FINAL PROJECT

POSITION KINEMATICS FOR DELTA ROBOT

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**TEAM NUMBER:** FINAL PROJECT-4

**GOAL**: The goal of this final project is to design, build and analyze the position kinematics of a delta robot.

**DELTA ROBOT- DESIGN AND QUALITATIVE ANALYSIS:**

A delta robot is a type of [parallel robot](https://en.wikipedia.org/wiki/Parallel_robot) that consists of three arms connected to [universal joints](https://en.wikipedia.org/wiki/Universal_joints) at the base. The key design feature is the use of [parallelograms](https://en.wikipedia.org/wiki/Parallelogram) in the arms, which maintains the orientation of the [end effector](https://en.wikipedia.org/wiki/Industrial_robot_end_effector). Industries that take advantage of the high speed of delta robots are the packaging industry, medical and pharmaceutical industry. For its stiffness, it is also used for surgery. Other applications include high precision assembly operations in a [clean room](https://en.wikipedia.org/wiki/Clean_room) for electronic components. The structure of a delta robot can also be used to create [haptic](https://en.wikipedia.org/wiki/Haptic_technology#Games) controllers. More recently, the technology has been adapted to [3D printers](https://en.wikipedia.org/wiki/3D_printers). These printers can be built for about a thousand dollars and compete well with traditional Cartesian printers.

We have designed and built a delta robot with 3 DOF, i.e., the robot can exhibit motion in X, Y and Z directions as detailed in figures below. The circuit design for motor movement, and the 3-D symbolic representation of the delta robot are as illustrated below.

