EN.530.666 Magnetically Actuated and Magnetic Resonance Imaging Compatible Robots
Lab 3: Magnetic Surgery Lab - PID Position Control

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Due Date: Friday, February 21, 11:59 PM

February 10, 2025

1 Problem Statement

In this lab assignment, you will explore and implement a closed-loop controller to control the position of your magnetic robot as shown in Figure 1. You will set a target location for the robot and the robot will move to the desired location under closed-loop control using the localization method developed in lab 2 as feedback. In this lab assignment you don't need to control the orientation of your robot, only the position. You will compare different combinations of proportional, integral, and derivative (PID) controllers. You will accomplish this through i) applying a P controller to the magnetic robot, ii) applying a PD controller to the magnetic robot, iii) applying a PI controller to the magnetic robot, iv) applying a PID controller to the magnetic robot, and v) performing an error analysis using your best performing controller.

2 Applying Proportional Gain (P) to your controller

In this section, you will apply a proportional gain (kp) to your closed-loop controller to make your robot move in only one direction. In the backbone script, you will set up a target position in robot coordinate and put the robot at a different starting location. You will put your robot somewhere in the petri dish and ask the robot move to one direction (x or y) for certain distance. You will do this by making the control effort in one direction 0 so that there will be only movement in one direction. You will convert the control effort into coil current commands that will be sent to the motor drivers. You will notice that the proportional controller is not very stable and might not work very well initially. You need to adjust your proportional gain **kp** to get better performance. Record a video of the magnetic robot moving in one direction with P controller and write down your observations in your report. Once you are confident

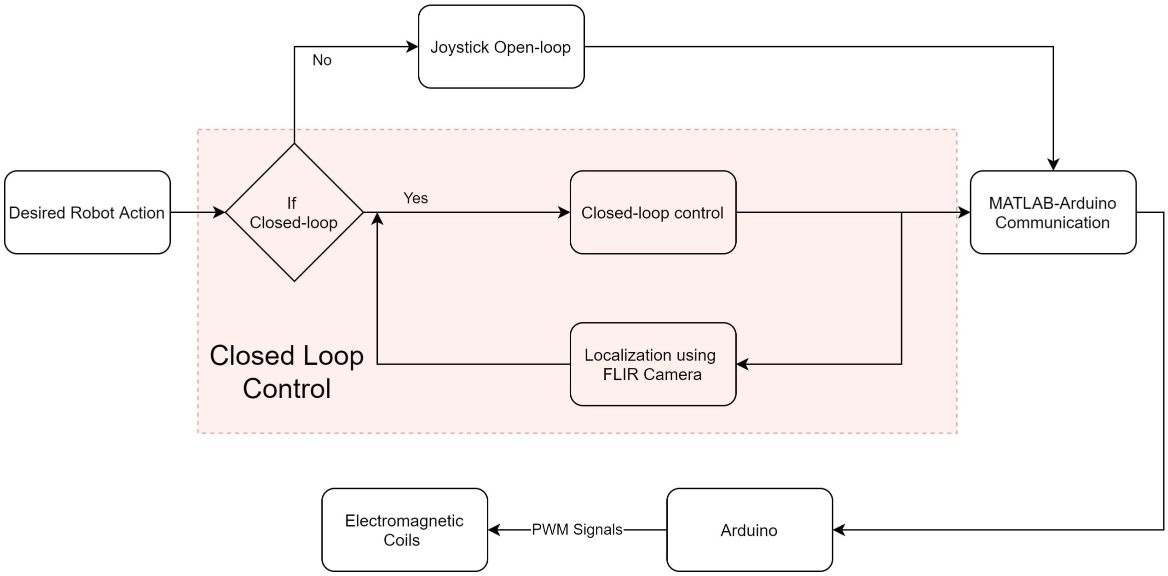

Figure 1: System architecture of the magnetic project.

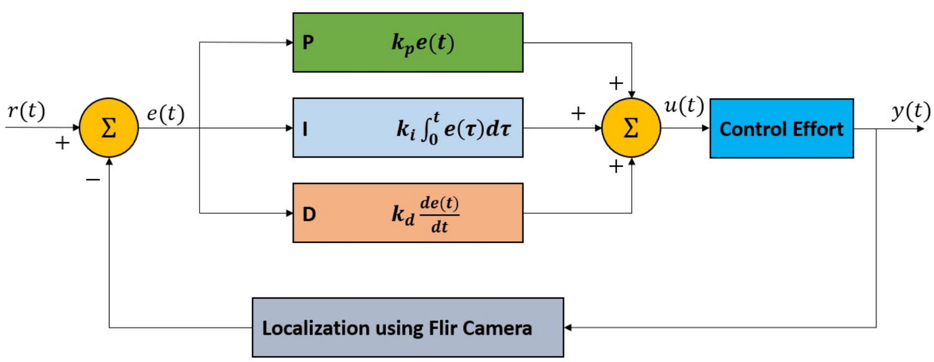

Figure 2: Closed-loop controller of the magnetic robot system.

with moving your robot with the P controller in one direction, move the target position to a location where it requires the robot to move in two directions to reach there. Adjust your kp value to observe different performances. Record a video of the magnetic robot moving in two directions with P controller and write down any observations you had. **During your experiment, you should use the joystick to move your robot to the start locations instead of opening the lid, so that there will be fewer issue with the camera.**

