ECE 4950 Project 5
Closed-loop Motor Position Control

Group 3 "No Induction Needed"
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Executive Summary

The goal of this project was to design a closed-loop motor control system that could be controlled from a Simulink program using the xPC/Quanser Real-Time Control workstation. The system input was the angle information calculated by the image processing system from Project 4. The system was to take the angle information and use PID control to move an "arrow" mounted to the motor to a given angle. It was necessary that the system be first simulated with a Hardware-in-the-loop system in order to fine-tune the gain values of the controller. Once the simulation function correctly it was necessary to build and test the actual system using a DC Tohoku Motor. After the system was designed and tested it was evaluated for its level of safety.

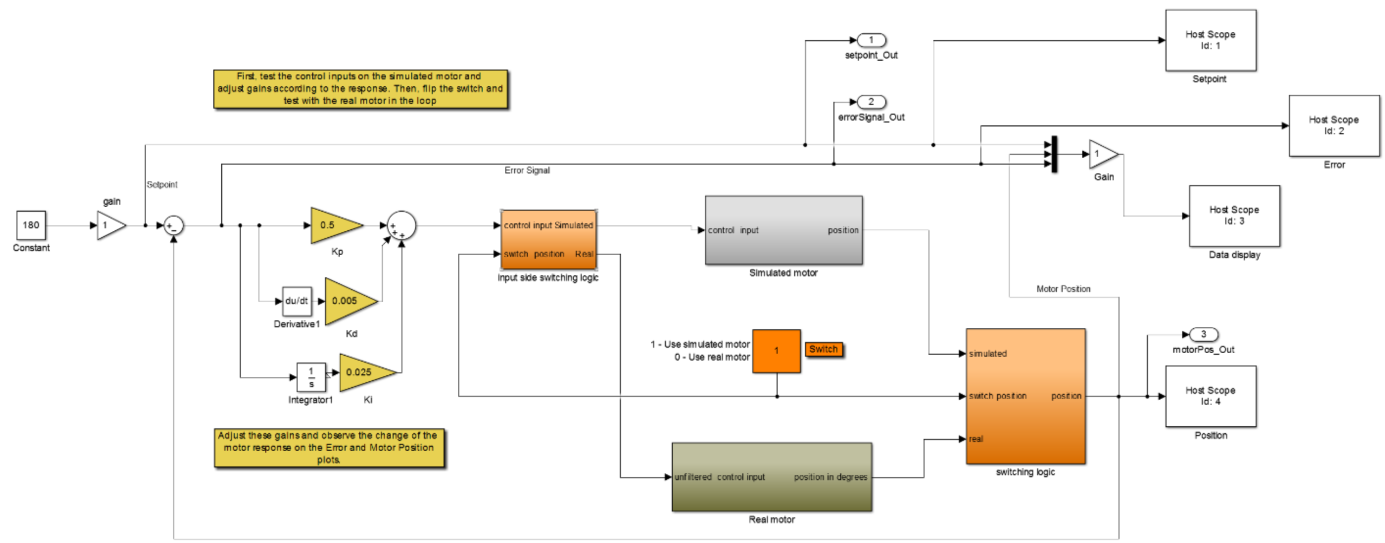
Motor Engineering Requirements

Customer Requirements	Engineering Requirements	Tests
Accurate	Set gain values to produce the least amount of error and keep angle for dot locations accurate	Test on all dot locations while monitoring the error and adjust to get low error
Smooth, swift movement	Set gain values to eliminate oscillations	Monitor output graphs and adjust values until there are a small amount of oscillations with a quick increase
Works in all lighting	Add lighting for low light situations and when shadows are present	Run with all variations of ambient light, shadowing, and with filters that reflect light to test if it still works properly
Points to colors properly	System reads between different colors. Also reads all colors with the lighting	Run for different colors in different locations to make sure it reads with all colors in all locations and check to see if it reads the proper color by running it for all the colors
Robust	Sturdy mounting for motor and camera with little movement and can handle being moved and tossed around	Push and pull at all parts on the mounting system to make sure they are sturdily mounted and will not break or move so that camera placement and motor center become inaccurate
Elegant Design	Build design so that it is attractive to the customer	Ask opinion of group and people outside of the group for feedback about things that could be changed

Overview of hardware in the loop

Hardware in the loop is a method used to test the development of real-time embedded systems. It accomplishes this by creating models of the hardware components that need to be tested in computer software. A full simulation will include the hardware component, but a hardware in the loop system only contains the model of the component. It allows you to tweak and adjust values in your system, without ruining expensive hardware or creating hazardous situations. In the case of this project the hardware that was simulated included a virtual DC motor as well as an interface to the physical motor. With this simulation file we could adjust the gain values for the virtual motor to see how it would affect the physical motor. After obtaining gain values that produced a desirable output from the model, we would test them on the actual hardware.

Simulink Model of Simulated Motor Experiments Documentation



We adjusted the values for K_p, K_d, and K_i in the simulation above to determine which values would cause the motor to have the best performance. The best performance was determined by the smallest difference between the set distance for the motor and the actual distance for the motor.