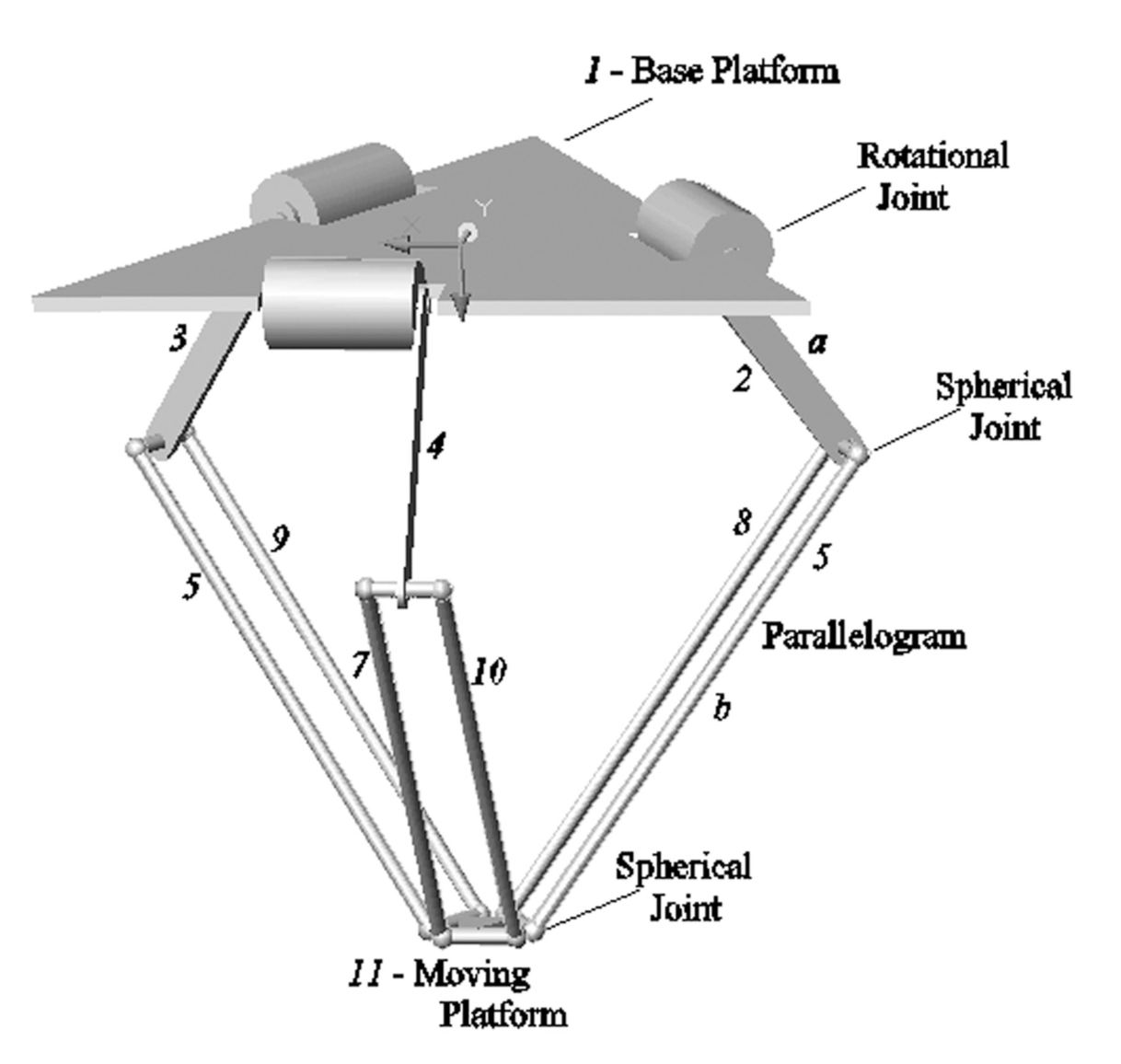


FIG 1. 3-D representation of delta robot

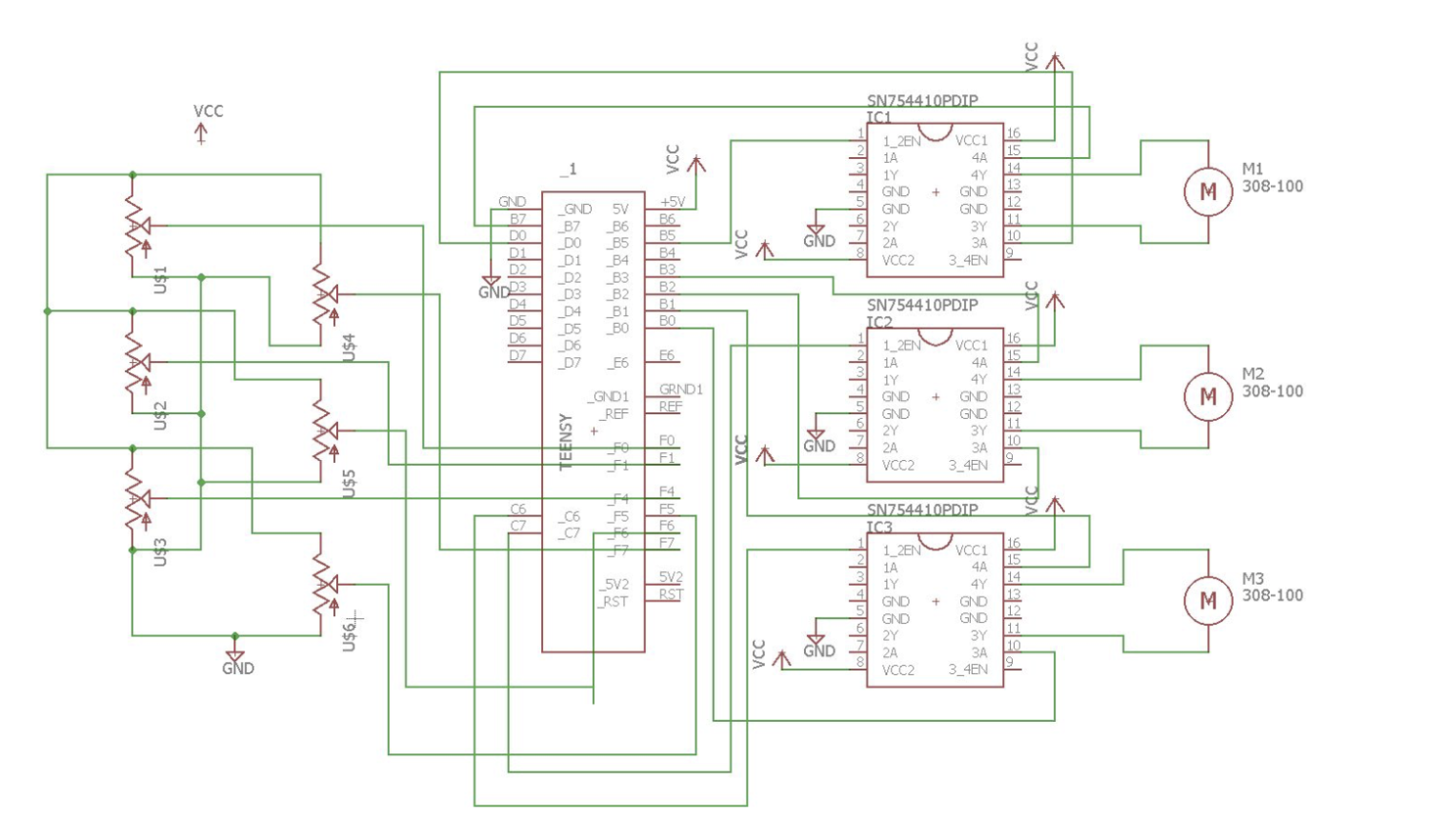
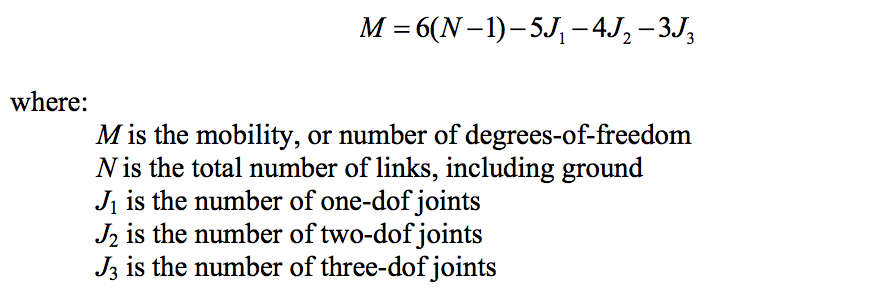


