AGH UST
University of Science and Technology

Faculty of Mechanical Engineering and Robotics
Mechatronic Engineering

Service Robots project class
Group No. 1

Aquarium Cleaning System

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1. State of Art

Since the time humans started domesticating animals, we have seen an evolution in the reasons for doing so. In the earliest era, wolves were domesticated for hunting, but over time, as that need diminished, they transformed into what we now know as "man's best friend" the dog. From that point on, humans began to breed animals for luxury, companionship, entertainment or simply the desire to care for an animal. This also affected the aquatic animals, leading to the breed of keeping fishes in small and large aquariums, just as we see today.

With the domestication of animals also came the need to create a clean and familiar environment for them. In the case of aquariums, early techniques involved rudimentary manual labor, such as draining the water (and securing the fish temporarily) and scrubbing all surfaces of the aquarium by hand to maintain cleanliness. Over time, these manual methods evolved, and people started using tools like sponges, scrapers, and later, magnetic brushes that allowed them to clean the aquarium glass without getting wet.

As technology advanced, so did aquarium maintenance for the fish keepers. Today, even though there are not too many different styles of solutions, we have automatic robots that handle this task for us. Such as "RoboSnail", for example, it autonomously moves along the glass at regular intervals to prevent algae buildup. Following the same line, "Moai" offers a more sophisticated solution with app-controlled navigation and even a built-in camera to monitor the aquarium remotely. These innovations highlight the ongoing trend toward making pet care more convenient and automated, reducing the need for manual effort.

2. New Product Presentation “A-Brush”

The care and maintenance of aquariums, especially large ones, generally is a challenge for fish enthusiasts. While technology has advanced to automate several aspects of aquarium care (like adding filters, oxygenation machines, measured systems, etc.), cleaning the glass surfaces remains a tedious, and often a manual task. Introducing A-Brush, a cutting-edge robotic device designed to automate the cleaning of aquarium walls. The inspiration for this innovative system was taken from the construction principles used in 3D printers, offering precise and efficient operation.

The A-Brush features a design similar to a 3D printer, leveraging a sophisticated system of sliders, distance sensors, and rotating brushes. The device is placed on top of the aquarium and securely attaches to the walls by its extendable side bars. Its intelligent distance sensors detect the edges of the tank, automatically calculating the maximum allowable movement for optimal performance.

A central horizontal and one sided slider move along the top of the aquarium, enabling the device to move from one side to the other in 2 axes directions. Attached to this is a vertical slider, which controls a bar that extends down into the tank. The vertical slider moves up and down to reach different heights along the aquarium walls.

A unique cleaning mechanism are the two rotational cylinders. The first cylinder, attached to the vertical slider, rotates 90 degrees each time, allowing the device to reach all four walls of the aquarium without manual repositioning. The second cylinder, connected to the first one, does the actual cleaning part with a cover brush. This brush rotates as it scrubs the surfaces, efficiently removing algae, grime, and debris from the glass.

The entire system works in perfect synchronization, ensuring that every corner of the aquarium is thoroughly cleaned. The rotating brush can adjust its position based on the orientation of the first cylinder, meaning the A-Brush can seamlessly transition from one wall to the next.

3. Advantages and disadvantages – Comparation with competitors

3.1 Moai

-) Advantages:

- Smart App Control: Moai can be controlled via an app, allowing users to schedule cleanings or manually direct the robot.

- Real-time Monitoring: It has an inner camera, enabling users to monitor the aquarium from anywhere.

- Versatile Movement: Moai moves freely along the glass, reaching difficult spots with ease.

-) Disadvantages:

- High Cost: Moai tends to be more expensive due to its advanced features, which may not be necessary for all users.

- Limited to Glass Cleaning: Moai focuses solely on cleaning one glass and does not offer additional functionality like water parameter monitoring or cleaning other parts of the tank.

- Power Dependency: Requires regular charging, and interruptions during cleaning sessions could leave areas unclean.

Figure 1. MOAI Cleaning Robot

3.2 RoboSnail

-) Advantages:

- Fully Autonomous: RoboSnail cleans the aquarium glass at pre-set intervals without the need for user input.

- Hands-free Maintenance: It provides regular cleanings without requiring any effort from the user.

