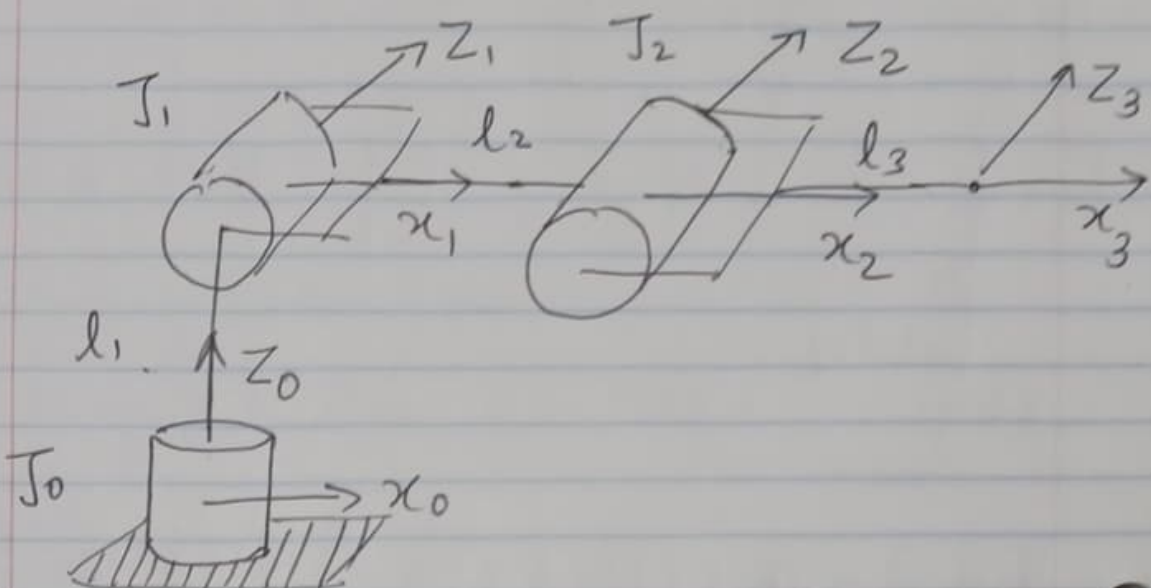


HW Assign. 2 RBE 500

Q.1



Step 1, 2: Assign z and x axes

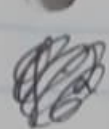
Step 3:- D-H table

| | θ | α | a | d |
|--------|--------------|----------|-------|-------|
| link 1 | θ_1^* | -90 | 0 | l_1 |
| link 2 | θ_2^* | 0 | l_2 | 0 |
| link 3 | θ_3^* | 0 | l_3 | 0 |

Step 4:- Calculate the A_i

$$A_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \cos(-90) & \sin \theta_i \sin(-90) & 0 \\ \sin \theta_i & \cos \theta_i \cos(-90) & -\cos \theta_i \sin(-90) & 0 \\ 0 & \sin(-90) & \cos(-90) & l_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos \theta_i & 0 & -\sin \theta_i & 0 \\ \sin \theta_i & 0 & +\cos \theta_i & 0 \\ 0 & -1 & 0 & l_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$A_2 = \begin{bmatrix} \cos \theta_2 & -\sin \theta_2 \cos(0) & \sin \theta_2 \sin(0) & l_2 \cos \theta_2 \\ \sin \theta_2 & \cos \theta_2 \cos(0) & -\cos \theta_2 \sin(0) & l_2 \sin \theta_2 \\ 0 & \sin(0) & \cos(0) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

