

# IVR Coursework

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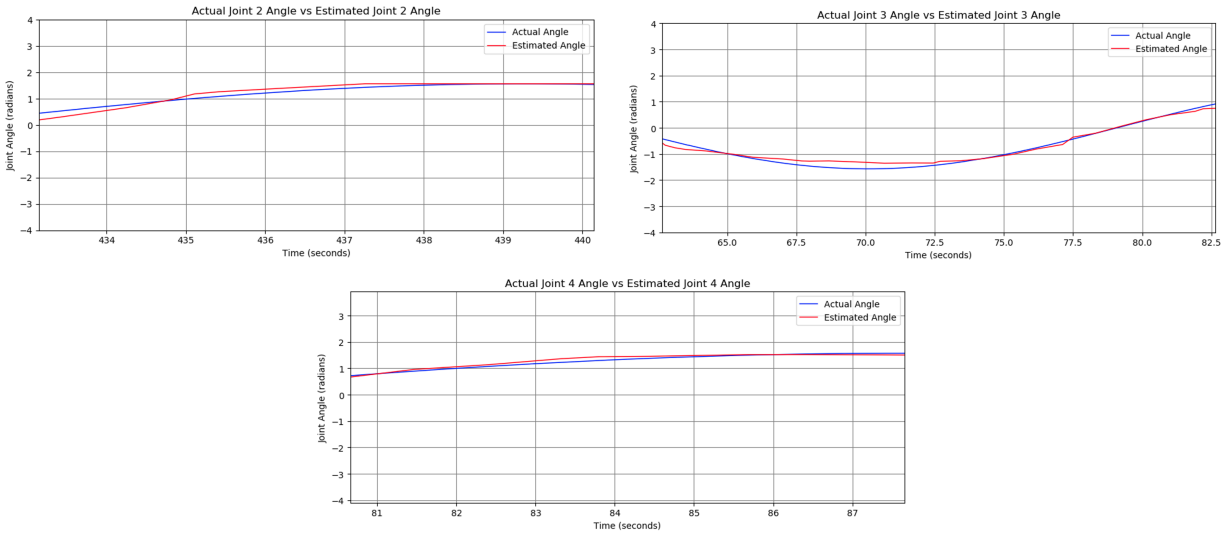
Neil and Matt worked on this coursework collaboratively - answering all questions and coding together. Thus there was an equal contribution from both members of the team.

Access the GitHub link to our code here: <https://github.com/the-raspberry-pi-guy/IVR-Assignment>

## 2 Robot Vision

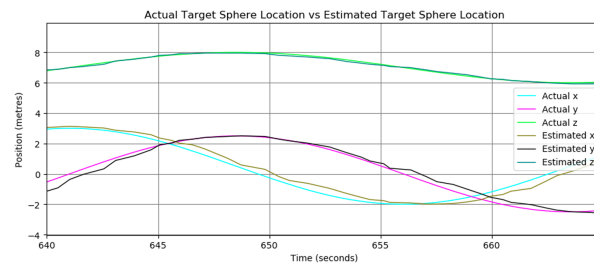
### 2.1 Joint State Estimation

*DESCRIBE ALGORITHM*



### 2.2 Target Detection

*DESCRIBE ALGORITHM & COMMENT ON SOURCES OF ERROR IN MEASUREMENTS*



### 3 Robot Control

#### 3.1 Forward Kinematics

$$\begin{bmatrix} 3s(\theta_1)s(\theta_2)c(\theta_3)c(\theta_4) + 3.5s(\theta_1)s(\theta_2)c(\theta_3) + 3s(\theta_1)s(\theta_4)c(\theta_2) + 3s(\theta_3)c(\theta_1)c(\theta_4) + 3.5s(\theta_3)c(\theta_1) \\ 3s(\theta_1)s(\theta_3)c(\theta_4) + 3.5s(\theta_1)s(\theta_3) - 3s(\theta_2)c(\theta_1)c(\theta_3)c(\theta_4) - 3.5s(\theta_2)c(\theta_1)c(\theta_3) - 3s(\theta_4)c(\theta_1)c(\theta_2) \\ -3s(\theta_2)s(\theta_4) + 3c(\theta_2)c(\theta_3)c(\theta_4) + 3.5c(\theta_2)c(\theta_3) + 2.5 \end{bmatrix}$$

