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# Robots and Their Applications

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**Abstract -** *In this study; The robotization process, which has increased its development from the past to the present, has been researched, robots have been examined according to their usage areas and the parts and mechanical structures of the robots have been investigated. Working principles of delta robots, which are among the parallel robot types which are frequently used in the industrial field, have been examined. Kinematic calculations for the purpose of designing delta robots in accordance with the working conditions have been investigated. The solid model of the delta robot is designed in accordance with the calculations. After the necessary electronic cards were supplied and the robot has been assembled and sample applications of the delta robot were made.*

***Key Words***: **Robots, Robotics, Parallel Robot, Delta Robot, Kinematics**

## 1. INTRODUCTION

Human beings have been constantly in facts and breakthroughs aimed at self-improvement and facilitating their lives. Humanity; first he learned the stone age, then after learning to shape the metal, lived the metal age. Constantly evolving and refusing to be content with what it has, humanity has opened the doors of innovations that have been going on for ages and has become an exemplary model for the next generations. In order to design smart machines in "Mechatronics" science, the foundations of which were first laid in Japan in 1969; In engineering and process, mechanical engineering has a strong relationship with electronics and computers. The content of the science of mechatronics can be listed as mechanical design and analysis, robotic systems, image processing, control engineering, artificial neural networks and virtual reality with artificial intelligence. [1].

Robots, which are electro-mechanical devices, are the most fundamental part of mechatronics science. The desire to give life to artificial systems lies in the earliest periods of human history, in the depths of history. [2].

When it comes to robots, first of all, there are devices with human features in the basic image in the mind of a large number of people. In fact, contrary to this image, the main robots are industrial robots used in industry in fast, serial and reliable production. In the world, which is constantly evolving and changing throughout the life of human beings, the industry has the same level of technological development. In this context, as humanity day by day and technology developed, they preferred to exercise their brain functions instead of exhausting themselves physically [3].

## 2. LITERATURE REVIEW

Liu and friends [4], they conducted a study titled "A New Approach to the Design of a DELTA Robot with a Desired Workspace.". In their study, they presented a desirable field of study and a new design study, taking into account the rotary spacing of the spherical joints of the delta robot. In their study, firstly; geometric descriptions of the working area of the delta robot were discussed. It is concluded that the design and implementation of the parallel robot, which is presented as a result of the design as an application example, is positive.

Afroun and friends [5], they conducted a work titled "Planning optimal motions for a DELTA parallel robot". The purpose of this study is about the problem of planning the most suitable trajectories of a delta robot. The planning process is a motion search process that provides the fulfilment of the given task, minimizes the cost function and provides various restrictions specific to robot kinematics and dynamics. A sequential and second order programming method was used. The proposed approach is applied in situations involving movements from one point to another or movements along specified paths.

Angel and friends [6], they conducted a study titled "Dynamic optimization and construction of a parallel delta type robot". In their work, as a result of concerns arising from robotic concerns of the Colombian industry, they see the delta robot as a remedy in this process. For the Colombian industry, the speed and reliability of the delta robot seems to be advantageous in product packaging and selection. They say that with the prototype robot they designed, they will inspire future applications in the regional industry.

Cubukcu and friends [7], they carried out a study titled "Identifying and Sorting Objects on 3-Axis Robot Mechanism with Image Processing". In their studies; Letters and numbers entered from the program have been created on a black background by a camera mounted on a 3 (three) axis carrier system. Location determination has been done by using image processing methods in matlab environment. After the positioning process is completed, the letters and numbers have been held with the vacuum holder and the words have been re-created.

The moving of letters and numbers to specified locations has been carried out using servo motors, S7-1200 PLC and servo drive cards.

Bakir and friends [8], they carried out the work titled "By a Camera Mounted in the 3-Axis Robot Mechanism; Defining and Separating Geometric Objects of Different Rotation and Dimensions with Vacuum Gripper". In their study, by a camera which is mounted on a 3 (three) axis carrier system has been studied to recognize different geometric objects which are on a black background with the help of image processing techniques and to separate the objects into boxes in different coordinates.