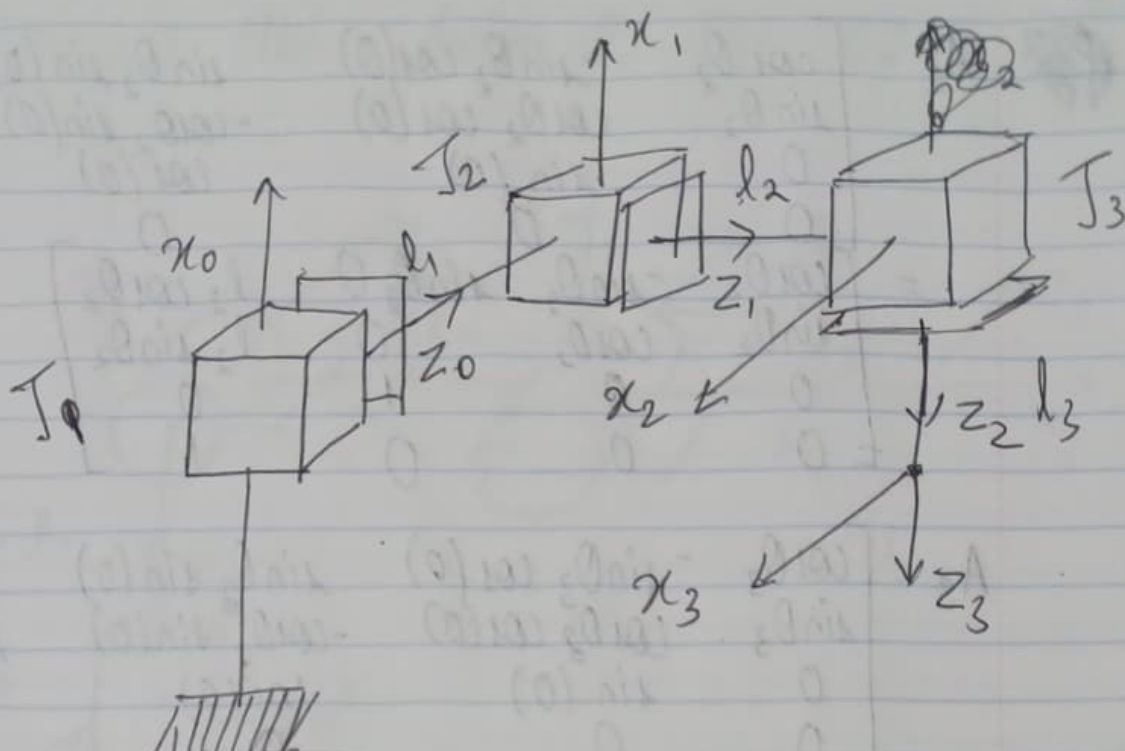
$$= \begin{bmatrix} \cos \theta_2 & -\sin \theta_2 & 0 & l_2 \cos \theta_2 \\ \sin \theta_2 & \cos \theta_2 & 0 & l_2 \sin \theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} \cos \theta_3 & -\sin \theta_3 \cos(0) & \sin \theta_3 \sin(0) & l_3 \cos \theta_3 \\ \sin \theta_3 & \cos \theta_3 \cos(0) & -\cos \theta_3 \sin(0) & l_3 \sin \theta_3 \\ 0 & \sin(0) & \cos(0) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos \theta_3 & -\sin \theta_3 & 0 & l_3 \cos \theta_3 \\ \sin \theta_3 & \cos \theta_3 & 0 & l_3 \sin \theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} //$$

$$T_n^0 = A_1 * A_2 * A_3 //$$

Q-2



| | | | | |
|-------------------|--------------|--------------|--------------|--------------|
| link 1 | 0 | x | a | d |
| link 2 | | | | |
| link 3 | | | | |

Step 1: Assign x and z axes

Step 2:- D-H Table

| | θ | α | a | d |
|--------|----------|----------|-----|---------|
| link 1 | 0 | -90 | 0 | d_1^* |
| link 2 | 90 | -90 | 0 | d_2^* |
| link 3 | 0 | 0 | 0 | d_3^* |

