Practical Project: Working with an Industrial Robot Arm

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This report is written as part of the Small Practical Project for the SCIENG302: Robotics course. The practical constitutes of two parts and the aim of this practical overall is to obtain an understanding of the Kawasaki RS03N robotic arm. The first part involves programming the robot through its teach pendant to perform a creative construction task using wooden Kapla blocks. The second part is an introduction to inverse kinematics where by understanding the structure of the robot, joint parameters are calculated manually to bring the tool head of the robot to a given 3D coordinate.

Part I: Programming the Robot using its Teach Pendant

In Part I, we will explore the process of programming the Kawasaki RS03N robot arm using its teach pendant. The teach pendant is a handheld device that allows the user to control and program the robot arm by manually moving it through a series of motions and recording them for later playback.

The initial planning phase involved brainstorming and discussing a variety of ideas for the build. We had a multitude of ideas ranging from a tank (which did not prove to be complex enough) to a house (which proved to be too generic). We wanted something that involved angling the wooden blocks in difficult positions. Thus we settled on building a sitting man with angled arms, as seen in Figure 1. We used 7 blocks in total (5 thin rectangular cuboids for-arms, legs, shoulders, 1 thicker rectangular cuboids for the body, 1 almost cube shaped cuboid for the head). To get the starting positions we set the blocks in a set order marked by a pencil-horizontally and at the end of the edge of the metal surface-vertically.

The second phase involved building and adjustments. To build a sitting man using the Kawasaki RS03N robot arm and its teach pendant, we would need to carefully plan out the series of motions required to create the desired posture. This would involve programming the arm to move each block to the correct angle. Consequently, adjusting and saving the progress of the build using the built in functions of the teaching pad for each motion to create smooth

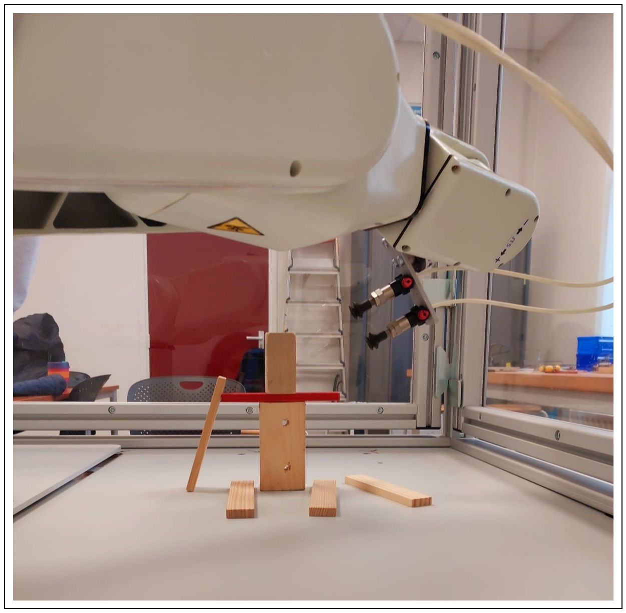

Figure 1
Final Product After the Robot Executed the Taught Sequence

motions and natural-looking sitting position. With patience and practice, we could use the teach pendant to create a fully sitting stick figure (resembled with human anatomical parts).

The most difficult part of the build was getting both of the arms to sit firmly on the shoulders due to the angle of 45 degrees and getting them to not slide off the shoulders. We had to experiment with various positioning until we found the right balance of stability and aesthetics. Thus, although challenging, the process of building the sitting man using the Kawasaki RS03N robot arm was an engaging and fulfilling experience.

Part II: Inverse Kinematics

The first part of this practical came with its challenges and involved the robot making a lot of steps. However, getting to use the teach pendant meant that there was no need to manually calculate the joint parameters of the robot for each step it had to take. Therefore, the aim of this part of the practical is to, given the coordinate (x = -330mm, y = 356 mm, z = -140 mm), perform inverse kinematics and manually calculate the joint parameters necessary to bring the robot and its end-effector to that coordinate.

There exist numerous methods to carry this process out but the challenge of this practical was to calculate the necessary joint parameters visually and by hand, simply using trigonometry. Before detailing the steps taken, it is important to understand the specifications of the Kawasaki RS03N robotic arm.

There is of course an official manual online (*Standard Specifications: RS003N-A*, 2020) comprising of every detail of the robot but everything required for this practical is described below. The robotic arm consists of six axes and hence six degrees of freedom. The specifications of each axis is summarised in Table 1.