Horoz and friends [9], they carried out the work titled "Transport of Objects Distinguished by a Camera with the 3-Axis Robot Mechanism". In this study; Objects on a black background have been transferred to the computer via a USB camera which have been mounted on the vertical axis of a 3 (three) axis Cartesian robot mechanism. If these transferred objects are letters, the name is printed; if it is a geometric shape, it is carried to another coordinate and if it is red, it is separated from other objects. Objects separated by image processing methods are then held with a vacuum gripper. Transportation is done by servo motors.

Huang and friends [10], they carried out a study titled "Conceptual design and dimensional synthesis of a novel 2-DOF translational parallel robot for pick-and-place operations". In this study; It relates to the conceptual design and dimensional synthesis of the optimal robot with two degrees of freedom for the pick and place operations. They have concluded that with a single degree of freedom feeding mechanism, a hybrid robot can be created to move objects step-by-step or long-distance movements normally.

Kose and friends [11], they carried out a study titled "Pantography Application with Real-Time PLC Based On Image Processing in Gantry Robot System". In this study; it is aimed to obtain the image again by subtracting the boundary coordinates of the image taken with the camera in Matlab environment. To achieve this goal, the servo drives of the Cartesian machine have been controlled and the application was realized. Two different methods were applied for the image taken in Matlab environment. The skeleton of the image was taken for the first method and then the boundary coordinates were determined. For the second method, the contour of the image has been first extracted. The coordinates of the contour image have been not directly used. These coordinates have been tried to be optimized. In this study, it is aimed to draw a desired image by drawing border coordinates in Matlab with Rexroth PLC on a Cartesian machine. As a result of the test studies, it was seen that the drawing process was carried out properly (according to the coordinates received) as a result of the analysis and measurement processes (metric caliper and measurement methods).

## 3. ROBOTICS WORLDWIDE

The robotics market worldwide is expected to reach a volume of $ 100 billion between 2018 and 2020.

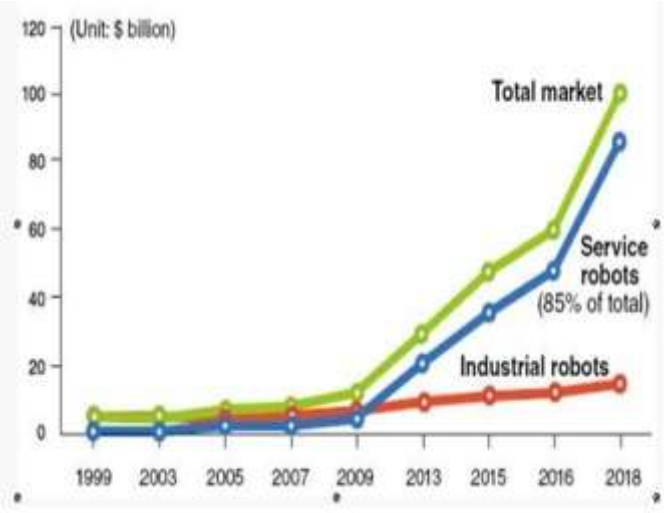


**Fig - 1:** Global Robot Market [12]

''In 2018, a significant increase has been observed in the robot market in both industrial and service areas. Compared to 2017; there were 422,000 industrial robots sales in 2018, with an increase of 6%. Accordingly; the global robot market was increased to $ 16.5 billion in volume" [13]. According to the 2017 IFR report, the robot density, for 10,000 employees in 2016 is given below.


**Fig - 2:** Robot Density by Countries in 2016 [14]

While South Korea, ranks first as country, Europe is the leader among the continents. In 2017, while installing 106 robots in European factories; America has made 91 and Asia has been 75 installations. According to the '' 2019 Employment Outlook '' report published by the OECD (Economic Cooperation and Development Organization) in 2019; humans, leave dangerous jobs to robots. In this way, people can work in jobs that are more qualified. According to

the report; The sales figures of robots were not even 100 in 2014, but this figure approached 400 thousand in 2017. Finally, in 2021, this figure is expected to be more than 600 thousand [15].

