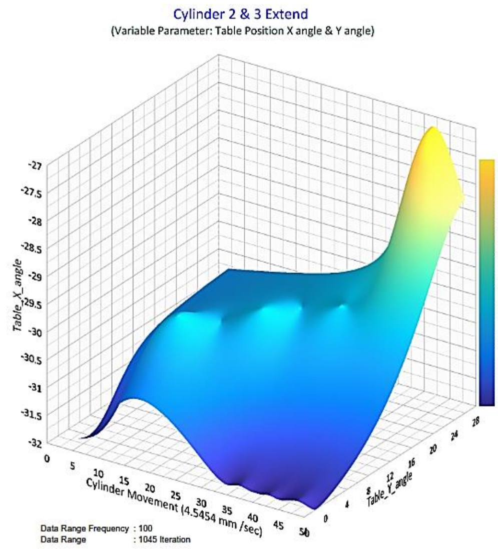
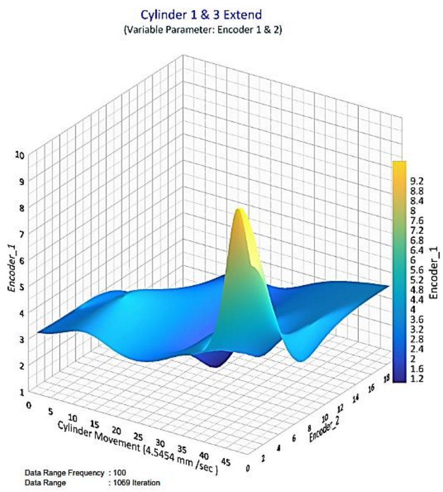


Figure:39 Encoder 1 &2 postion for Cylinder 2&3 Extend

Figure:40 Table position for Cylinder 2&3 xtend



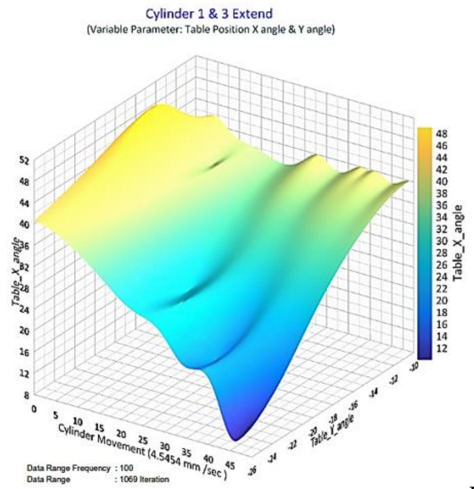
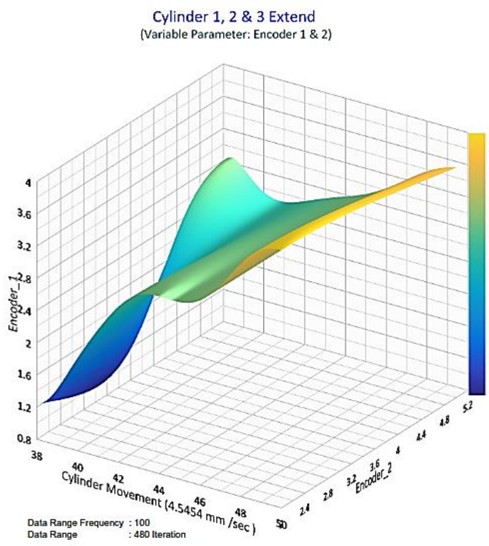