Operating Axis	Motion Range
Arm Rotation (JT1)	$\pm 160°$
Arm Out-In (JT2)	$+150°$ - $-60°$
Arm Up-Down (JT3)	$+120°$ - $-150°$
Wrist Swivel (JT4)	$\pm 360°$
Wrist Bend (JT5)	$\pm 135°$
Wrist Twist (JT6)	$\pm 360°$

Table 1
Axis Specifications

Along with that, the following official illustrations (*Standard Specifications: RS003N-A*, 2020) of the robotic arm were used to retrieve link lengths and obtain a clear understanding of the robot's build, movements and limits.

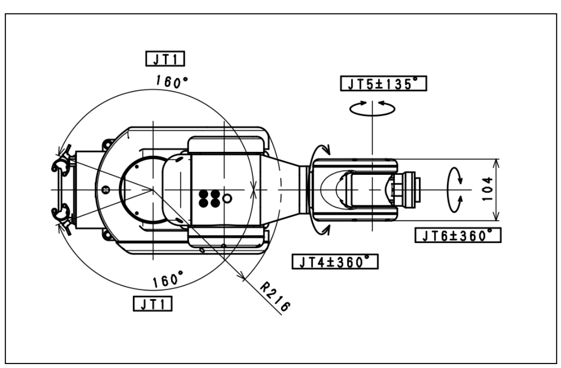

Figure 2
*Illustration **I** of the Robotic Arm (JT1, JT4, JT5, JT6)*

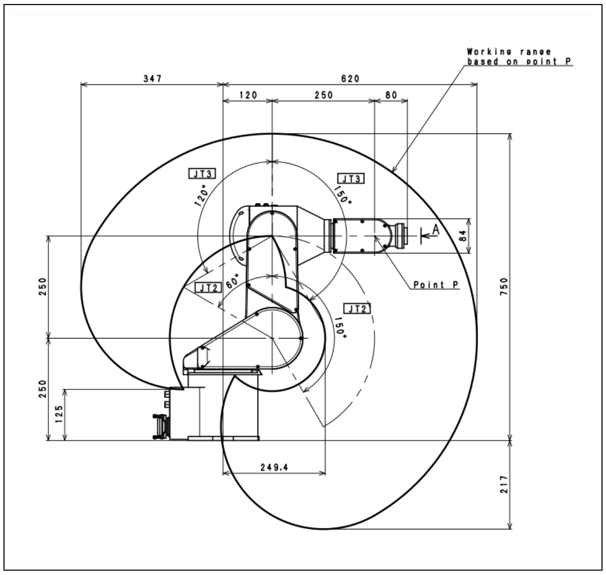

Figure 3
*Illustration **II** of the Robotic Arm (JT2, JT3)*

As seen from the illustrations, since the arm only contains revolute joints, the joint parameters to be calculated are all joint angles. To make the calculations as precise and convenient as possible, Mathematica was used (see Appendix A for the code). Now that all measurements and tools are available, the first step is to get the arm, in the XY plane, to the coordinate (x = -330 mm, y = 356 mm).

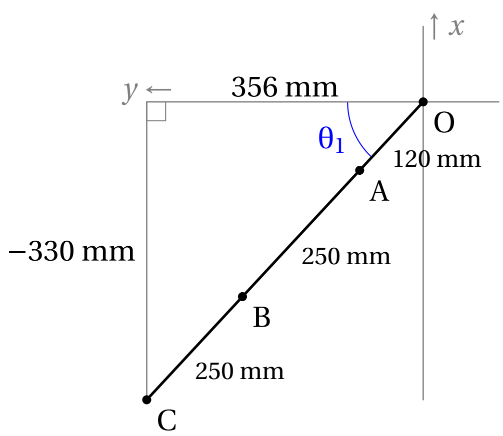

Figure 4
Robot Arm (Geometric Diagram, Top View)

The desired distance along the y axis is 356 mm, the desired distance along the x axis is

-330 mm. Angle θ_1 is relative to the positive y axis.

$$\theta_1 = \arctan\left(\frac{-330}{356}\right) = -42.8295^\circ \tag{1}$$

This is all visualised in Figure 4

For the other angles, a side view will be used as seen in Figure 5.