## 4. DELTA ROBOTS

There are robots with different structures that are produced for use in many areas. In general, there are 3 (three) main elements that are expected from the robots. These elements are; It can be said as speed, accuracy and precision. Today, industry is developing depending on the development of science and technology. Until now; robots have been developed in the industry on serial kinematic logic. As the objects that the robot will carry grow, the structure of the robot grows. This too will cause an increase in mass. Naturally, increasing mass will cause a decrease in acceleration and speed. To solve these problems, a design has been made where the joints, are on the same platform. According to this; each arm, will move separately and will not create a load on each other. Thanks to the lightness in the joints, the robot will work more efficiently and faster [16].

Delta robots, especially in industry; they take part in jobs where speed and precision are important. In its design, the parallelogram principle prevails. They consist of joints with an angle of 120 degrees between them. In this way, they can easily perform most tasks. They are used in different fields in the industry. Delta robots are used in the industry, in the applications that require careful attention, in the arrangement, collection, separation and packaging of the products. The speed and high quality of the work has been effective in reducing the cost [17].

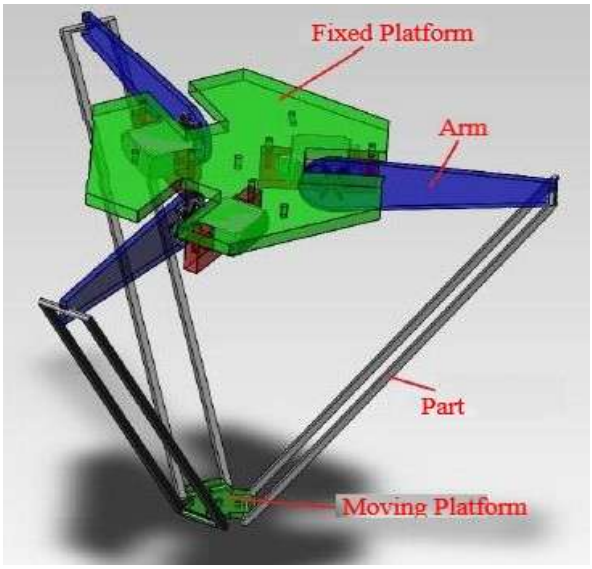


**Fig - 3:** Delta Robot's Mechanical Structure [18]

### 4.1 Delta Robots Usage Areas

Delta robot's, are often used on the especially during the packing of products packaged in the food industry. After programming how many packaged products will be put into the boxes and in what ways this will be done, delta robots successfully fulfills these desired tasks. Such, transactions are carried out in the pharmaceutical industry in the same way. Delta robots' properties to work with or without camera adds extra features to them. Thanks to these features, the reasons for being preferred in the industry are gradually increasing [17].

**Fig – 4:** Packing Delta Robot [19]

Recently, an increase has been observed in the usage areas of delta robots. It has started, to be used in food, electronics, pharmaceutical industries and as well as in sectors such as textile, automotive and furniture sectors. Delta robots, are also preferred in mold making, drawing processes, copying and cutting processes in these sectors since they work fast and error-free. In addition, very successful results are also obtained in surgical applications [20].

**Fig – 5:** Delta Robot Used in Surgical Applications [19]

In the electronic industry since the preparation of circuit boards requires fine workmanship, the delta robots used in preparing the circuit boards in this sector work very successfully.

**Fig – 6:** Delta Robot Preparing Electronic Circuit Board [19]

## 5. MATERIAL AND METHOD

In order for the designed robot to work in suitable conditions, the necessary mathematical calculations must be made. Using these mathematical calculations, the dimensions of the elements of the robot can be determined. In this study a suitable delta robot prototype has been developed, and various applications have been carried out with the robot where the necessary materials, have been obtained and assembled. Figure 7, shows the solid model of the delta robot designed in a computer environment. After this stage, kinematic calculations of the robot are made.