- Cost-effective: It's usually less expensive than more advanced robots like Moai, making it a more affordable automated solution.

-) Disadvantages:

- Basic Functionality: RoboSnail lacks any app control, customization options, or real-time monitoring, so it's a simpler, less interactive device.

- Limited Mobility: It can sometimes miss spots on the aquarium if algae builds up in harder-to-reach corners or edges.

- Only for individual Glass: Like Moai, RoboSnail is limited to cleaning just one glass surface.

Figure 2. RoboSnail Cleaning Robot

3.3 A-Brush

-) Advantages:

- Total Cleaning: Unlike Moai or RoboSnail, A-Brush is designed to reach all four walls of the aquarium. Its dual rotational system allows for thorough coverage of every surface.

- Advanced Edge Detection: With distance sensors to detect the tank's edges, A-Brush automatically adapts to different aquarium sizes and shapes.

- Rotational Brushes: Its rotating brush system provides deep cleaning, scrubbing algae and debris from the surface more effectively than static brushes.

- User-friendly: Once installed, A-Brush offers a fully automated cleaning experience with minimal maintenance required.

-) Disadvantages:

- Setup Complexity: The installation of A-Brush requires mounting and ensuring the sliders and sensors are properly aligned. This might be more complex compared to simpler devices like RoboSnail.

- Lack of additional Functionality: Such as RoboSnail, it also lacks any app control, customization options, or real-time monitoring, water parameter, etc. so it's a simpler, less interactive device.

- Higher Initial Investment: Like Moai, A-Brush may come with a higher price tag due to its sophisticated design and broader functionality.

