Lab 2 – Forward and Inverse Kinematics

## Overview:

Two ways to categorize robot control is open and close-loop control. In open-loop control, the robot system receives no feedback or information about the environment. As it is performing its actions, it is essentially blind. The advantage of open-loop control is that the robot does not need sensors and the controller does not require much logic. In closed-loop, the robot has access to sensor information and feedback to inform its actions. Closed-loop control is theoretically more robust, but also requires more components (sensors) and programming logic.

For Lab 1 and 2, we will be focusing on open-loop control. Open-loop control requires that the environment and the correspondence between robot commands and the physical movement is known. One way to obtain the corresponded between robot commands and actual actions is to measure how the robot moves given different command values and generate a calibration curve.

## Objectives:

**In this Lab, you will be implementing the forward and inverse kinematics of a robot arm to program its movement and draw simple shapes.**

- Gain familiarity programming and working with the EV3 robots.
- Implement forward and inverse kinematics.
- Program the movement of a robotic arm to draw simple shapes.

## Procedure

1. Task 1 - Setup and Forward Kinematics Test
    a. Follow the instructions for assembling the robot arm.
    b. Tape a piece of paper down infront of the robot. You should try to center the paper within the working area (reach) of the robot. Note, the origin (0,0) is going to be directly under the axle of servo1.
    c. Take measurements of the arm and fill in your forward kinematics equations.
    d. Using your forward kinematics equations, find the x and y positions of the end effector for two different sets of servo angles. These angles should result in the end effector being roughly within the working area.
    e. Program the robot to move to these angles and measure the resulting location and error of the end affecter for two sets of angles.
        i. **For the EV3 robots, you will have to calibrate the angles of the servos before each 'run'. Straighten the arm so that servo1 is at 90 degrees and servo2 is at 0 degrees. In your code, set the angles for these motors to be 90 and 0 respectively.**
    f. Take five measurements for each set of angles
    g. Take a photo of one of the angle tests for your Results. In your Results, you should describe the experiment that produced the photo and information like the servo angles and x and y positions of the end effector. You can also annotate the photo to convey

information. **This type of reporting goes for all the photos you will take and add to the Results.**

2. Task 2 - Single points
    a. Write out the inverse kinematic equations and fill in the lengths of the robot arm.
    b. Plug the two sets of x and y coordinates from the forward kinematics of Task 1 into your equations and verify that you get the correct angles.
    c. Program the robot arm to move to these locations and measure the error.
3. Task 3 – Marking vertices
    a. Attach a marking object to the end effector. You can use something like mechanical pencil lead and have the lead overhang the lego axle by about 0.5 cm.
    b. Program servo3 to lower and raise the pen. Because the servos do not have an absolute encoding it will be difficult to tell it to move up and down consistently. You can try various methods to control the location of servo3, but I found that lowering the pen until the servo stalled and then raising it for some set amount was a good way to lower and raise it respectively.
    c. Figure out the coordinates for the vertices of a square and triangle within the working area.
    d. For each shape, have the robot move to the vertices and make some type of mark. You can have one of the servos rotate a few degrees to make a little slash. Take a picture of the final drawings for both the square and triangle.

*Figure 1 Example of how to attach pencil lead to the end effector.*

4. Task 4 – Straight lines
    a. Program the robot to draw the longest and most straight horizontal, vertical, and diagonal line. Have each line be a separate trial. Take a picture of each and a video of one of them.
5. Task 5 – Draw Shapes
    a. Draw a complete square and triangle with sides. Take a picture of each and a video of one of them.

## Questions

1. Why is drawing a straight line between two points non-trivial?
2. How did you deal with the hard constraints in your inverse kinematics?
3. For each desired target location, the analytical method produces two sets of angles. How did you decide which one to use?
4. Were the movements of the arm accurate? Why or why not?
5. What was the biggest difficulty in working with the robot arm?

## Hand in/write up notes

1. Methods
    a. Derivation and explanation of forward and inverse kinematics. It needs to be descriptive enough such that you could come back in a year and use it to remember how you got the equations in the first place. You can use figures and illustrations.

    b. Very brief and general description of your setup.
2. Results
    a. Pictures and description of each task and what happened.
3. Discussion
    a. See questions
4. Code (Supplementary Material)
    a. Python files. Each task should be initiated by a method. That methods can take parameters like angles or shape names. That method can also call other methods. But initiating a task, an experiment should be with a single method that you call from main.
    b. Videos submitted via Canvas.

## Rubric – Lab 2

General formatting (10)

- Title, date, name, section headings
- Miscellaneous style and formatting

Abstract (15)

- Gives a brief intro or overview of the Lab and/or topics covered.
- Gives a brief summary of the Results and main points from the Discussion.
- Well written and concise without typos or grammar issues.

Methods (15)

- Possess all relevant equations and algorithm explanations
- Looks nice and is easy to follow.

Results (45)

- Figures and text for all experiments.
- Figures are properly formatted (labels, legends, captions, etc.).

Discussion (15)

- All questions are answered.
- Well written and concise without typos or grammar issues.