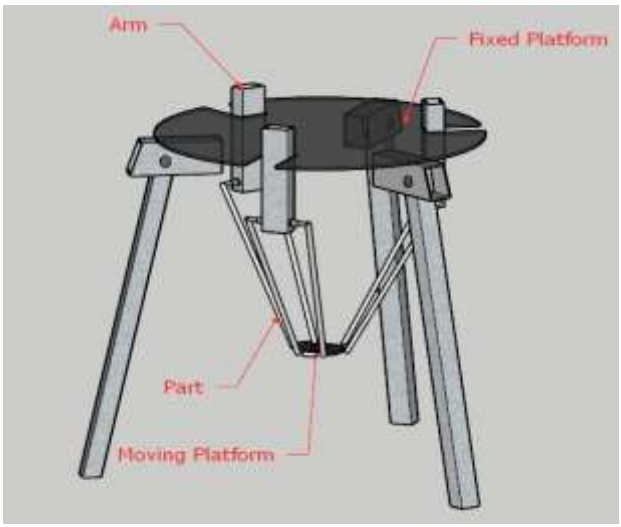


**Fig – 7 :** Solid Model of the Robot

### 5.1 Kinematic Design

The branch of science that studies the geometric position of movements is called kinematics. To perform kinematic calculations of a robot, the robot's joint variables must first be determined [21].

### 5.2 Determination of Joint Variables

Many methods are used in determining joint variables in the robot. For example, exponential method and Pieper-Roth method. The most widely used and preferred method among the methods is the Denavit-Hartenberg method, represented as D-H.

### 5.3 D-H (Denavit-Hartenberg) Method

In the D-H method, 4 (Four) variables are used when calculating the kinematics of a robot. These 4 (four) main variables;

- the ligament length between the two axes shown as ($a_{i-1}$),
- the angle of ligament between the (i-1) and i axes denoted as ($\alpha_{i-1}$),
- joint shift between overlapping ligaments ($d_i$),
- and ($\Theta_i$), is the joint angle between the two ligaments.

These 4 (four) main variables are called the D-H variable for short. In order to determine the variables, the axes of rotation in the robot must first be determined and numbering must be made to the determined axes of rotation. Then the coordinate system is placed, on each axis. The Z axis in the coordinate system, represents the axis of rotation of the ligaments. [21].

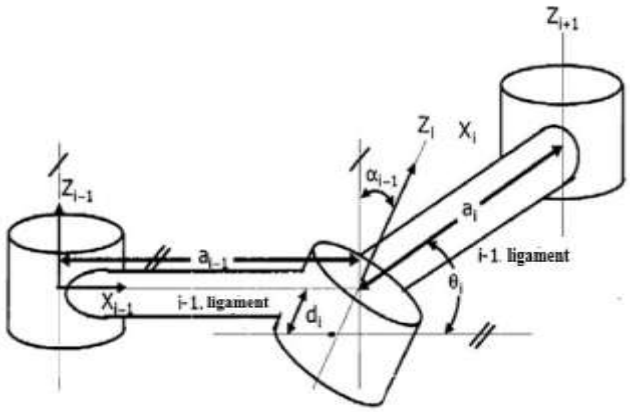


**Fig – 8:** Representation of Joint Variables [21]

Here, ($a_{i-1}$) and ($\alpha_{i-1}$) are variables that are not dependent on the motion of the robot, that is the change in the motion of the robot does not change these parameters. But parameters ($d_i$) and ($\Theta_i$) vary depending on the robot's

motion. Here the important, thing is to know that only one of the parameters that change depending on the motion of the robot will change [21].

### 5.4 Placement of Coordinate Systems in Joints

There are some steps to follow when placing coordinate systems. And coordinate systems are placed according to these steps. These steps are given below.