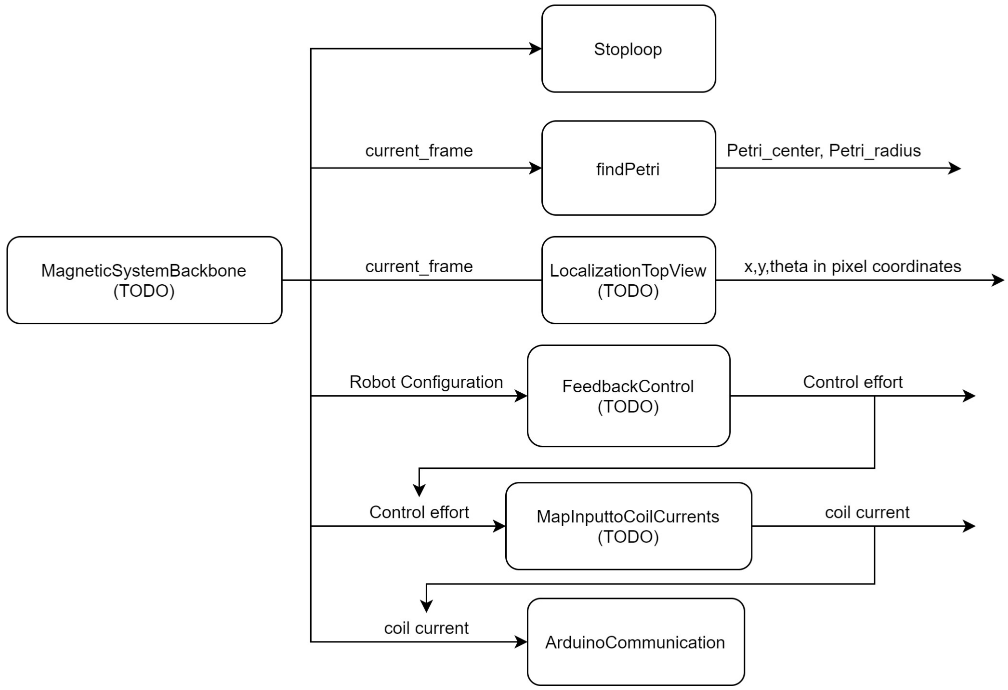

Figure 3: Schematic of functions for lab 8.

3 Applying Proportional and Derivative Gain (PD) to your controller

In this section, you will add an additional derivative gain, **kd** to your proportional controller. You will find the derivative of the error by dividing the error by the time difference as shown in Figure 2. You can also start this section by moving the robot in one direction and then apply to two directions. Record a video of PD controller with good performance and report your kp and kd values.

4 Applying Proportional and Integral Gain (PI) to your controller

In this section, you will add an additional integral gain, **ki** to your proportional controller. You will find the integral of the error by accumulating all the error as the experiment starts as shown in Figure 2. Similarly, you can move your robot in one direction first with your PI controller and then move the robot in two directions. Record a video of PI controller with good performance and report your kp and ki values.

5 Applying Proportional, Integral, and Derivative Gain (PID) to your controller

In this section, you will apply proportional, integral, and derivative gain to your closed loop controller. Tune your kp, ki, and kd to improve your controller performance. Your goal is to move the robot to any target position in the Petri dish and the error between the final robot position and the target position should be within 2 mm. Take a video of the robot moving with PID controller and record your kp, ki, and kd values.

6 Error Analysis of Position Controller

In this section you will repeat positioning experiments with your magnetic robot moving from the center of the petri dish to at least 10 different desired end points. These 10 points should be equally distributed in the petri dish. You are free to use your best performing controller that you have developed. You will need to measure the final positioning error at the end point (distance from desired end point to actual end point defined by manually marking the final magnet position on the image in Matlab, e.g. using ginput) and the time elapsed from start. Report your average and standard deviations of the positioning error and settling time. You will also make a time plot for at least one representative experiment with one subplot showing x position vs. time and another subplot showing y position vs. time. You will show your steady-state error, settling time, and percent overshoot on this plot as well.

7 Helpful notes

The homework file contains multiple code files, which might make it challenging to determine where to start. However, you are not required to read and understand all of them. The best approach to completing the MATLAB code is to begin with MagneticSystemBackbone.m. Use "Ctrl+F" to search for "TODO" and follow the provided instructions. If the TODO directive refers to another function file, open it and complete the required code accordingly.

From this lab on, please only use the robot assigned to your group at all times. Misusing of different magnetic robots would cause inconsistency with the robot performance and endless parameter tuning!

8 Submission

A zip file per project team (100 points) containing the following items:

1. A single PDF file per project team with a short lab report containing a summary of the lab with the following items:
   - Observation of P controller (10 points)
   - Observation of PD controller (10 points)
   - Observation of PI controller (10 points)

- Observation of PID controller (10 points)
- Does your control performance vary with desired position? Is your PID controller designed to address differences in starting and desired positions? (10 points)
- Comparison of different controllers (10 points)
- Error and control time analysis (20 points)

2. Two videos of robot moving to target location with P controller (one direction and two directions) (5 points)
3. A video of robot moving to target location with PI controller (5 points)
4. A video of robot moving to target location with PD controller (5 points)
5. A video of robot moving to target location with PID controller (5 points)
6. A zip file containing all your MATLAB scripts (Required to receive a grade for this assignment)