Lab 2 : Kinematic analysis and design of a 3-RRR planar parallel robot

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1 Introduction

The objective of this lab is to design a 3-RRR robot. The main problem of this type of robot is the avoidance of singularity. It is possible to adjust some design parameter to maximize the workspace with a given robot base link length. The singularity calculation is only mentioned in this work, but this calculation is already performed by the java script. This script give us the ability to control the robot with the direct and inverse geometric model. In each case, the program presents the serial and parallel singularities of the robot.

2 Discussion on given exercises

Exercise 2

Visualize the Type 2 singularity loci and place the tooltip of the mobile platform on a singularity point. Click on the Calculate button and visualize solutions 1 and 2. What do you observe?

We observe on figure 1 that there are two identical assembly modes and therefore, the same type two singularity loci.

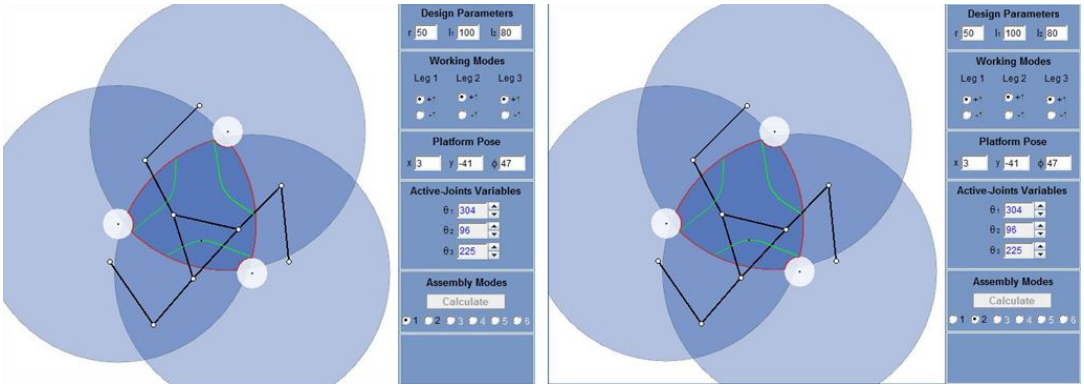


Figure 1: 2 identical solutions to the Direct Kinematic Model with same Type-2 singularity

Exercise 1

For the default design, go to $x = -60, y = -40, \phi = -40°$, and click on the Calculate button to visualize six real solutions to the direct kinematic problem. Is it possible to have only one real solution?

Yes, it is possible to have only one real solution (confer to figure 1), the robot must be in a Type-2 singularity and there must be only two solutions to the Inverse Geometric model, which are exactly identical. The active joint values remain constant at $\theta_1 = 30$, $\theta_2 = 163$ and $\theta_3 = 224$

Exercise 3

The program relies on the Newton-Raphson iterative algorithm to displace the robot in active-joint variables mode. Visualize the Type 2 singularity loci and try to cross them in active-joint variables mode. Why isn't it possible?

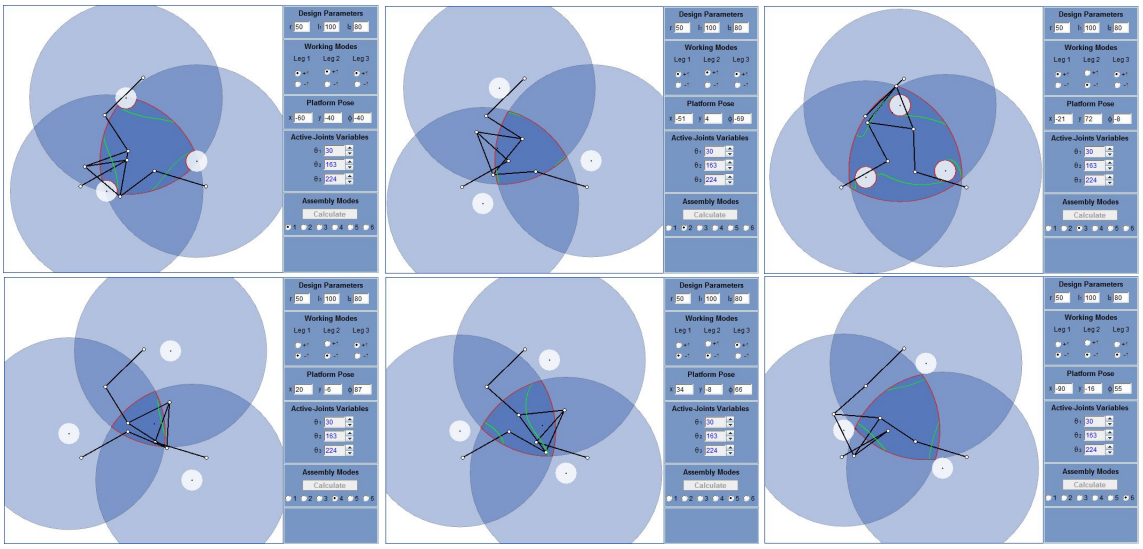


Figure 2: 6 real solutions to the direct kinematic model

The next position is calculated from a previous iteration with a linearization method and also relies on a matrix which become singular at a type 2 singularity, preventing then this iterative calculation.