~~A_i Calculation~~

~~$$A_1 = \begin{bmatrix} \cos(0) & -90 \end{bmatrix}$$~~

Step 3:- Calculate the A_i

$$A_1 = \begin{bmatrix} \cos(0) & -\sin(0)\cos(d_1) \\ \sin(0) & \cos(0)\cos(d_1) \\ 0 & \sin(-90) \\ 0 & 0 \end{bmatrix}$$

$$A_1 = \begin{bmatrix} \cos(0) & -\sin(0)\cos(-90) & \sin(0)\sin(90) & 0 \\ \sin(0) & \cos(0)\cos(-90) & -\cos(0)\sin(-90) & 0 \\ 0 & \sin(-90) & \cos(-90) & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} \cos(90) & -\sin(90)\cos(-90) & \sin(90)\sin(-90) & 0 \\ \sin(90) & \cos(90)\cos(-90) & -\cos(90)\sin(-90) & 0 \\ 0 & \sin(-90) & \cos(-90) & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

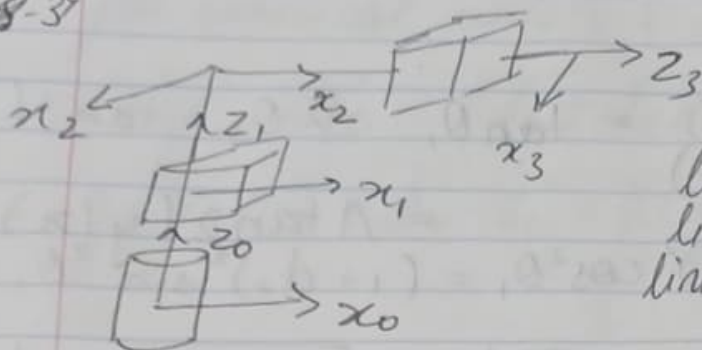
$$= \begin{bmatrix} 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} \cos(0) & -\sin(0)\cos(0) & \sin(0)\sin(0) & 0 \\ \sin(0) & \cos(0)\cos(0) & -\cos(0)\sin(0) & 0 \\ 0 & \sin(0) & \cos(0) & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_n^0 = A_1 * A_2 * A_3 //$$

Q-8-3



| | a | α | d | θ |
|--------|-----|-------------|-----------|--------------|
| link 1 | 0 | 0 | 1 | θ_1^* |
| link 2 | 0 | -90° | d_2^* | -90° |
| link 3 | 0 | 0 | $1+d_3^*$ | 0 |

$$T_1^0 = A_1 = \begin{bmatrix} \cos \theta_1 & -\sin \theta_1 & 0 & 0 \\ \sin \theta_1 & \cos \theta_1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2^1 = A_2 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & d_2^* \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^2 = A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1+d_3^* \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^0 = T_0^1 T_1^2 T_2^3 = \begin{bmatrix} \cos \theta_1 & 0 & \sin \theta_1 \\ \sin \theta_1 & 0 & \cos \theta_1 \\ 0 & 0 & 1 \end{bmatrix}$$

Assuming the end-effector position to be (x, y, z)