4. Draft kinematic Scheme for A-Brush

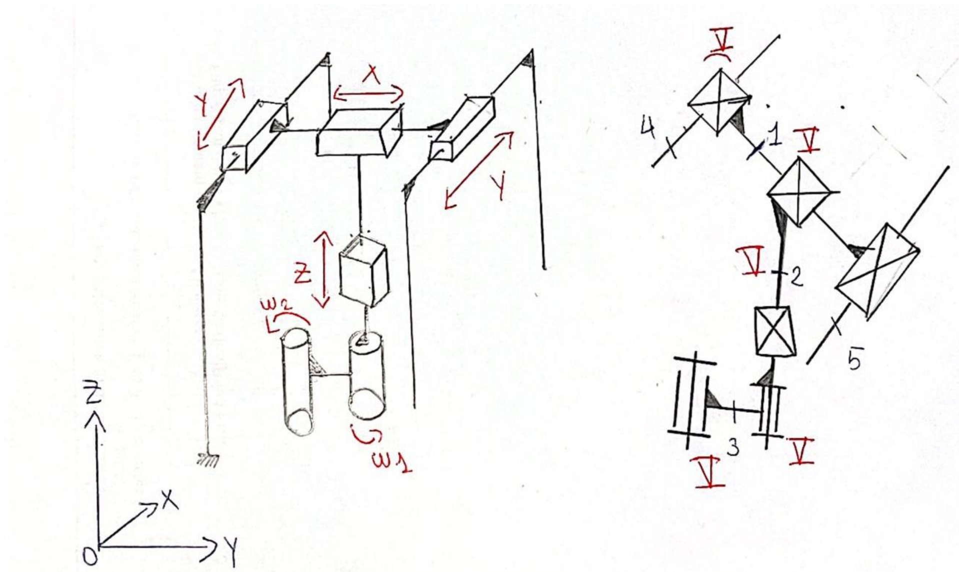

Figure 3. A-Brush Cleaning Robot draft Kinematic scheme

$$W = 6 * 4 - 5 * 5 = 5\ DOF$$

4.1 Draft proposal for sketch

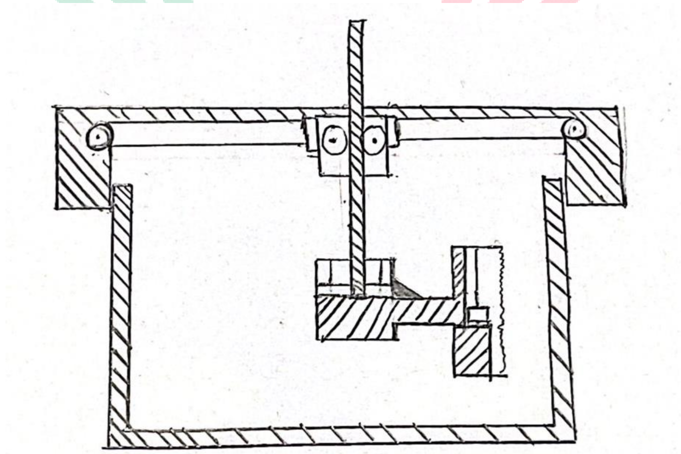

Figure 4. A-Brush Cleaning Robot First sketch version

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5. Final scheme and 3D model for A-Brush

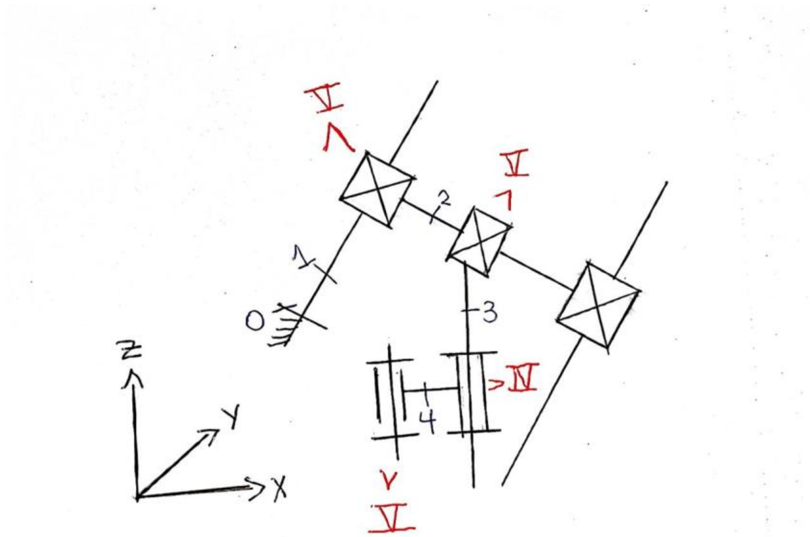


Figure 5. A-Brush Cleaning Robot Kinematic scheme

$$W = 6 * 4 - 5 * 3 - 4 * 1 = 5\,DOF$$

Figure 6. A-Brush 3D model

5.1 Cleaning simulation

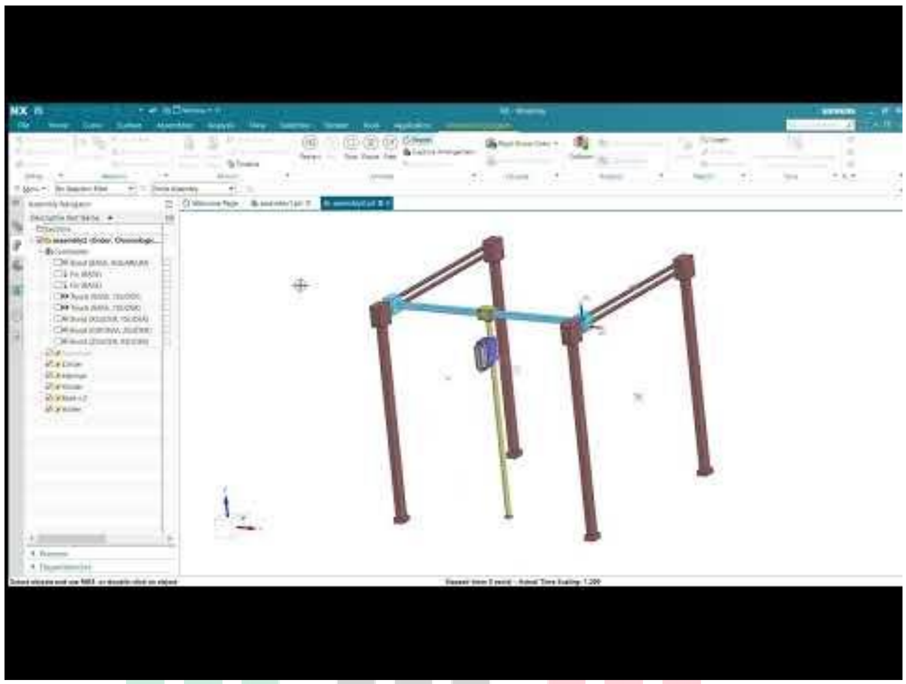
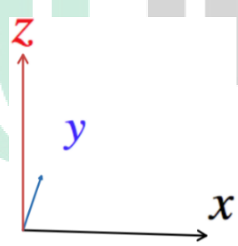