3 Singularity-free Workspace Design

The objective is to attain a large free of singularity work-space (in x,y) at $\phi = 0$. We will be able to modify the workspace by modifying the link length, the radius of the platform and the working mode of the platform. We will notice that the base radius has been set to a constant value equal to 135. All the robot length are function of this base length and should been adapted (proportional relation) if we wanted to create a bigger or smaller robot.

3.1 Shape of the workspace

The workspace free from serial singularity is the intersection of :

- Three circles of radius $l_1 + l_2 + r$ with three center A_i.
- The complementary space of three circle of center A_i and radius $|l_1 - l_2|$.

The center A_i position are defined with the radius of the platform and the orientation of the platform. Let O_i be the point where each leg is attached to the ground. Hence, the length $||\overrightarrow{O_iA_i}||$ is equal to radius r and the angle between x_0 and $\overrightarrow{O_iA_i}$ is a proportional image of the orientation of the platform. The small circles centered with A_i, having radius as $|l_1 - l_2|$ and the points A_i that are at a distance of radius r from these O_i centers. Point A_i and O_i can be seen in Figure 4b given later.

In such a workspace, some Type 2 singularity appears. They are calculated and appear on the applet with green line. It is desirable to try to adjust the parameters such that these singularities shift towards the boundary of the workspace, so that there is no singularity crossing risks inside the workspace. Simultaneously, we will try to increase the workspace completely free of serial singularity.

3.2 Definition of the optimal workspace

Depending on the application, the shape of workspace required could vary. We will assume that the workspace needed has only one aspect. Moreover, it can be useful to have a workspace not to have any singularity. To do that, we can search for the biggest included square or circle to avoid strange shape of workspace. We will try then to maximize this criteria. Once obtained, we will look the completed total workspace and analyze it.

Design rule considerations

The important design parameters are discussed below:

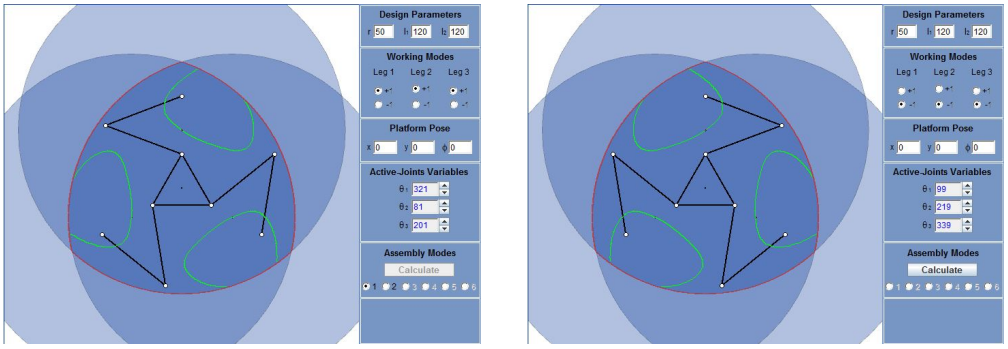
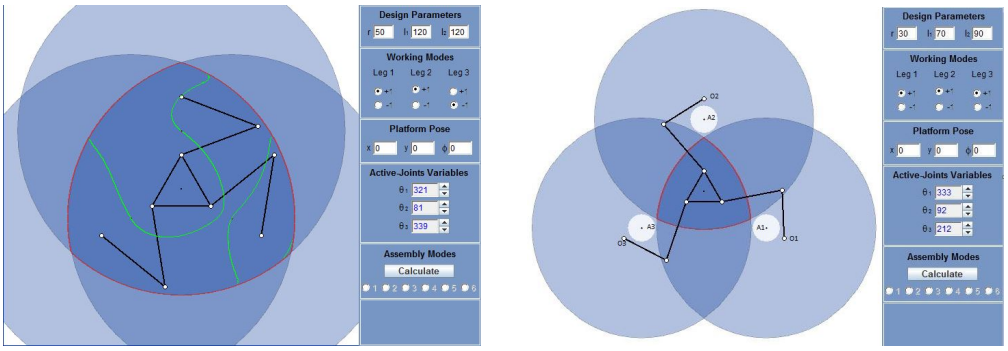


Figure 3: Workspace in two opposite working modes



(a) Workspace shape with varying parameter p (b) OA Circle

Figure 4: Parameters affecting workspace shape

- Inside the workspace, there are risks of attaining circular voids of radii $(l_1 - l_2)$. So the lengths are kept equal, $l_1 = l_2$ to make those area as small as possible.
- The radius impact directly the size of workspace free of serial singularity. We can note that the center of the circle A_i correspond to serial singularity position. With an angle $\phi = 0$, the point A_i are between the point O_i and the center of the base. To make those point as far as possible from the base center, it is compulsory to reduce the radius of the platform. The point A_i are then closer to point O_i and don't lie in the middle of the base.
- Increasing the lengths will allow larger workspace but lengths cannot be increased indefinitely since larger workspaces also have risks of more Type-2 singularity loci. There is then no general rules and they must be studied carefully by iteration.
- All legs must be in the same pose (all in elbow up or all in elbow down configuration)

The objective now is to find the best working mode and link length.

