3.2.4 Calibration

The calibration procedure includes two processes. The first process is calibrating each of arm segments to make sure it really rotates an expected angle and reducing the amount of error for second process of calibration. The second part is calibrating the whole SCARA robot system to make it move to a desire coordinate with an acceptable error.

Both two calibrating processes are conducted manually by replacing the electrical magnetic at pick and place tool to a pen. The pen is used for marking the points on paper to check the rotation angle of each arm segment and the real coordinate of the arm end effector (or the electrical magnetic).For increasing the accuracy in measurement, a caliper with accuracy of 0.1 mm is used.

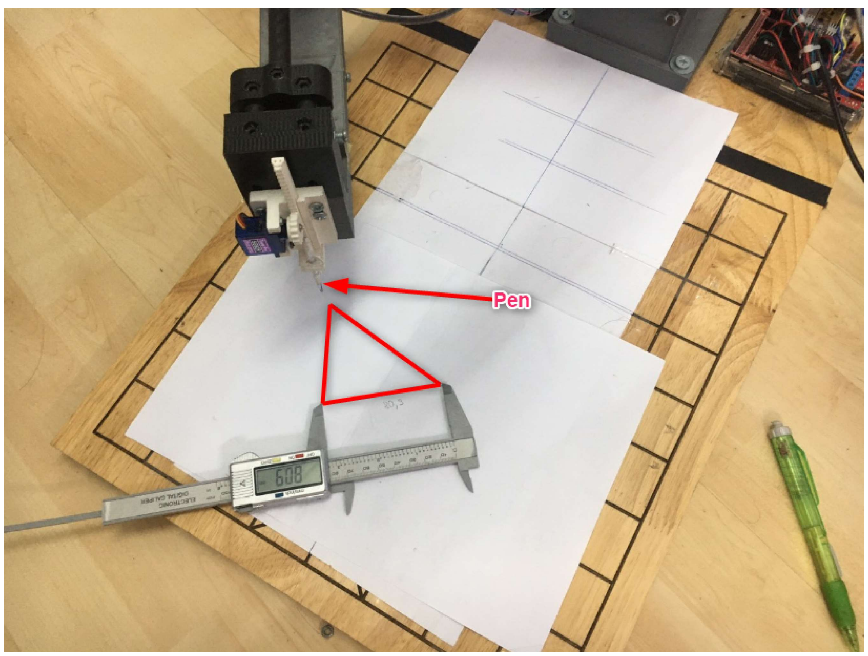

Figure 3.46: Calibration process 1

For calculating the rotation angle of the outer arm segment, two point is marked on paper. Given the length of the arm segment and distance between two point, using the law of Cosines, the real rotated angle of the arm segment can be calculated.

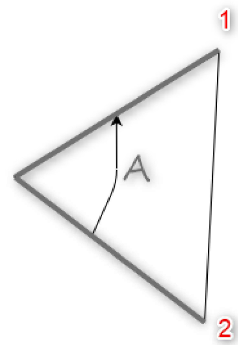

Figure 3.47: Outer arm calibration

The two gray line is the outer arm segment, point 1 and 2 is the marked point by the pencil. The below formula result the rotated angle A of the arm segment.

$$\mathrm{ArcCos}\,(A) = \frac{-(\mathrm{BC}^2 - 2\ ARM\_LENGTH^2)}{2 * ARM\_LENGTH} \tag{27}$$

The process of measure rotate angle of the inner arm segment is depicted as figure 3.48 , in this process, only the inner arm segment is rotated, the outer arm segment is hold standstill.

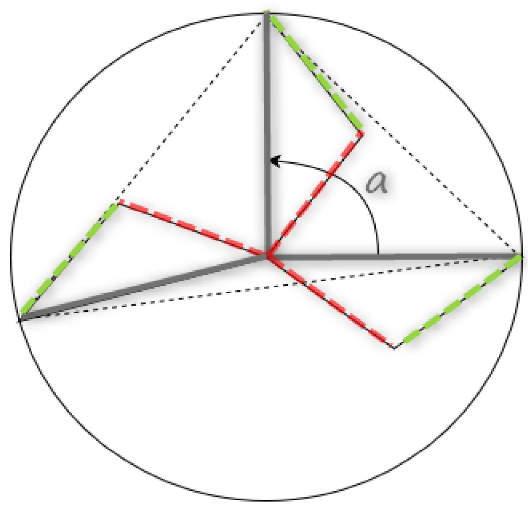

Figure 3.48: Inner arm calibration

Three point B,C,D is marked on paper when rotating the inner arm segment, which is represent in red in figure 3.48. The radius of BCD triangle circumscribed circle is calculated to get distance from the original point (0,0) to the end effector of the robot. Using the circle radius and law of Cosines, the angle **a** is derived. This angle is equal to the rotated angle of the inner arm segment because the outer arm segment is hold standstill in the whole process.

The circumscribed circle radius is calculated as follows:

1. Calculating the half triangle perimeter

$$P = \frac{BC + BC + CD}{2} \tag{28}$$

2. Calculating the triangle area with Heron formula

$$S = \sqrt{P * (P - BC) * (P - BD) * (P - DC)} \tag{29}$$

'1

3. Calculating the radius of the circle

$$R = \frac{BC * CD * BD}{4 * S} \tag{30}$$

For calibrating the whole SCARA robot, the arm is controlled to move to a number of points on the x = 0 axis, then these point is marked on paper and measured the distance from the correct position points to derived their coordinatation.

Figure 3.49: Calibration process 2

The x = 0 is chosen as the reference axis to facilitate the process of derived coordinate of marked points. showed in figure is a paper which is attached above the chess board with line coincide to the chess board line, these line help to coordinate the marked points. Beside that, using the x = 0 or other parallel axis will show the error of placing the SCARA robot base when trying to make it coincide to the chess board coordinate.

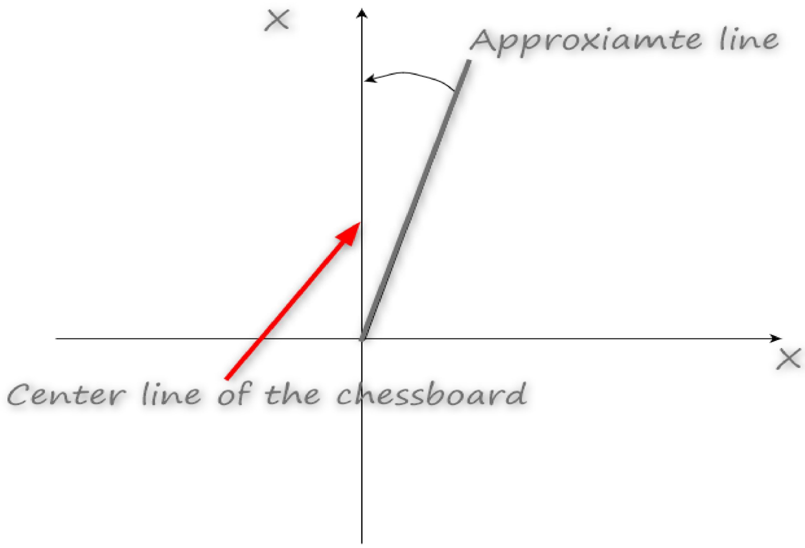

Figure 3.50: Lagging angle between two coordinates

Using the marked point and least square fit method, an approximate line of these point is derived. The least square fit is deployed to reduce the error when measuring the coordinate of these points manually. The angle between the approximate line and the reference axis is calculated and used for adjust the coordinate of the input points to the SCARA robot. The input points are then rotated as the derived angle before calculating for the arm to move.