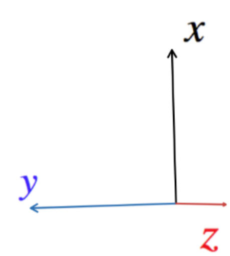
Figure 7. A-Brush Cleaning simulation

Axes at each joint:

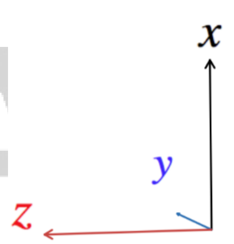
- **Initial position:**



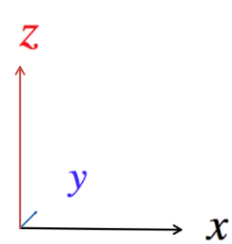
- **First joint:**



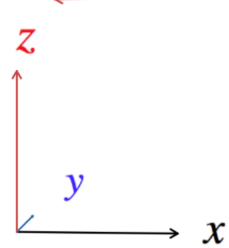
- **Second joint:**



- **Third joint:**



- **Fourth joint:**



6. Forward and inverse kinematics for 5 positions

//REMARK//

Knowing the way how A-brush was meant to move is really important for the further calculations. The third joint (cylindrical joint) rotates only by 90 degrees (π/2) each time to be able to reach all 4 walls of the aquarium, and from the third joint there is a bar connection that goes on the x-axis by -200 that connects it to last joint (the revolute one at the cleaning sponge), which is the end effector point.

From here on by having any point at the end effector, it is simple to calculate all possible configurations to reach the desired point (inverse kinematics). It can be done by simply drawing an r=200 circle from the end effector point and draw a cross sign, from here just move the third joint to each of the points and rotate the Z-slider to match the middle point (final point of the end effector).

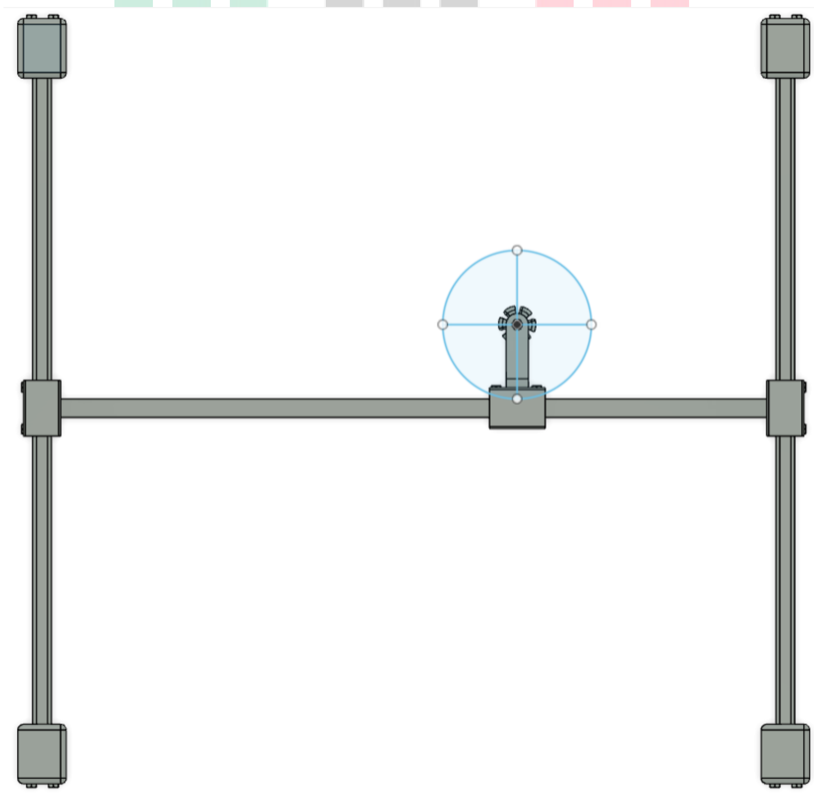


Figure 8. A-brush top view

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- Position 1:

Forward Kinematics:

T1: $Rot_x\left(\frac{\pi}{2}\right)\cdot\ Rot_z\left(\frac{\pi}{2}\right)\cdot Trans_z(-1000) = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 1000 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T2: $Rot_x\left(-\frac{\pi}{2}\right)\cdot Trans_z(-900) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & -900 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T3: $Rot_y\left(\frac{\pi}{2}\right)\cdot Trans_z(-1500) = \begin{bmatrix} 0 & 0 & 1 & -1500 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T4: $Trans_x(-200) = \begin{bmatrix} 1 & 0 & 0 & -200 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T∆1: $\begin{bmatrix} 1 & 0 & 0 & 700 \\ 0 & 1 & 0 & 1000 \\ 0 & 0 & 1 & -1500 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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Inverse kinematics:

$$T\Delta 1 = (700, 1000, -1500)$$

$$(x + 200, y, z) = (700{,}1000, -1500)$$

$$x = 700 - 200 = 500, y = 1000, z = -1500$$

From the top view, let's calculate all possible positions of the end-effector's origin (the third joint) with the following formula:

$$(xt, yt) = (xt + 200cos(\theta), yt + 200sin(\theta))$$

From here, the positions were easily found by replacing the angle θ for 0, 90, 180 and 270 degrees respectively.

- Orientation 1 ($\boldsymbol{\theta = 0}$): $(xt, yt) = (500 + 200 \cdot cos(0){,}1000 + 200 \cdot sin(0)) = (700{,}1000)$

Resulting on the following: Z1 = 1000, Z2 = 700, Z3 = -1500

- Orientation 2 ($\boldsymbol{\theta = 90}$): $(xt, yt) = (500 + 200 \cdot cos(90){,}1000 + 200 \cdot sin(90)) = (500{,}1200)$

Resulting on the following: Z1 = 1200, Z2 = 500, Z3 = -1500

- Orientation 3 ($\boldsymbol{\theta = 180}$): $(xt, yt) = (500 + 200 \cdot cos(180){,}1000 + 200 \cdot sin(180)) = (300{,}1000)$

Resulting on the following: Z1 = 1000, Z2 = 300, Z3 = -1500

- Orientation 4 ($\boldsymbol{\theta = 270}$): $(xt, yt) = (500 + 200 \cdot cos(270){,}1000 + 200 \cdot sin(270)) = (500{,}800)$

Resulting on the following: Z1 = 800, Z2 = 500, Z3 = -1500

Being all 4 results suitable and possible to be accomplished by the A-brush.

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- Position 2:

Forward Kinematics:

T1: $Rot_x\left(\frac{\pi}{2}\right)\cdot\ Rot_z\left(\frac{\pi}{2}\right)\cdot Trans_z(-1200) = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 1200 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T2: $Rot_x\left(-\frac{\pi}{2}\right)\cdot Trans_z(-1500) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1500 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T3: $Rot_y\left(\frac{\pi}{2}\right)\cdot Trans_z(-800) = \begin{bmatrix} 0 & 0 & 1 & -800 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T4: $Trans_x(-200) = \begin{bmatrix} 1 & 0 & 0 & -200 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T∆2: $\begin{bmatrix} 1 & 0 & 0 & 1300 \\ 0 & 1 & 0 & 1200 \\ 0 & 0 & 1 & -800 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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Inverse kinematics:

$$T\Delta 2 = (1300, 1200, -800)$$

$$(x + 200, y, z) = (1300, 1200, -800)$$

$$x = 1300 - 200 = 1100, y = 1200, z = -800$$

From the top view, let's calculate all possible positions of the end-effector's origin (the third joint) with the following formula:

$$(xt, yt) = (xt + 200cos(\theta), yt + 200sin(\theta))$$

From here, the positions were easily found by replacing the angle θ for 0, 90, 180 and 270 degrees respectively.