- After determining the directions (Rotation and Shift) of the axes first, a line parallel to the axis is drawn.
- The direction of rotation is determined as Z for the rotary axis joints. In prismatic joints the sliding direction is determined as Z.
- The X-axis which is perpendicular to the Z-axis is chosen as the bond length.
- After determining the Z and X axes, the Y axis is determined according to the rule of the 'right hand' [22].

### 5.5 Inverse Kinematics of Robots

Using position and orientation information, the calculation of required joint variables can be defined as inverse kinematics. In other words, it is the, process of converting position and orientation from Cartesian coordinate to joint coordinate system [22].

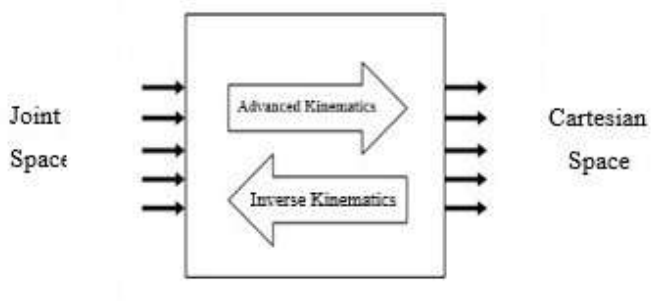


**Fig – 9:** Schematic Representation of Forward and Inverse Kinematic Problem [21]

### 5.6 Inverse Kinematic Problems

The solution of inverse kinematic problem is quite difficult compared to advanced kinematics. The properties that cause it to be difficult are given below.

- In terms of analytics; the equations it contains are complex, and not linear.
- The ease of solution of the inverse kinematic system, is directly proportional to the excess of the number of prismatic joints. But if the number of rotational joints is too much, the kinematic solution becomes harder.
- Mathematical solutions may not always be enough for a physical solution. There may be, situations where there is a mathematical solution but there is not a physical solution.
- Sometimes, multiple solutions may have to be created for the same end functionalist.
- In cases where results cannot be achieved using analytical solution, numerical methods can be used. However, while analytical solutions provide much faster work in computer environment, equations for numerical solution work much slower in computer environment [21].

### 5.7 Delta Robot Kinematics

The delta robot designed by Clavel is seen as the most successful robot ever.