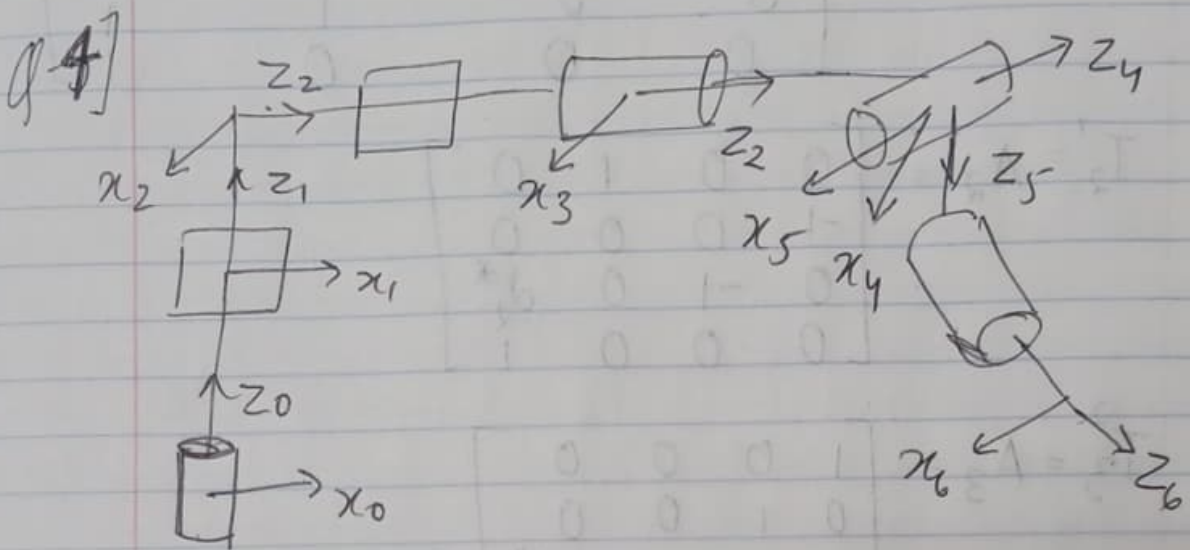
$$\begin{aligned} x &= (1+d_3^*) \cos \theta_1 \\ y &= (1+d_3^*) \sin \theta_1 \\ z &= 1+d_2^* \end{aligned}$$

~~#4~~ Then, $d_2^* = z - 1$

$$\frac{y}{z} = \frac{\sin \theta_1 (1 + d_3^*)}{\cos \theta_1 (1 + d_3^*)} = \tan \theta_1 \Rightarrow \theta_1 = \tan^{-1}(y/x)$$

$$\Rightarrow x^2 + y^2 = (1 + d_3)^2 \cos^2 \theta_1 = (1 + d_3)^2 \sin^2 \theta_1 = A \tan^2(y/x)$$

$$x^2 + y^2 = (1 + d_3)^2 \Rightarrow d_3 = \sqrt{x^2 + y^2} - 1$$



$$T_6^0 = \begin{bmatrix} R_6^0 & 0_6^0 \\ 0 & 1 \end{bmatrix}$$

(Assume)

$$= \begin{bmatrix} r_{11} & r_{12} & r_{13} & x_p \\ r_{21} & r_{22} & r_{23} & y_p \\ r_{31} & r_{32} & r_{33} & z_p \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

for spherical wrist,

$$O_4^0 = O_6^0 - (l_6 + l_5) Z_6^0$$

$$\therefore O_4^0 = O_3^0 + l_4 \cdot Z_3^0 = \begin{bmatrix} (1+d_3) \cos \theta_1 \\ (1+d_3) \sin \theta_1 \\ 1+d_2 \end{bmatrix} + \begin{bmatrix} \cos \theta_1 \\ \sin \theta_1 \\ 0 \end{bmatrix} l_4$$

$$= \begin{bmatrix} (1+d_3+l_4) \cos \theta_1 \\ (1+d_3+l_4) \sin \theta_1 \\ 1+d_2 \end{bmatrix}$$

$$= \begin{bmatrix} x_p - (l_5+l_6) \cdot r_{31} \\ y_p - (l_5+l_6) \cdot r_{32} \\ z_p - (l_5+l_6) \cdot r_{33} \end{bmatrix}$$

$$d_2 = z_p - (l_5 + l_6) \cdot r_{33} - 1$$

$$\text{Take } y_5 = y_p - (l_5 + l_6) \cdot r_{32}$$

$$x_5 = x_p - (l_5 + l_6) \cdot r_{31}$$

$$d_3 = \sqrt{x_5^2 + y_5^2} - 1 - l_4$$

$$\theta_1 = \text{Atan2}(y_5, x_5)$$

$$R_1^0 \text{ is } R_3^0 = R_0^3, R_6^0 = R_3^0{}^T \cdot R_6^0$$

$$R_6^3 = \begin{bmatrix} \sin \theta_1 & -\cos \theta_1 & 0 \\ 0 & 0 & -1 \\ \cos \theta_1 & \sin \theta_1 & 0 \end{bmatrix} \cdot \begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{bmatrix}$$