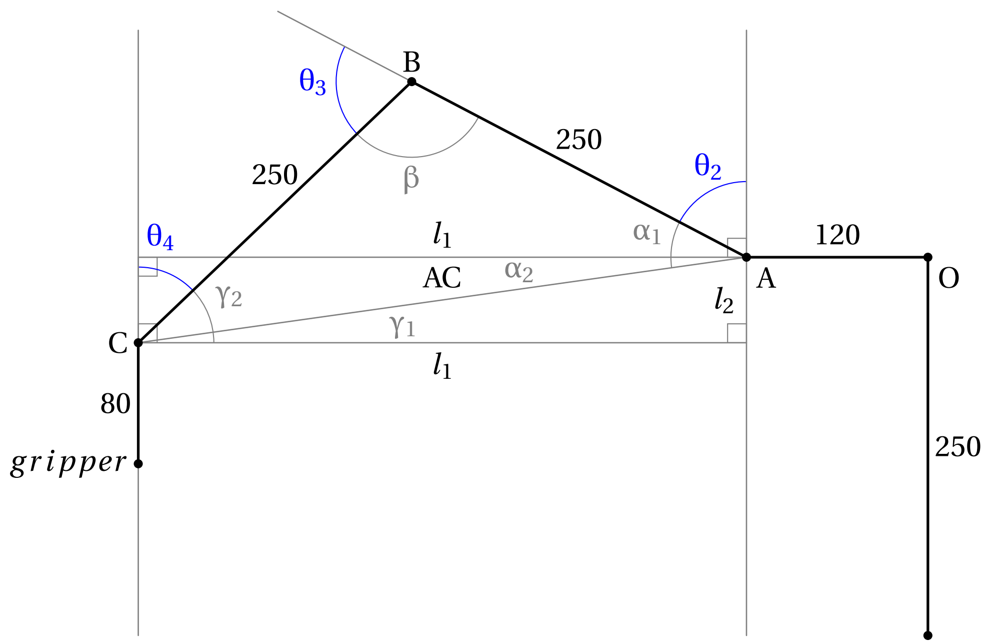

Figure 5
Robot Arm (Geometric Diagram)

The desired distance for the gripper along the Z axis is -140 mm, this is measured from point O as seen in Figure 5. This means that for point C, the length of the final link should be subtracted.

$$l_2 = 140 - 80 = 60 \tag{2}$$

Similarly, the distance l_1 should be the horizontal distance to point C from O, subtracting the length of the horizontal link.

$$l_1 = \sqrt{(-330)^2 + 356^2} - 120 = 365.424 \tag{3}$$

With Equations 2 and 3 we can find AC.

$$\mathrm{AC} = \sqrt{l_1^2 + l_2^2} = \sqrt{365.424^2 + 60^2} = 370.317 \tag{4}$$

The cosine rule is defined such that

$$\mathrm{BC}^2 = \mathrm{AB}^2 + \mathrm{AC}^2 - 2 \cdot \mathrm{AB} \cdot \mathrm{AC} \cdot \cos(\alpha) \tag{5}$$

where BC is the edge opposite of angle α on a triangle. Equation 5 can be used to find angles by rewriting it as such:

$$\alpha = \arccos\left(\frac{\mathrm{BC}^2 - \mathrm{AB}^2 - \mathrm{AC}^2}{-2 \cdot \mathrm{AB} \cdot \mathrm{AC}}\right) \tag{6}$$

Filling out the value from Equation 4 in Equation 6 gives $\alpha_1 + \alpha_2$:

$$\alpha = \alpha_1 + \alpha_2 = \arccos\left(\frac{\mathrm{BC}^2 - \mathrm{AB}^2 - \mathrm{AC}^2}{-2 \cdot \mathrm{AB} \cdot \mathrm{AC}}\right) = 42.2146^\circ \tag{7}$$

α_2 can also be found using l_1 and l_2:

$$\alpha_2 = \gamma_1 = \arctan\left(\frac{l_2}{l_1}\right) = 9.32437^\circ \tag{8}$$

Combining Equations 7 and 8 gives

$$\alpha_1 = \alpha - \alpha 2 = 32.8903^\circ \tag{9}$$

$$\theta_2 = 90^\circ - \alpha_1 = 57.1097^\circ \tag{10}$$

Again filling out Equation 6, but this time for angle β, gives

$$\beta = \arccos\left(\frac{\mathrm{AC}^2 - \mathrm{AB}^2 - \mathrm{BC}^2}{-2 \cdot \mathrm{AB} \cdot \mathrm{BC}}\right) = 95.5708^\circ \tag{11}$$

Because of the orientation of the robot arm, if angle θ_3 is negative, the arm will end up in the correct orientation.

$$\theta_3 = -(180 - \beta) = -84.4292^\circ \tag{12}$$

For the third time filling out Equation 6, but this time for angle γ_2, gives

$$\gamma_2 = \arccos\left(\frac{AB^2 - AC^2 - BC^2}{-2 \cdot AC \cdot BC}\right) = 42.2146^\circ \tag{13}$$