- Orientation 1 ($\boldsymbol{\theta = 0}$): $(xt, yt) = (1100 + 200 \cdot cos(0), 1200 + 200 \cdot sin(0)) = (1300, 1200)$

Resulting on the following: Z1 = 1200, Z2 = 1300, Z3 = -800

- Orientation 2 ($\boldsymbol{\theta = 90}$): $(xt, yt) = (1100 + 200 \cdot cos(90), 1200 + 200 \cdot sin(90)) = (1100, 1400)$

Resulting on the following: Z1 = 1400, Z2 = 1100, Z3 = -800

- Orientation 3 ($\boldsymbol{\theta = 180}$): $(xt, yt) = (1100 + 200 \cdot cos(180), 1200 + 200 \cdot sin(180)) = (900, 1200)$

Resulting on the following: Z1 = 1200, Z2 = 900, Z3 = -800

- Orientation 4 ($\boldsymbol{\theta = 270}$): $(xt, yt) = (1100 + 200 \cdot cos(270), 1200 + 200 \cdot sin(270)) = (1100, 1000)$

Resulting on the following: Z1 = 1000, Z2 = 1100, Z3 = -800

Being all 4 results suitable and possible to be accomplished by the A-brush.

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- ## Position 3:

Forward Kinematics:

T1: $Rot_x\left(\frac{\pi}{2}\right)\cdot\ Rot_z\left(\frac{\pi}{2}\right)\cdot Trans_z(-1740) = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 1740 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T2: $Rot_x\left(-\frac{\pi}{2}\right)\cdot Trans_z(-1900) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1900 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T3: $Rot_y\left(\frac{\pi}{2}\right)\cdot Trans_z(-\mathbf{1}810) = \begin{bmatrix} 0 & 0 & 1 & -1810 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T4: $Trans_x(-200) = \begin{bmatrix} 1 & 0 & 0 & -200 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T∆3: $\begin{bmatrix} 1 & 0 & 0 & 1700 \\ 0 & 1 & 0 & 1740 \\ 0 & 0 & 1 & -1810 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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Inverse kinematics:

$$T\Delta 3 = (1700, 1740, -1810)$$

$$(x + 200, y, z) = (1700, 1740, -1810)$$

$$x = 1700 - 200 = 1500, y = 1740, z = -1810$$

From the top view, let's calculate all possible positions of the end-effector's origin (the third joint) with the following formula:

$$(xt, yt) = (xt + 200cos(\theta), yt + 200sin(\theta))$$

From here, the positions were easily found by replacing the angle θ for 0, 90, 180 and 270 degrees respectively.

- Orientation 1 ($\boldsymbol{\theta = 0}$): $(xt, yt) = (1500 + 200 \cdot cos(0), 1740 + 200 \cdot sin(0)) = (1700, 1740)$

Resulting on the following: Z1 = 1740, Z2 = 1700, Z3 = -1810

- Orientation 2 ($\boldsymbol{\theta = 90}$): $(xt, yt) = (1500 + 200 \cdot cos(90), 1740 + 200 \cdot sin(90)) = (1500, 1940)$

Resulting on the following: Z1 = 1940, Z2 = 1500, Z3 = -1810

- Orientation 3 ($\boldsymbol{\theta = 180}$): $(xt, yt) = (1500 + 200 \cdot cos(180), 1740 + 200 \cdot sin(180)) = (1300, 1740)$

Resulting on the following: Z1 = 1740, Z2 = 1300, Z3 = -1810

- Orientation 4 ($\boldsymbol{\theta = 270}$): $(xt, yt) = (1500 + 200 \cdot cos(270), 1740 + 200 \cdot sin(270)) = (1500, 1540)$

Resulting on the following: Z1 = 1540, Z2 = 1500, Z3 = -1810

Being all results suitable and possible to be accomplished by the A-brush except the one at orientation 2.