Use DH table to get R_6^3

$$\begin{array}{c|c|c|c} a & \alpha & d & \theta \\ \hline 0 & -90^\circ & l_4 & 90+\theta_4 \\ 0 & 90^\circ & 0 & \theta_5 \\ 0 & 0 & l_5+l_6 & \theta_6 \end{array}$$

$$R_4^3 = \begin{bmatrix} \sin \theta_4 & 0 & -\cos \theta_4 \\ \cos \theta_4 & 0 & -\sin \theta_4 \\ 0 & -1 & 0 \end{bmatrix}$$

$$R_5^4 = \begin{bmatrix} \cos \theta_5 & 0 & \sin \theta_5 \\ \sin \theta_5 & 0 & -\sin \theta_5 \\ 0 & 1 & 0 \end{bmatrix}$$

$$R_6^5 = \begin{bmatrix} \cos \theta_6 & -\sin \theta_6 & 0 \\ \sin \theta_6 & \cos \theta_6 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_6^3 = R_4^3 \cdot R_5^4 \cdot R_6^5$$

$$= \begin{bmatrix} \sin \theta_4 \cos \theta_5 \cos \theta_6 - \sin \theta_6 \cos \theta_4 \\ \cos \theta_4 \cos \theta_5 \cos \theta_6 - \sin \theta_6 \cos \theta_4 \\ \sin \theta_4 \sin \theta_5 \cos \theta_6 - \sin \theta_6 \sin \theta_4 \\ \cos \theta_4 \sin \theta_5 \cos \theta_6 - \sin \theta_6 \sin \theta_4 \\ \sin \theta_4 \cos \theta_5 \sin \theta_6 - \cos \theta_6 \cos \theta_4 \\ \cos \theta_4 \cos \theta_5 \sin \theta_6 - \cos \theta_6 \cos \theta_4 \\ \sin \theta_4 \sin \theta_5 \sin \theta_6 - \cos \theta_6 \sin \theta_4 \\ \cos \theta_4 \sin \theta_5 \sin \theta_6 - \cos \theta_6 \sin \theta_4 \\ \sin \theta_6 \cos \theta_4 \end{bmatrix}$$

#

$$\therefore \theta_4 = \text{Atan2}(\cos \theta_1 x_{32} - \sin \theta_1 x_{31} - x_{33})$$

$$\theta_5 = \text{Atan2}(-x_{33} / \cos \theta_4, \cos \theta_1 x_{31} + \sin \theta_1 x_{32})$$