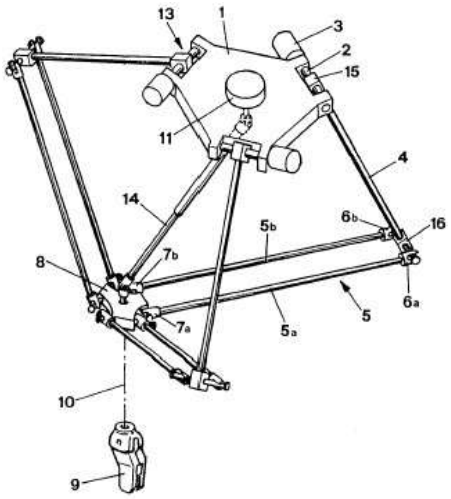


**Fig – 10:** Delta Robot Original design [23]


**Fig – 11:** Delta Robot Commercial Design [23]

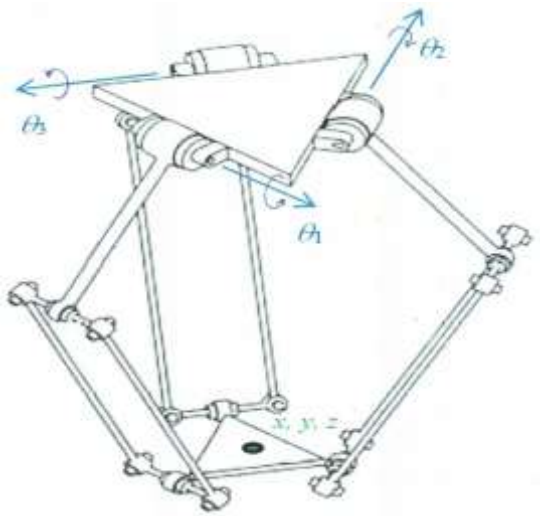

**Fig – 12:** Delta Robot Schematic Display [23]

The figure above shows a delta robot with 3 degrees of freedom. This robot has a fixed platform at the top and a movable platform at the bottom. Movement is provided by motors fixed to the platform above. The places indicated by Θ are the joint angles of the robot. With the delta robot with 3 (three) degrees of freedom, the rotating control of the mobile platform can be achieved [23].

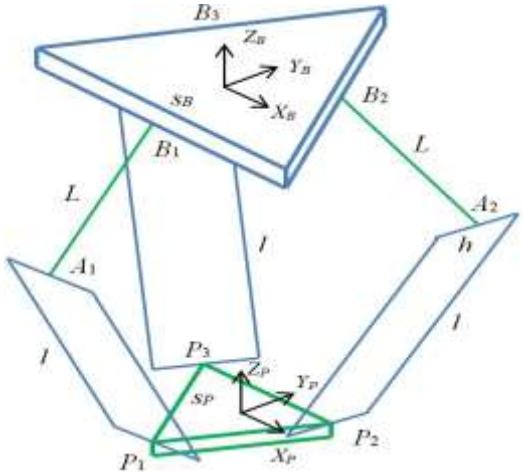

**Fig – 13:** Delta Robot Kinematic Diagram [23]

If the kinematic diagram is examined; The reference point of the equilateral triangle of the fixed platform at the top is the point B, which is the exact middle point. Likewise, the reference point of the equilateral triangle of the mobile platform at the bottom, is the point P, which is the exact middle point. Arm lengths have been indicated as L and, limb lengths as I.

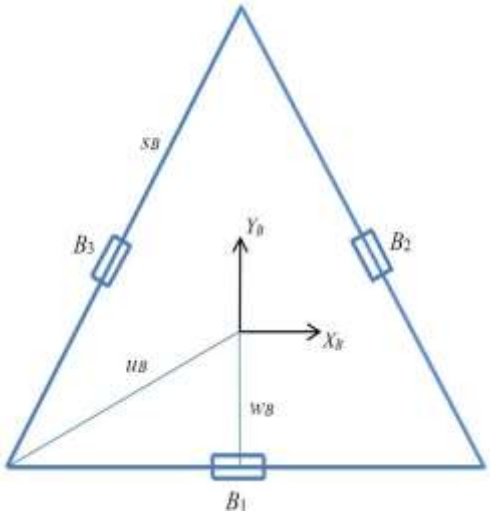

**Fig – 14:** Geometric Representation of Fixed Platform [23]

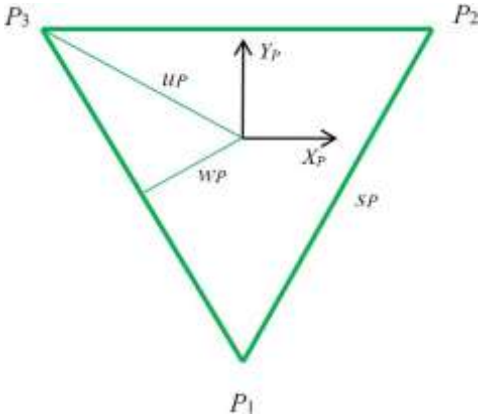

**Fig – 15:** Geometric Representation of the Mobile Platform [23]

**Table – 1:** Symbols and Meanings [23]

| Symbols | Meanings |
|---|---|
| $s_B$ | An edge of the equilateral triangle of the fixed platform |
| $s_P$ | An edge of the equilateral triangle of the moving platform |
| L | Upper leg length |
| l | Lower leg length |
| h | Width between two limbs |
| $w_B$ | The distance of the center point of the fixed platform to one edge of the triangle |
| $u_B$ | Distance of the center point of the fixed platform to the diagonal |
| $w_P$ | Distance of the center point of the moving platform to one side of the triangle |
| $u_P$ | Distance of the center point of the moving platform to the diagonal |