FIG 2. CIRCUIT DESIGN FOR MOTOR MOVEMENT

The designed robot has only revolute and spherical joints, its kinematic arrangement is found to be RUU (U represents the universal joints used in the delta robot, which are implemented using 3 non-collocated revolute joints).

This qualitative analysis of DOF estimation is backed up by the Kutzbach mobility equation given below:



Substituting for N, J1 , J2 and J3 as 14, 15, 0 and 0 (as per design of the delta robot) in the Kutzbach equation, we obtain a DOF of 3.

**METHOD:**

The kinematic scheme of the delta robot is as illustrated below. The delta robot has 2 equilateral triangle platforms: moving platform with the end-effector, and stationary one with the motors. As evident from figure below, the joint angles are theta1, theta2 and theta3, the end-effector position is Eo (xo, yo and zo).

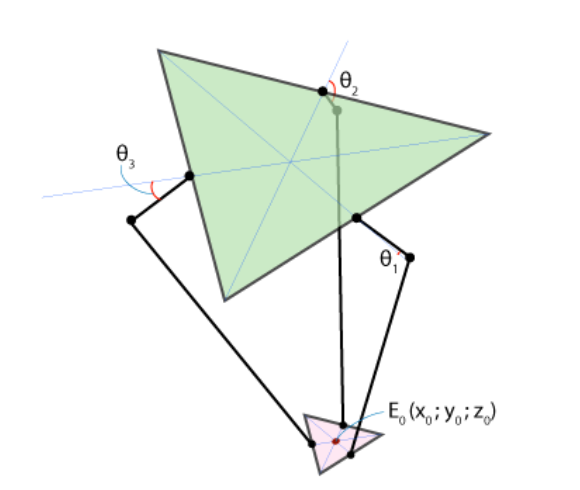


FIG 3. SCHEMATIC OF DELTA ROBOT

1. **Inverse Position Kinematics for Delta robot:**

Given a desired end-effector position, the solution for joint angles of robot is inverse kinematics. For parallel robots, it is easier to identify the inverse kinematics solution before forward kinematics (as multiple forward solutions exist for parallel robots). Therefore, we will first solve for inverse position kinematics on the delta robot. We use the geometric approach to solve this problem as it is much simpler than the analytical approach.