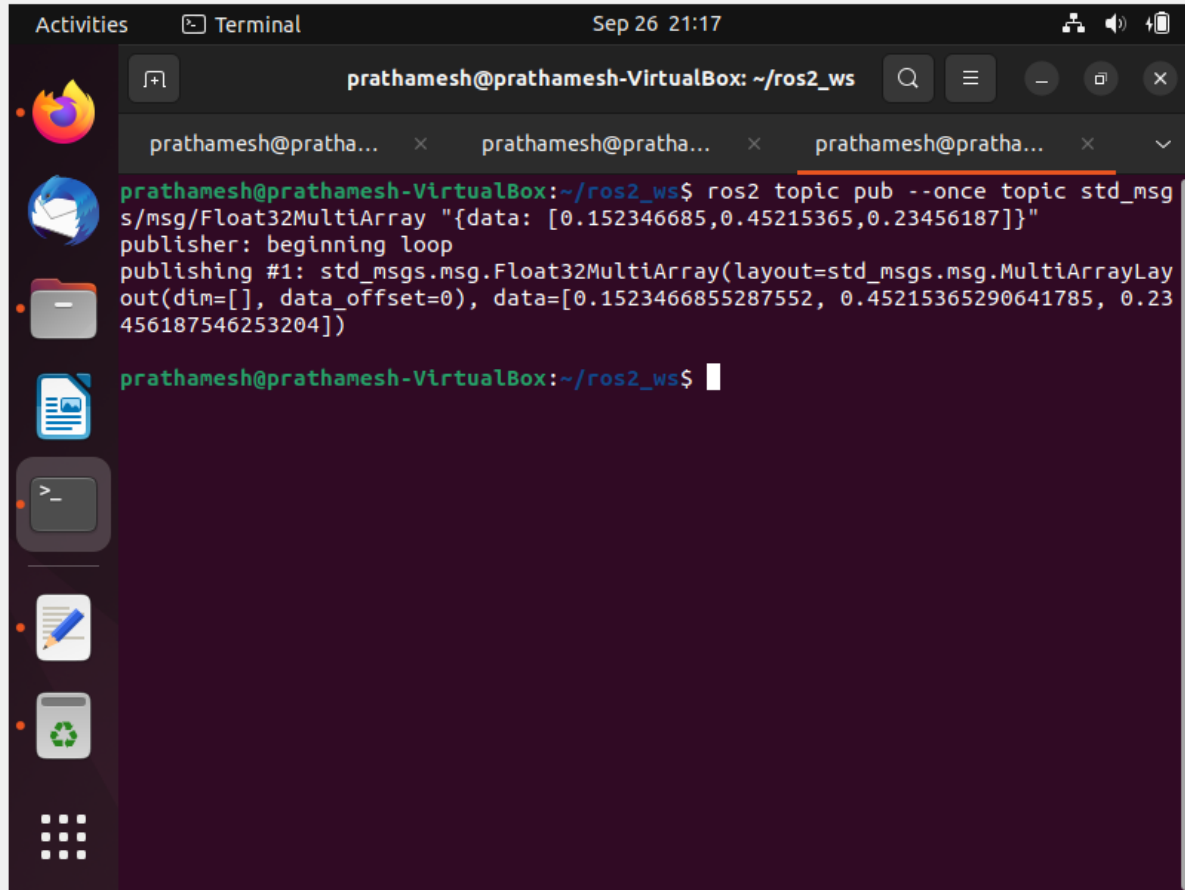
$$\theta_6 = \text{Atan2}(\cos \theta_1 x_{21} + \sin \theta_1 x_{22} - \cos \theta_1 x_{11} - \sin \theta_1 x_{12})$$

In the implementation mentioned, we make use of the `std-megs` library. ~~§~~

There is an input in form of euler ~~and~~ values i.e. (angle values corresponding to yaw, pitch and roll) in accordance to xyz euler angles then this input is converted to quaternion ~~with~~ with the help of the conversion formula and thus the output is a quaternion value set consisting of x, y, z, w values for the inputted euler angles.

The output is printed out using `%f` as its float in nature.