Figure:41
Encoder 1 &2 postion for Cylinder 1&3 Extend

Figure:42 Table position for Cylinder 1&3 Extend



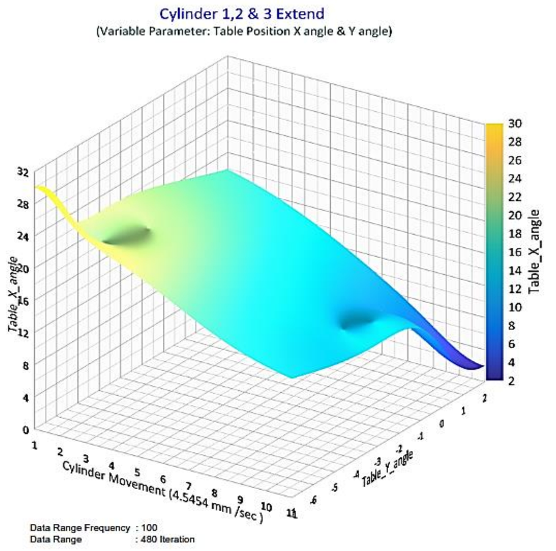


Figure:43 Encoder 1&2 postion for Cylinder 1,2&3 Extend

Figure:44 Table position for Cylinder 1,2&3 Extend

8. Achievements with respect to objectives

Sr. No.	Objectives	Status	Achievement
1.	Kinematic analyses of an RSSR-SS spatial mechanism to develop closed form input output nonlinear relation with numerical method	Completed	• **One Review Papers Published in following journals** International Journal for Research in Engineering Application & Management (IJREAM) ISSN : 2454-9150 Vol-04, Issue-10, Jan 2019
2.	Synthesis of RSSR-SS spatial for finding out the relationship between input and output linkages.	Completed	• **One Research Paper Published in following journals** International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8, Issue-12S, October 2019 (Scopus Indexed)

3.	Design, develop and analyze the RSSR-SS spatial mechanism.	Completed.	• **Patents filed** I. Application no.202021052060A Date: 30-11-2020 II. Publication Date 01-01-2021
4.	Compare the Experimental results of Mechanism with SimMechanics / MatLab result.	Completed.	• **Research Paper accepted for publication in following journal** Recent Advances in Engineering Materials(ICRAEM2022) ,Materials Today: Proceedings, Science Direct (Scopus Indexed)

9. Conclusion

9.1 Kinematic analyses

This study concentrated on mathematical modelling and the design and implementation of an RSSR SS Manipulator's real-time control system.

- Simulink® / SimMechanics® model accuracy is critical because it is used to create control systems. Additionally, Arduino and Processing 4.0 will assist us in obtaining real-time feedback in the form of a graphical depiction.
- The friction at the joints and the rigidity of the components are overlooked
- In order to evaluate the constructed model of RSSR SS, Jacobian kinematic solutions were specified in closed form. Tests were undertaken to determine the locations of links with regard to the required degrees of tilt of the top platform. The output findings were compared to analytical and simulated results, and the kinematic investigation led to the following conclusions.
- Individual link actuation position analysis revealed that experimental findings were more consistent with software-simulated and analytical results.
- It was discovered that the following parameters had an effect on the output angles of tilt of the top platform and the limited locations of nuts.
- From the graph, Cylinder 1 extends at a rate of 4.5454 mm/sec during the first 200 mm cylinder length Encoder 1 and moves at a rate of 0^o-8^o, then remains expanding at a rate of 10^o-16^o, and the platform table remains stable during rotations of 0^o-45^o in the x direction and 0^o-32^o in the y direction Figures (31-32).