Consider the following parameters that depend on robot geometry designed:

* f – fixed platform equilateral triangle
* e – moving platform with end-effector
* rf – length of upper joint
* re – length of parallelogram joint

As the delta robot is designed to have a reference frame with its origin at the center of symmetry of the fixed triangle (as illustrated below), the z-axis is always pointed towards the negative direction.

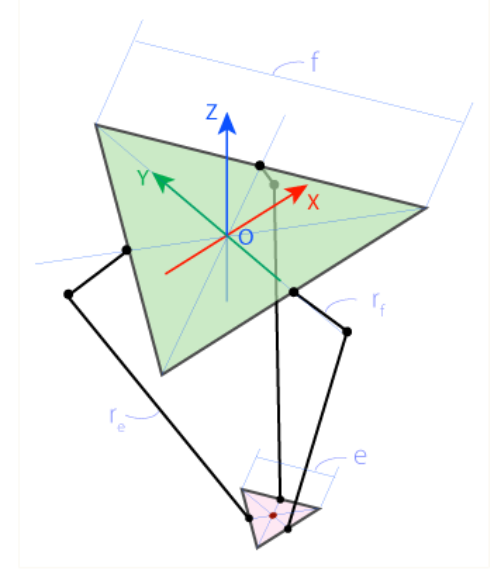


FIG 4. FRAME OF REFERENCE FOR FIXED PLATFORM

Joint F1J1 can only rotate in YZ plane, hence tracing a circle (as illustrated in figure below) at center at F1 with radius rf. J1 and E1 are the universal joints. Similarly, the joint E1 and J1 can trace a sphere relative to E1 at center E1 and radius re. The intersection of the formed sphere and YZ plane of the robot is circle at center E1’ and radius E1’J1 (E1’ is the projection of point on the YZ plane). Now, point J1 can be estimated from the intersection of circles (of known radius) at centers E1’ and F1. Once J1 is calculated, we can easily arrive at the joint angle theta1 using the below equations.