### 5.8 Calculation of Degrees of Freedom

While calculating the degree of freedom, some variables should be known. These variables can be found by referring to the robot diagram. The calculation, can be done with the Kutzbach equation. The required parameters and the equation to be used for the operation are given below.

$$M = 6(N-1) - 5J_1 - 4J_2 - 3J_3 \quad (1)$$

The meanings of the parameters in the equation are given in the table below.

**Table – 2:** Kutzbach Equation Parameters [23]

| Symbols | Meanings |
|---|---|
| **M** | Degree of freedom |
| **N** | Total number of limbs (including platforms) |
| $J_1$ | Number of uniaxial joints |
| $J_2$ | Number of biaxial joints |
| $J_3$ | Number of triaxial joints |

When calculating the degrees of freedom of delta robots which are difficult to solve statically, this equation may not always give correct result. Even if one of the parallel limbs of the delta robots is removed, there will be no kinematically any change [23].

## 6. RESEARCH RESULTS AND DISCUSSION

In parallel with the rapid development of technology and quality of life; it is seen that robotization has become prominent especially in the industrial field. In addition to this; the interest in robotization has been effective also in the fields of defense industry, medicine, etc.

In this study, in addition to general research on robots especially in industry, delta robot design, working with the principle of holding and placing, is made. In this design, the kinematic calculations of the robot handled. The solid model design of the robot has been drawn in the computer environment and after these stages, the prototype of the delta robot has been manufactured.

**Fig – 16:** Delta Robot with Prototype

In this study, the joints of the robot are cut according to the determined dimensions. For the control of motor movements, servo motor control card has been used. In order to use the robot in different applications; external power cards and electronic cards that will perform the tasks of the receiver and transmitter have been supplied. A hobby delta robot with 3 degrees of freedom has been obtained by combining all parts of the robot in laboratory.

Kinematic calculations of the robot have been used to determine the arm and leg lengths of the robot. It has been observed that there is no any design problem in the mini delta robot, produced according to these calculations.

In the prototype delta robot manufactured; any design problem was not observed in the test process. The arms of the intended mini delta robot, are designed to make 180° axial movement. Test softwares, has shown that the robot can move in real time.

In order to control servo motors, the software must be loaded on the PIC16F877A microcontroller on the motor driver board. Pickit 3 application has been installed on the computer to install the software. The "hex" file format of the software has been loaded on the microcontroller using this application. In this way, each program has been loaded on the microcontroller and the working of the programs has been checked.

### 6.1 Sample Application

Many applications have been made on the operation of the Delta robot. The application in which metal objects are taken from the moving tape and moved to a desired location is shown below as an example.