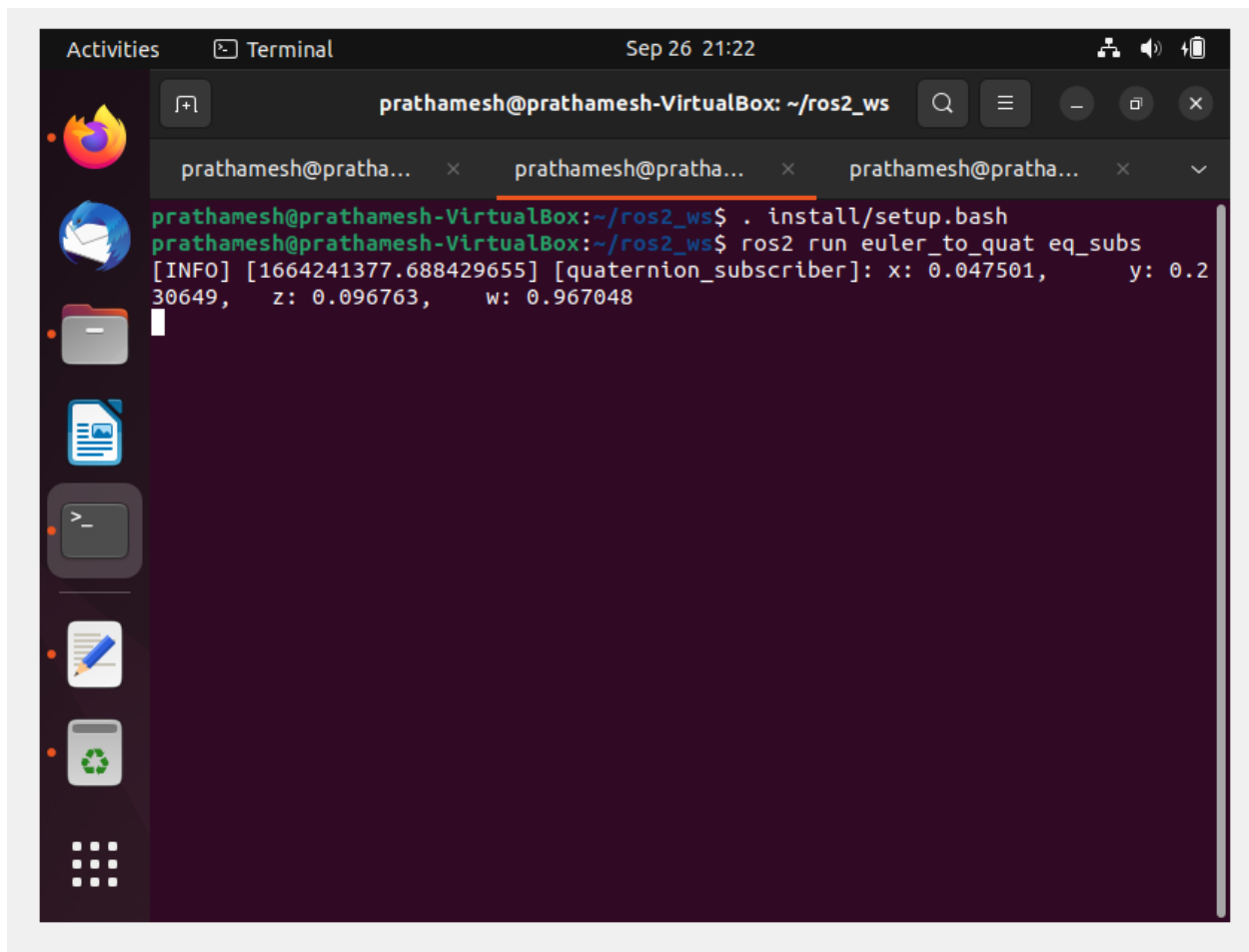
The publisher publishes this converted quaternion value and the ~~send~~ subscriber ~~also~~ receives the same and displays it into the subscriber node. ~~This fix~~



The image shows a terminal window titled "Terminal" with a date and time of "Sep 26 21:17". The terminal is running a ROS2 command to publish a message. The output shows the publisher starting a loop and publishing a message of type `std_msgs/msg/Float32MultiArray` with three data points. The terminal window is part of a desktop environment with a sidebar on the left containing icons for Firefox, a mail client, a file manager, a document viewer, a code editor, and a system monitor. The terminal's title bar includes a search icon, a menu icon, and window control buttons. The terminal's address bar shows the current directory as `~/ros2_ws` and the user as `prathamesh@prathamesh-VirtualBox`.

```
prathamesh@prathamesh-VirtualBox: ~/ros2_ws$ ros2 topic pub --once topic std_msgs/msg/Float32MultiArray "{data: [0.152346685,0.45215365,0.23456187]}"
publisher: beginning loop
publishing #1: std_msgs.msg.Float32MultiArray(layout=std_msgs.msg.MultiArrayLayout(dim=[], data_offset=0), data=[0.1523466855287552, 0.45215365290641785, 0.23456187546253204])
prathamesh@prathamesh-VirtualBox: ~/ros2_ws$
```

Publisher Node



Subscriber Node