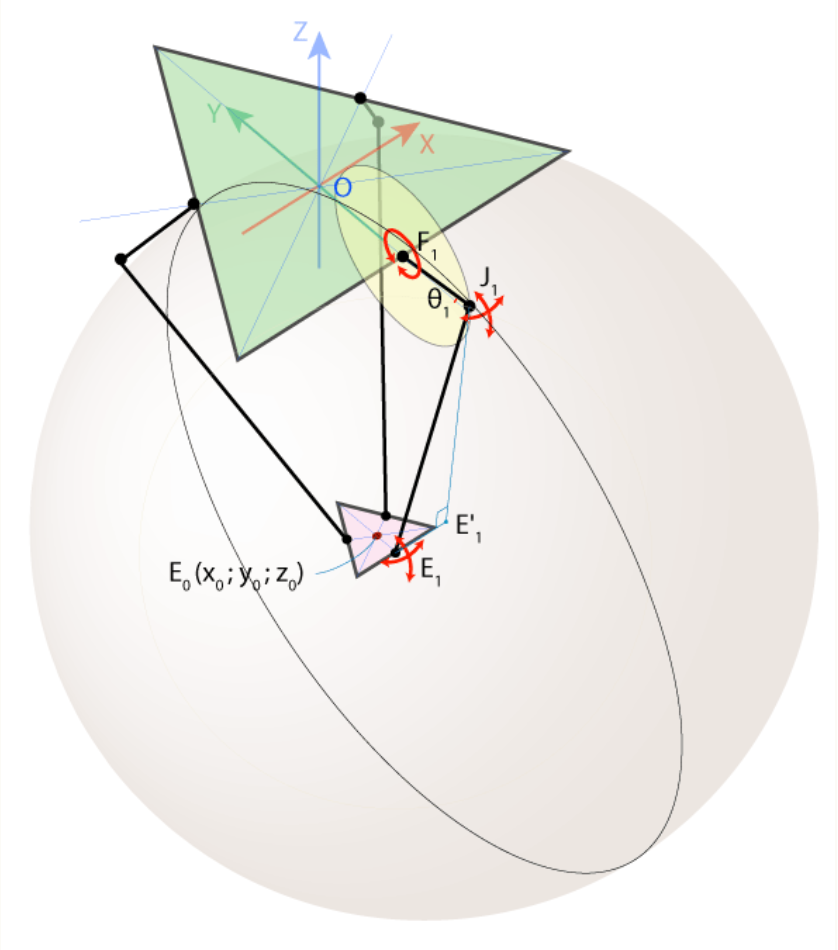
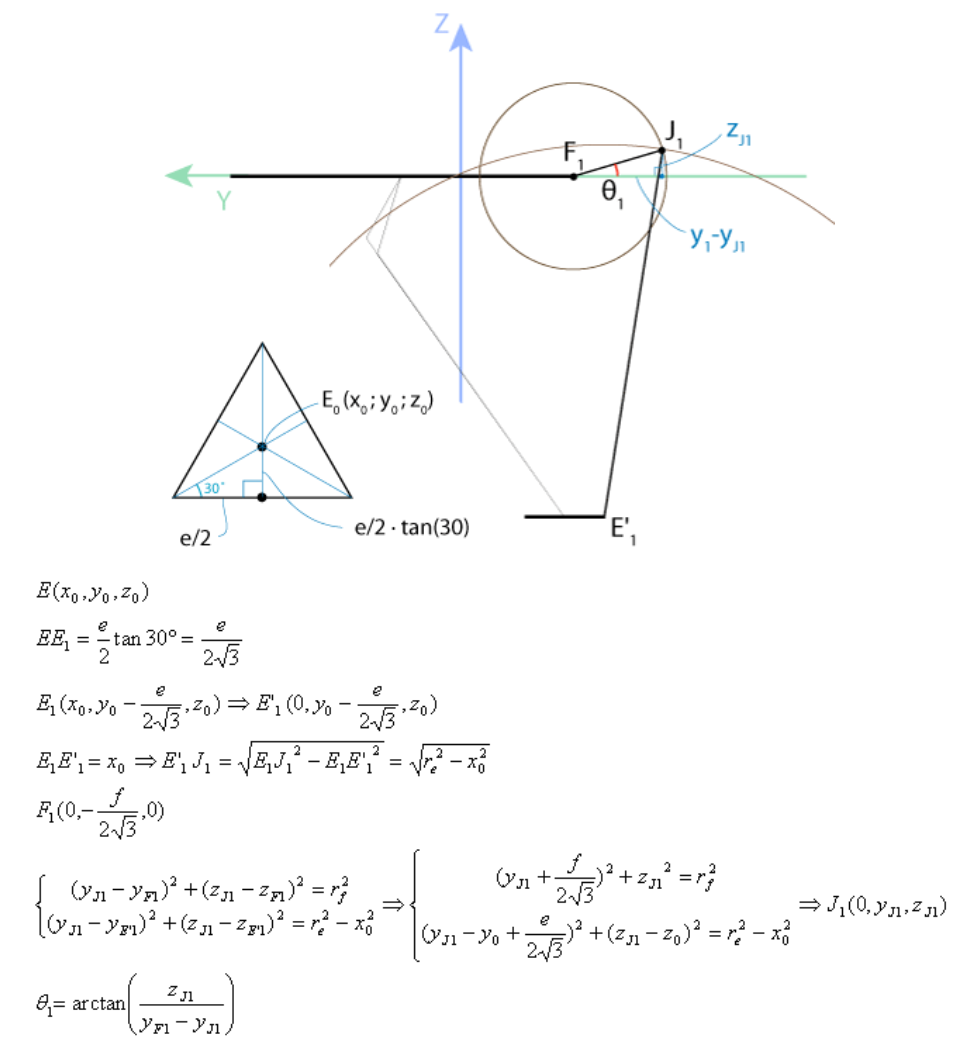


FIG 5. TRAJECTORY OF F1J1 JOINT MOVEMENT IN YZ PLANE

Using the symmetry of the parallel robot to our advantage, we can estimate angles theta2 and theta3. Upon choosing a frame of reference that has a joint moving in a single plane, we can omit the 3rd axis. To use this concept to calculate theta2 and theta3, we can rotate the coordinate system in XY plane about the Z axis by an angle of 1200 counterclockwise to obtain a new frame of reference as shown in figure below. We can easily the joint angle theta2 from the new frame of reference X’Y’Z’ in a manner similar to calculation of theta1. The only difference in calculation is that we must now determine co-ordinates x0’ and y0’ of E0. This can be achieved using corresponding rotation matrix (to account for the rotated in frame of reference). Similarly, theta3 can be found by rotating frame of reference in a clockwise direction.