- During operation of cylinder-2, both encoders provide rotating motion in the range 0o-14o and an average stability angle of 7.5^{o} after 735 iterations, indicating that the system is stable Figures (33-34).
- The angle of variation for encoder 1 is 2^{o}-9^{o} and for encoder 2 is 4^{o}-13^{o}, and the platform remains stable with an x-axis angle of 0^{o}-8^{o} and a y-axis angle of -4^{o}-13^{o}. During 988 iterations, stability increases by 0.4^{o} to 7.6^{o} Figures (35-36).
- Cylinder 1 & 2
  - Encoder variation ranges from 4o to 9.6o during combined extension of cylinder 1 & 2 • Platform table remains stable at 8o-22o in X direction and 9o-21^{o} in Y direction after 710 iterations. Figures (37-38)
- Cylinder 2 & 3
  - During the operation of cylinder 2 & 3, encoder one more time with 3^{o}-13^{o}where is encoder to you the variation from 4^{o}-18^{o} with the stability also the table platform gives a negative value in the X direction, indicating that it is sustainable, and a value between 2^{o} and 28^{o} in the y direction. This is the outcome of 1045 iterations. Figures (39-40)
- Cylinder 1 & 3
  - Similarly, after 1069 readings, the graph shows combining the extension of cylinder 1 and 3 encoders from 1.2^{o} to 29.2^{o} and encoder to give rotation with 0^{o} to 28^{o} where the platform remains stable in both X and Y directions with 0o-26^{o}. Figures (41-42)
- Cylinder 1, 2 & 3
  - After combining all three cylinders in extended positions, we get stability from 1.2^{o} to 3.6^{o} only where When the MatLab findings are compared to the experimental results (for the x and y axes), a maximum divergence of 3.5 percent is seen.(Figures 43-44)

The suggested manipulator is static and kinematically analyzed to evaluate the legs' stability and coordination.

9.2 Synthesis of RSSR-SS spatial / Design / Simulation

- The simulation results demonstrate the efficacy of the proposed technique and the RSSR-SS manipulator's dynamic equations, as well as the effect of Leg/Actuator inertia and that of its components on the overall system's dynamics.

- The Jacobian matrix and position vector techniques are used to generate kinematic equations. Dimensional synthesis is performed using the RSSR SS derived kinematic equations by considering a range of beginning angles (=30°, =60°, and =90° to =50°, =80°, and =110° with a 5° increase in all angles). The findings indicate that the Platform table tilt is directly related to the starting angle between the RSSR SS parallel manipulator's connection and base platform.
- The percentage difference between experimental and mathematical findings, as well as between simulation and experimental results, is determined to be no more than 5%.
- The given synthesis findings might be used to build and create a new generation of RSSR SS type manipulators for industrial applications. According to the findings of the synthesis, the angles of tilt of the top platform rose as the cylinder Leg Length was raised.

10. Scope for future study

Dynamic analysis, mathematical stability, and stiffness must all be modelled and verified to provide a better product design, after which industrialization of this RSSR-SS type PM may be planned.

- The inherent issue of vibration dampening is also perceived as a constraint on positioning accuracy. Vibration analysis is essential to determine the stiffness of PM connectors.
- Work volumes may be determined by factoring in the vertical distance (Z Direction) increased by the top adjustable platform.
- By using linear motors rather of planar or servo motors, the manipulator's design may be reduced.
- The structural analysis completed using ANSYS may be compared to the stiffness equation developed to maximize the PM's performance in angular machining applications.
- To optimize workspace for a variety of setup and kinematic properties, efficient optimization algorithms may be used.

11. List of all publications arising from the thesis

- K. V. Patel and P. M. Bhatt, “Design and dynamic balancing of multi-loop spatial mechanism-A Review,” Int. J. Res. Eng. Appl. Manag., vol. V, no. 10, pp. 433–438,

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- K. Patel and P. M. Bhatt, “An Application of Jacobian Matrix in Kinematic of Multi-loop Spatial Mechanism,” Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 12S, pp. 701–704, 2019. (Scopus Indexed Journal)
- “Modeling and dynamic analysis of multi loop RSSR-SS parallel manipulator”, Research Paper accepted for publication in journal Recent Advances in Engineering Materials(ICRAEM2022),Materials Today: Proceedings, Science Direct (Scopus Indexed journal)

12. Patents

- Kaushik Patel, Bhatt P.M. filed Full patent on “RSSR SS Motion platform with stability control using Universal Joint”. Date of filling: 30/11/2020, Application Number: 202021052066A. Application is published on the Indian **Patent Office Journal No. 01/2021 Dated 01/01/2021.**

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