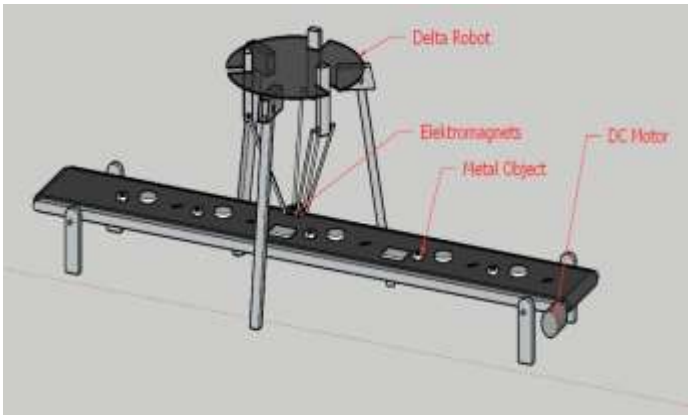


**Fig – 17:** Schematic Diagram of the Application

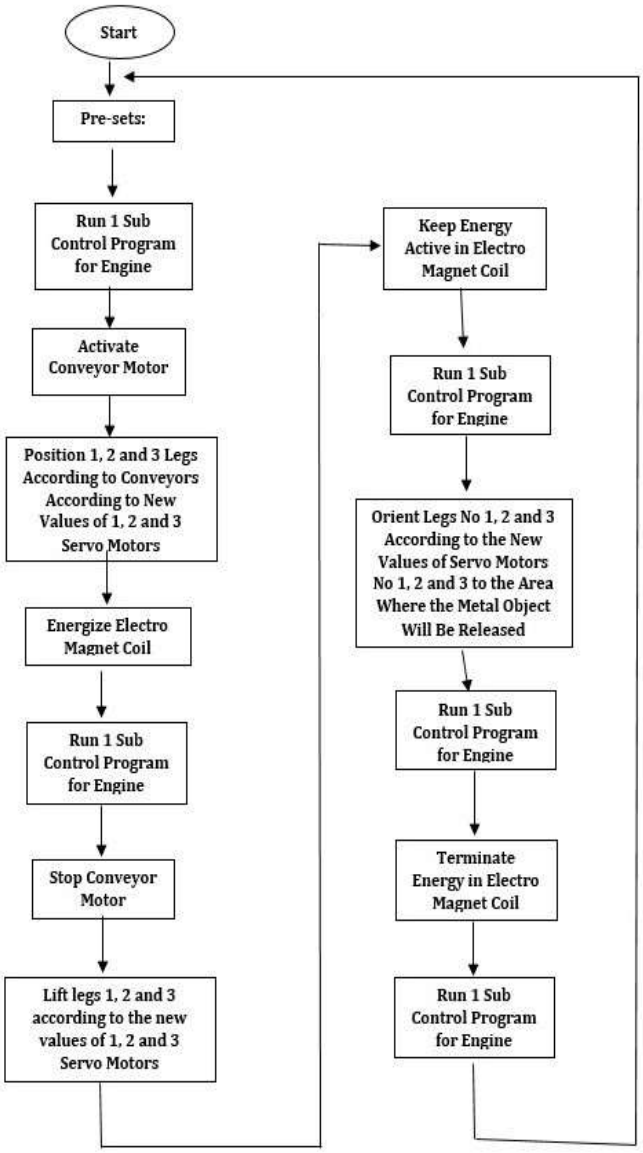


**Fig – 18:** Flowchart of the Application Program

In the program, metal objects coming from the moving conveyor have been left in another place after they are held with the help of electromagnet. According to the flow chart, the starting positions of the motors have been determined. Then the subprogram has been run. After this step, the motor of the conveyor has been run, new value has been entered to each motors and positioned according to the conveyor. After the electromagnet coil was energized The sub-program was run and the conveyor was stopped after the process was completed. Afterwards, the energy in the coil of the electromagnet was kept active and all the arms of the robot were raised upwards according to the entered values and the subprogram was run. Then; for the arms to return without magnetization, the energy in the electromagnet coil was terminated and the arms were positioned according to the new values entered. At this stage, the object has been dropped somewhere else.

## 7. RESULTS AND SUGGESTIONS

In this study firstly a wide literature research about robots was made and delta robots, which are widely used in the industry, were investigated in detail. Working principles of delta robots were researched and kinematic equations were obtained. A general purpose prototype delta robot has been designed and physically realized. With the test software written for the prototype delta robot, it has been seen that the arm movements and positioning are at the desired accuracy. The maximum and minimum distance the robot arms can reach from the center point were examined. With the prototype delta robot; the application which the metal objects are taken from the moving band and moved to a desired location is shown as an example.

In the application, it has been observed that the delta robot performs well. With the additional software for the operation of the delta robot realized, applications such as identifying the objects based on image processing, and drawing any image using artificial intelligence based algorithms can be realized. With this prototype delta robot, applications requiring speed can be realized by using different software and hardware.

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