EQUATIONS TO SOLVE FOR THETA1, AND BY EXTENSION THETA2 AND THETA3:



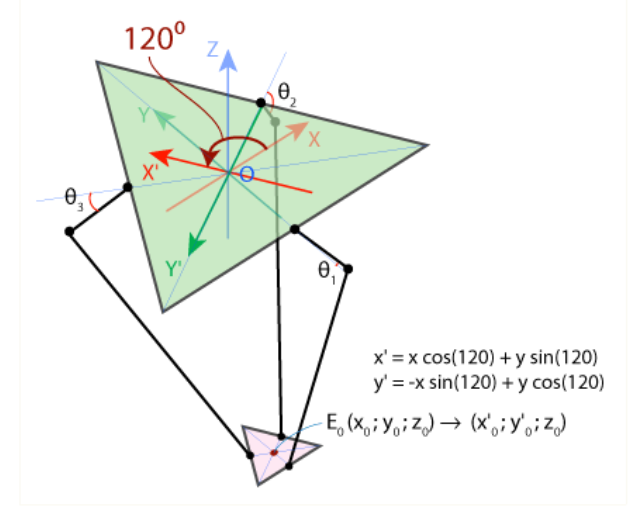


FIG 6. ROTATION OF XY PLANE ABOUT Z AXIS TO FIND THETA2

Hence, we can solve the inverse kinematics problem using the geometric approach in manner described above to find the joint angles theta1, theta2 and theta3.

1. **Forward Position Kinematics for Delta robot:**

Finding the position of the end-effector given the joint angles of the robot is the forward kinematics solution. Solving this problem is generally very difficult as it requires the solution of multiple coupled nonlinear algebraic equations. Multiple valid solutions generally exist. As the 3-DOF delta robot is translation only, there exists a straightforward analytical solution for which the correct solution is easily chosen.

Given the 3 joint angles theta1, theta2 and theta3, we can find the coordinates of points J1, J2 and J3. It is evident from the figure below that joints J1E1, J2E2 and J3E3 can freely rotate around joints J1, J2 and J3, respectively (this movement will trace circles of radius re).

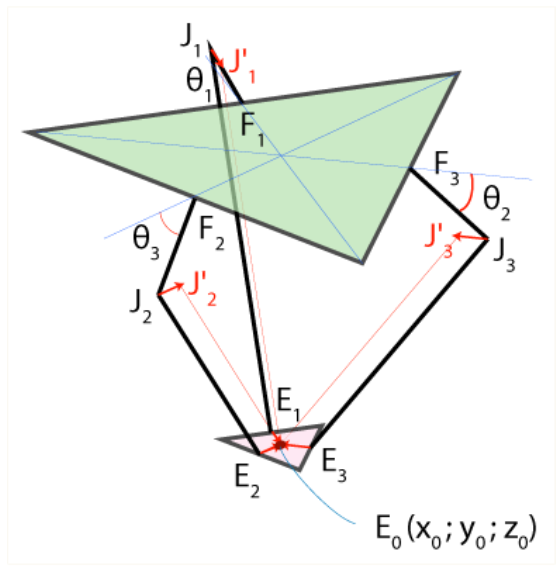


FIG 7. SCHEMATIC REPRESENTATION FOR FORWARD POSITION KINEAMTICS

By transitioning the center of these spheres from J1, J2 and J3 to J1’, J2’ and J3’ using E1E0, E2E0 and E3E0 as ‘transition vectors’, the spheres will now intersect at point E0 as shown in figure below:

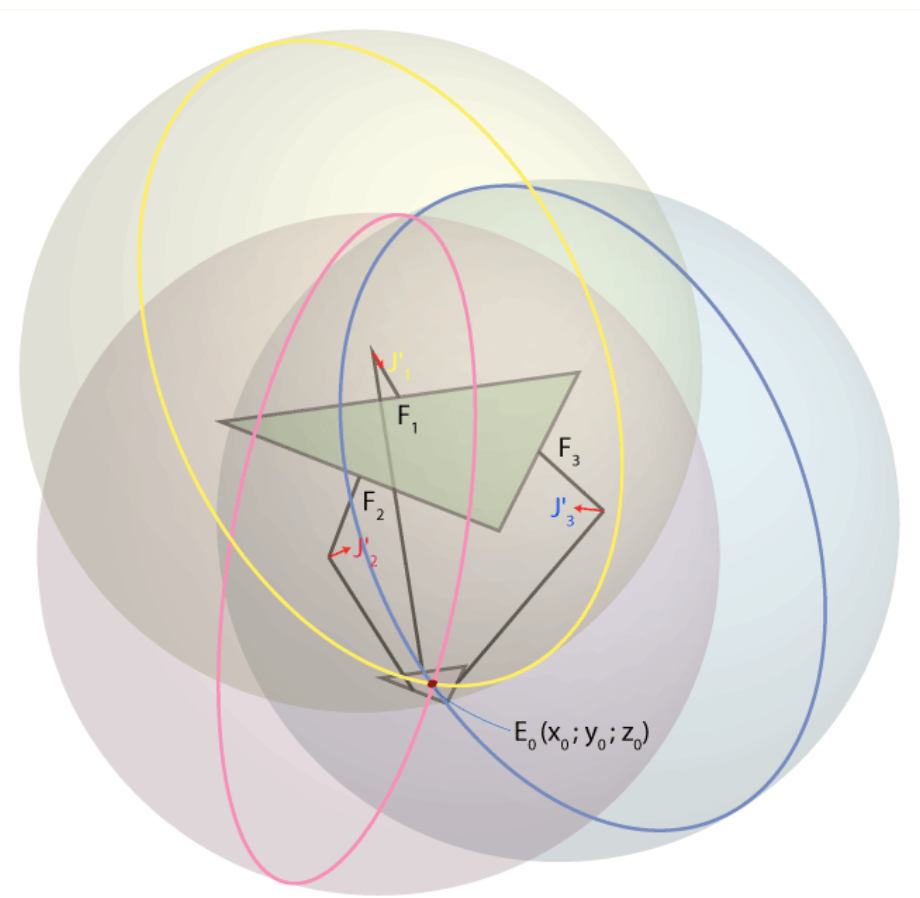


FIG 8. INTERSECTION OF TRASITIONED CENTERS OF SPHERES

Now, to arrive at the end-effector co-ordinates of E0, we can solve the equations of form (x-xj)^2+(y-yj)^2+(z-zj)^2 = re^2 for these 3 spheres simultaneously (as shown below). Before that, to find the coordinates of transformed points J1’, J2’ and J3’ we follow the setup below:

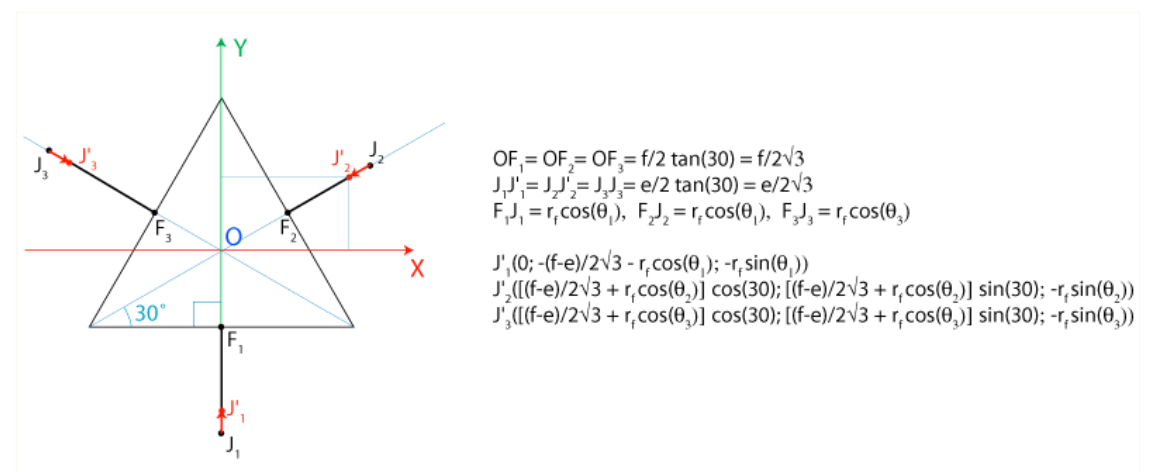
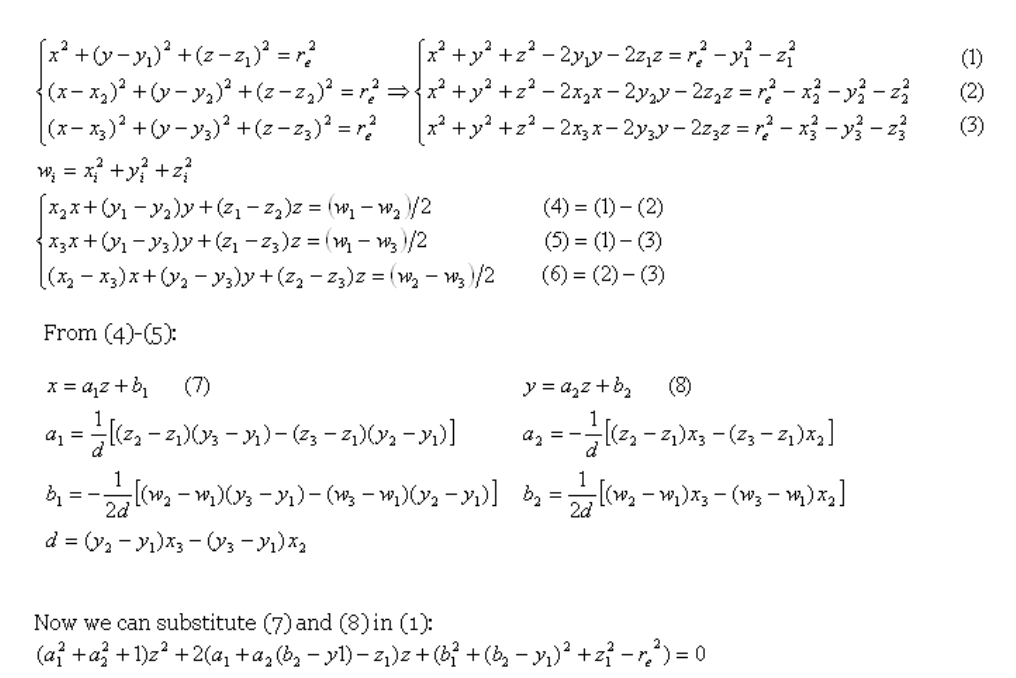


FIG 9. TO FIND COORDINATES OF J1’, J2’ AND J3’



Hence, we can solve the forward kinematics problem using the geometric approach in manner described above to find the end-effector co-ordinates.

**PSEUDO-CODE:**

**EVALUATION:**

**ROBOT SETUP- MASTER SLAVE FORMAT**

1. Forward Kinematics: 3 TEST CASES WITH FIGURES
2. Inverse Kinematics: 3 TEST CASES WITH FIGURES

**ANALYSIS:**

* Comparison with expected results: Simulation?
* When does it work well? And when does it not?
* Any differences from expected result?
* Workspace

**FUTURE SCOPE OF PROJECT:**

Although we studied parallel robots in class, we did not extensively analyze the kinematics of the same. We found this to be a good opportunity to utilize the skills acquired through this course and exercise the same. We also found the final project to be a good opportunity to understand current literature on robots/kinematics. The scope of this project is not limited to current implementation, given more time we could have explored the following avenues for better performance.

* Velocity kinematics analysis on delta robot to identify which method works better (position or velocity kinematics) for various applications.
* Can extend this project for haptic applications.

**REFERENCES:**

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