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- Position 4:

Forward Kinematics:

T1: $Rot_x\left(\frac{\pi}{2}\right) \cdot\ Rot_z\left(\frac{\pi}{2}\right) \cdot Trans_z(-500) = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 500 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T2: $Rot_x\left(-\frac{\pi}{2}\right) \cdot Trans_z(-300) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & -300 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T3: $Rot_y\left(\frac{\pi}{2}\right) \cdot Trans_z(-\mathbf{1}000) = \begin{bmatrix} 0 & 0 & 1 & -1000 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T4: $Trans_x(-200) = \begin{bmatrix} 1 & 0 & 0 & -200 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T∆4: $\begin{bmatrix} 1 & 0 & 0 & 100 \\ 0 & 1 & 0 & 500 \\ 0 & 0 & 1 & -1000 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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Inverse kinematics:

$$T\Delta 4 = (100, 500, -1000)$$

$$(x + 200, y, z) = (100, 500, -1000)$$

$$x = 100 - 200 = -100, y = 500, z = -1000$$

From the top view, let's calculate all possible positions of the end-effector's origin (the third joint) with the following formula:

$$(xt, yt) = (xt + 200cos(\theta), yt + 200sin(\theta))$$

From here, the positions were easily found by replacing the angle θ for 0, 90, 180 and 270 degrees respectively.
- Orientation 1 ($\boldsymbol{\theta = 0}$): $(xt, yt) = (-100 + 200 \cdot cos(0), 500 + 200 \cdot sin(0)) = (100, 500)$

Resulting on the following: Z1 = 500, Z2 = 100, Z3 = -1000

- Orientation 2 ($\boldsymbol{\theta = 90}$): $(xt, yt) = (-100 + 200 \cdot cos(90), 500 + 200 \cdot sin(90)) = (-100, 700)$

Resulting on the following: Z1 = 700, Z2 = -100, Z3 = -1000

- Orientation 3 ($\boldsymbol{\theta = 180}$): $(xt, yt) = (-100 + 200 \cdot cos(180), 500 + 200 \cdot sin(180)) = (-300, 500)$

Resulting on the following: Z1 = 500, Z2 = -300, Z3 = -1000

- Orientation 4 ($\boldsymbol{\theta = 270}$): $(xt, yt) = (-100 + 200 \cdot cos(270), 500 + 200 \cdot sin(270)) = (-100, 300)$

Resulting on the following: Z1 = 300, Z2 = -100, Z3 = -1000

Being only result at orientation 1 suitable and possible to be accomplished by the A-brush.

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- **Position 5:**

Forward Kinematics:

T1: $Rot_x\left(\frac{\pi}{2}\right) \cdot \; Rot_z\left(\frac{\pi}{2}\right) \cdot Trans_z(0) = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T2: $Rot_x\left(-\frac{\pi}{2}\right) \cdot Trans_z(0) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T3: $Rot_y(\pi) \cdot Trans_z(0) = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T4: $Trans_x(-200) = \begin{bmatrix} 1 & 0 & 0 & -200 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

T∆5: $\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 200 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

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Inverse kinematics:

$$T\Delta 5 = (0, 0, 200)$$

$$(x + 200, y, z) = (0,0,200)$$

$$x = 0 - 200 = -200, y = 0, z = 200$$

From the top view, let's calculate all possible positions of the end-effector's origin (the third joint) with the following formula:

$$(xt, yt) = (xt + 200cos(\theta), yt + 200sin(\theta))$$

From here, the positions were easily found by replacing the angle θ for 0, 90, 180 and 270 degrees respectively.

- Orientation 1 ($\theta = 0$): $(xt, yt) = (-200 + 200 \cdot cos(0), 0 + 200 \cdot sin(0)) = (0,0)$

Resulting on the following: Z1 = 1000, Z2 = 700, Z3 = -1500

- Orientation 2 ($\theta = 90$): $(xt, yt) = (-200 + 200 \cdot cos(90), 0 + 200 \cdot sin(90)) = (-200,200)$

Resulting on the following: Z1 = 1200, Z2 = 500, Z3 = -1500

- Orientation 3 ($\theta = 180$): $(xt, yt) = (-200 + 200 \cdot cos(180), 0 + 200 \cdot sin(180)) = (-400,0)$

Resulting on the following: Z1 = 1000, Z2 = 300, Z3 = -1500

- Orientation 4 ($\theta = 270$): $(xt, yt) = (-200 + 200 \cdot cos(270), 0 + 200 \cdot sin(270)) = (-200, -200)$

Resulting on the following: Z1 = 800, Z2 = 500, Z3 = -1500

Being only the result at orientation 1 suitable and possible to be accomplished by the A-brush.

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Figures