With the results of Equations 8 and 13, θ_4 can be found

$$\theta_4 = 90^\circ - \gamma_1 - \gamma_2 = 38.461^\circ \tag{14}$$

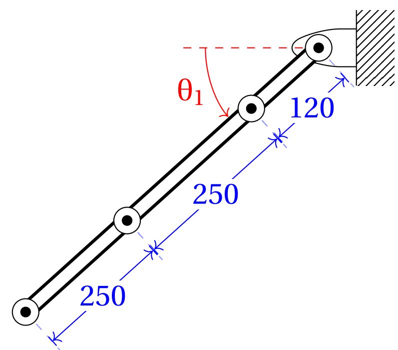

Figure 6
Robot Arm (Top View)

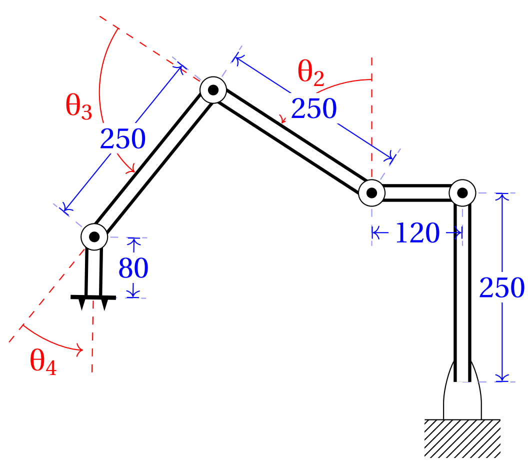

Figure 7
Robot Arm (Side View)

Results and Conclusion

Table 2 summarises the four joint angles calculated that are necessary to bring the tool head of the robotic arm to the coordinate (x = -330mm, y = 356 mm, z = -140 mm). The robotic arm was then positioned at these joint angles and the current coordinates of the tool head was noted to verify if it matched the desired coordinate. The result is again summarised in Table 3.

θ_1	$-42.8295°$
θ_2	$57.1097°$
θ_3	$-84.4292°$
θ_4	$38.461°$

Table 2
Joint Variables

	Desired Position	Measured Position
X	-330 mm	-328 mm
Y	356 mm	355 mm
Z	-140 mm	-141 mm

Table 3
End Effector Position

As seen in the table, the result is very close to the desired value with the coordinates off by at most 2mm. This is most likely due to some rounding off-errors that might have occurred despite being as precise as possible. Overall, it was a very successful project.

References

Standard Specifications: RS003N-A (90151-0095DEC). (2020, October 12). Retrieved April 9, 2023, from https://kawasakirobotics.com/uploads/sites/2/2022/01/specifications_robots_small-medium-payload-robots_rs_rs003n_en_01_2021.pdf

Appendix

A. Mathematica Code

```
OA = 120;
AB = 250;
BC = 250;
Cgrip = 80;
θ1 = N[ArcSin[desiredX/desiredDistXY]/Degree];
desiredDistXY = Sqrt[desiredX^2 + desiredY^2];
l1 = N[desiredDistXY - OA];
l2 = Abs[desiredZ] - Cgrip;
AC = N[Sqrt[l1^2 + l2^2]];
α12 = N[ArcCos[(BC^2-AB^2-AC^2)/(-2*AB*AC)]/Degree];
α2 = γ1 = N[ArcTan[l2/l1]/Degree];
α1 = α12 - α2;
θ2 = 90 - α1;
β = N[ArcCos[(AC^2-AB^2-BC^2)/(-2*AB*BC)]/Degree];
θ3 = -(180 - β);
γ2 = N[ArcCos[(AB^2-AC^2-BC^2)/(-2*AC*BC)]/Degree];
θ4 = 90 - (γ1 + γ2);
Print["OA=",OA]
Print["AB=",AB]
Print["BC=",BC]
Print["Cgrip=",Cgrip]
Print["l1=",l1]
Print["l2=",l2]
Print["AC=",AC]
Print[]
```

```
Print["α₁ + α₂ =",α12]
Print["α₁=",α1]
Print["α₂=γ₁=",α2]
Print["β=",β]
Print["γ₂=",γ2]
Print[]
Print["θ₁=",θ1]
Print["θ₂=",θ2]
Print["θ₃=",θ3]
Print["θ₄=",θ4]
Print[]
Print["expected θ₁=",−42]
Print["expected θ₂=",57]
Print["expected θ₃=",−85]
Print["expected θ₄=",36]
Print[]
Print["desired X=",desiredX]
Print["desired Y=",desiredY]
Print["desired Z=",desiredZ]
Print[]
Print["measured X=",−328]
Print["measured Y=",354.5]
Print["measured Z=",−141]
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