| Joint Angle<br><i>Joint 1,2,3,4 (rad)</i> | Estimated via FK<br><i>x,y,z (m)</i> | Estimated via Images<br><i>x,y,z (m)</i> |
|---|--------------------------------------|--|
| 1,0.5,0.1,-1                              | 0.47,0.31,8.18                       | 0.33,0.33,8.76                           |
| -1,-1,-1,1                                | -1.52,4.15,6.12                      | -1.36,3.68,6.59                          |
| 0.25,0.25,0.25,0.25                       | 2.09, -1.79, 8.33                    | 2.24,-2.06,9.16                          |
| 1,1,0.5,0.5                               | 6.05,-0.39,4.20                      | 6.11,-0.59,4.64                          |
| -1,-0.5,-0.1,1                            | 4.20,2.09,5.76                       | 3.68,2.72,6.22                           |
| 1,1,1,-1                                  | 3.14,3.10,6.12                       | 2.54,3.72,6.77                           |
| -0.25,-0.25,-0.25,-0.25                   | -0.98,2.58,8.33                      | -0.92,2.43,8.65                          |
| -1,-1,-0.5,-0.5                           | 2.88,5.34,4.20                       | 2.13,6.33,4.97                           |
| $\pi, \pi/2, \pi/4, -0.1$                 | -4.58,4.59,2.80                      | -3.72,3.64,3.86                          |
| $-\pi, -\pi/2, -\pi/4, 0.1$               | 4.59,-4.58,2.80                      | 6.07,-6.15,2.43                          |

COMMENT ON ACCURACY

#### 3.2 Closed-Loop Control

$$A =$$

$$\begin{bmatrix} -3s(\theta_1)s(\theta_3)c(\theta_4) - 3.5s(\theta_1)s(\theta_3) + 3s(\theta_2)c(\theta_1)c(\theta_3)c(\theta_4) + 3.5s(\theta_2)c(\theta_1)c(\theta_3) + 3s(\theta_4)c(\theta_1)c(\theta_2) \\ 3s(\theta_1)s(\theta_2)c(\theta_3)c(\theta_4) + 3.5s(\theta_1)s(\theta_2)c(\theta_3) + 3s(\theta_1)s(\theta_4)c(\theta_2) + 3s(\theta_3)c(\theta_1)c(\theta_4) + 3.5s(\theta_3)c(\theta_1) \\ 0 \end{bmatrix}$$

$$B =$$

$$\begin{bmatrix} -3s(\theta_1)s(\theta_2)s(\theta_4) + 3s(\theta_1)c(\theta_2)c(\theta_3)c(\theta_4) + 3.5s(\theta_1)c(\theta_2)c(\theta_3) \\ 3s(\theta_2)s(\theta_4)c(\theta_1) - 3c(\theta_1)c(\theta_2)c(\theta_3)c(\theta_4) - 3.5c(\theta_1)c(\theta_2)c(\theta_3) \\ -3s(\theta_2)c(\theta_3)c(\theta_4) - 3.5s(\theta_2)c(\theta_3) - 3s(\theta_4)c(\theta_2) \end{bmatrix}$$

$$C =$$

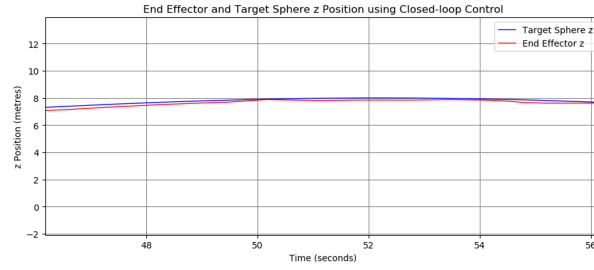
$$\begin{bmatrix} -3s(\theta_1)s(\theta_2)s(\theta_3)c(\theta_4) - 3.5s(\theta_1)s(\theta_2)s(\theta_3) + 3c(\theta_1)c(\theta_3)c(\theta_4) + 3.5c(\theta_1)c(\theta_3) \\ 3s(\theta_1)c(\theta_3)c(\theta_4) + 3.5s(\theta_1)c(\theta_3) + 3s(\theta_2)s(\theta_3)c(\theta_1)c(\theta_4) + 3.5s(\theta_2)s(\theta_3)c(\theta_1) \\ -3s(\theta_3)c(\theta_2)c(\theta_4) - 3.5s(\theta_3)c(\theta_2) \end{bmatrix}$$

$$D =$$

$$\begin{bmatrix} -3s(\theta_1)s(\theta_2)s(\theta_4)c(\theta_3) + 3s(\theta_1)c(\theta_2)c(\theta_4) - 3s(\theta_3)s(\theta_4)c(\theta_1) \\ -3s(\theta_1)s(\theta_3)s(\theta_4) + 3s(\theta_2)s(\theta_4)c(\theta_1)c(\theta_3) - 3c(\theta_1)c(\theta_2)c(\theta_4) \\ -3s(\theta_2)c(\theta_4) - 3s(\theta_4)c(\theta_2)c(\theta_3) \end{bmatrix}$$

Where A, B, C and D are column vectors that form the Jacobian when arranged like (formatted to save space):

$$\begin{bmatrix} A & B & C & D \end{bmatrix}$$



## 4 Final Task

### 4.2 Null-space Control

*DISCUSS ALGORITHM AND HOW IT IS DIFFERENT FROM PREVIOUS CONTROLLER. THREE PLOTS COMPARING THE POSITION OF THE ROBOT END-EFFECTOR WITH THE POSITION OF THE SPHERE AND THE POSITION OF THE BOX.*