Study of the working mode We can select the working mode with a variable named p. This parameter can take for value 1 or -1.

We observe that there are only two different cases- either all the working modes are identical or they are all different. This is due to symmetry of the system. In order to see this, we try first the opposite configuration where all parameter are put to 1, and then all are put to -1. The result are displayed on figure 3. We see that the two workspace are changed just with a symmetrical reflection.

The same result can be obtain with the other type of workspace. All the 6 other workspace are similar to the one given on figure 4a. Only rotational and reflexion symmetry give all the workspace.

We need then to compare the workspace with all identical parameter shown on figure 3 with the one with varying parameter presented on figure 4a. As the design parameter doesn't change, the serial singularity are identical. We see that with constant parameter three line of parallel singularity appear. They divide the workspace in four aspect. There is three identical small aspect and one fourth big aspect. We note that the size of those aspect can change with the link length we have to settle. In the other configuration, the workspace is divided in three aspect with irregular shape. Two are big and occupy most of the space. Finally the case with the same parameter give access to a bigger workspace.

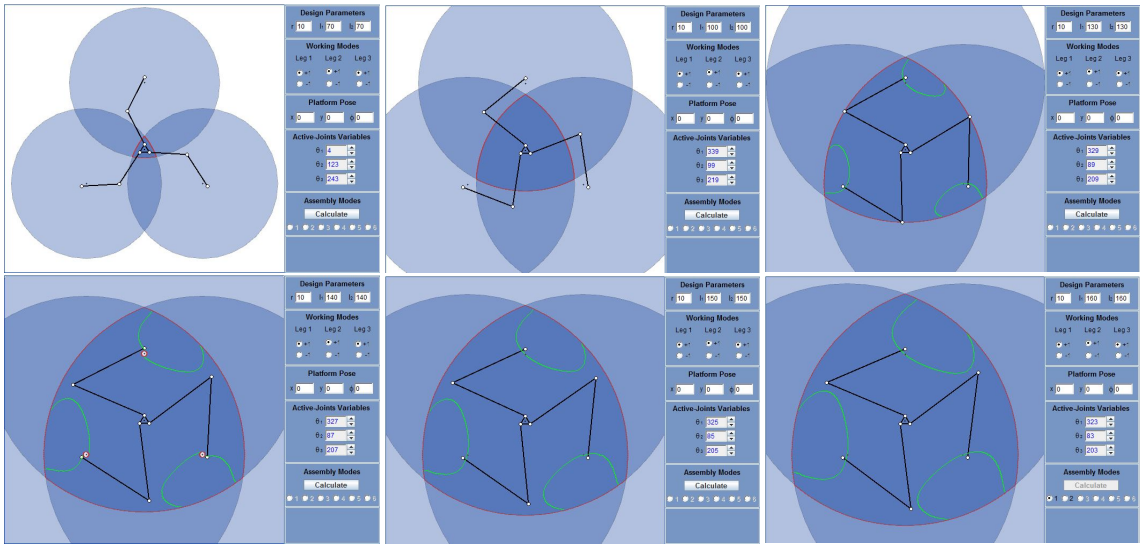


Figure 5: Six different workspace with a varying link length (respectively: 70, 100, 130, 140, 150, 160

Study of the link lengths

To study the effect of the link length we take the smallest radius possible (r=10) and try with different value of link. The length of the link, l_1 and l_2 are put to a same equal length as discuss previously. The result are given on figure 5. We see from those graph the evolution of the workspace in function of the workspace in function of the link length. The workspace that is free of serial singularity increases with an increasing link length as discussed previously. For small link length we see that there is no parallel singularity. This can be interesting if we don't want to care on the control to avoid singularity. But further increasing the link lengths leads to appearance of increasing green lines indicating rising parallel singularity. Even as some parallel singularity starts appearing, the workspace free of singularity continue to rise. A good way to determine the best workspace will be to calculate directly the area of the workspace. We can take the workspace with the biggest possible circle contained within the singularity-free workspace. To conclude, the best design we chose is the one with a link length of 150 because visually it seems to correspond to the best compromise.

4 Conclusion

To sum up, this work investigates the parameters for which it maybe possible to gain maximal workspace free of singularities. Important design considerations are the radius and the link lengths, as well as the working modes. Identical lengths are chosen (value of 150) with a minimal radius of 10. It is important to choose the same working mode for all legs. Possible design parameters have been also been provided for a large workspace design. As an extension to this work, a numerical computation of workspace area could be performed to confirm the results since the current applet cannot numerically compute it, and conclusions were drawn visually.