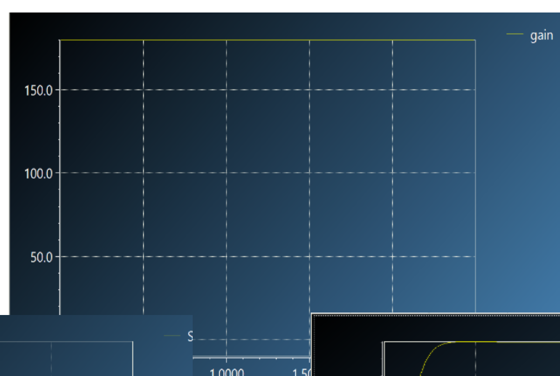
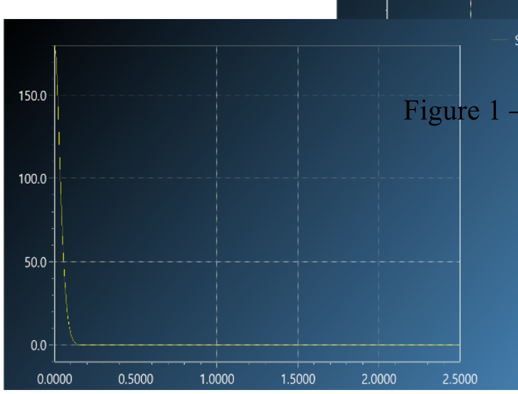


Figure 1 – Graph of Input Angle



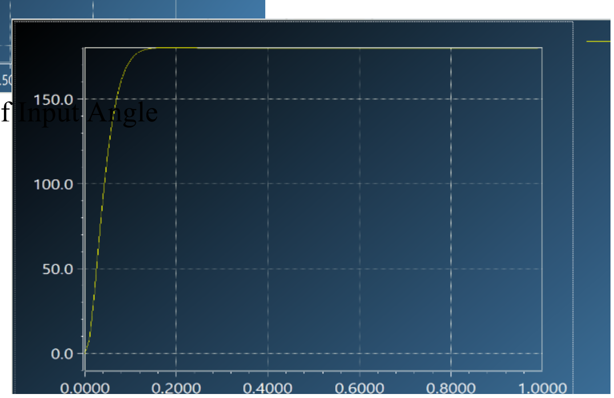


Figure 2 – Error with Final Gain Values

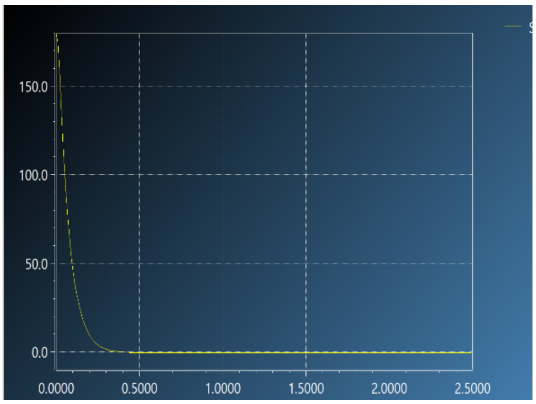


Figure 3 – Motor Position with Final Gain Values

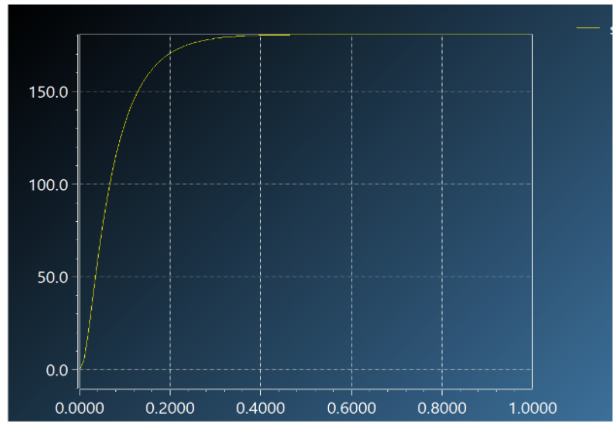


Figure 4 – Error with $K_p = 0.75$

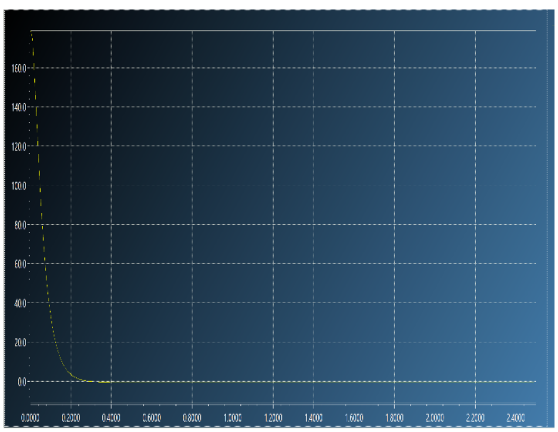


Figure 5 – Motor Position with $K_p = 0.75$

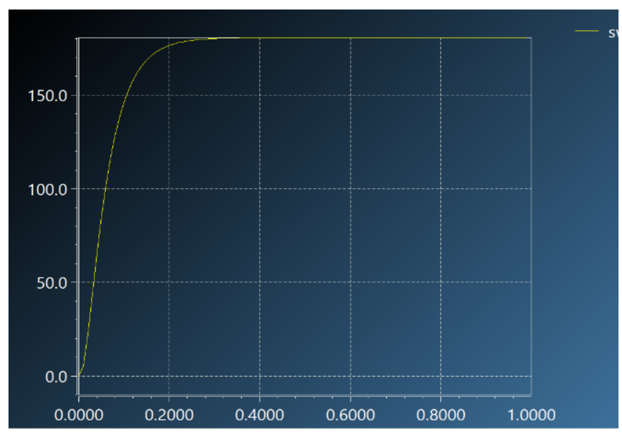


Figure 6 – Error with $K_d = 0.011$

Figure 7 – Motor Position with $K_d = 0.011$

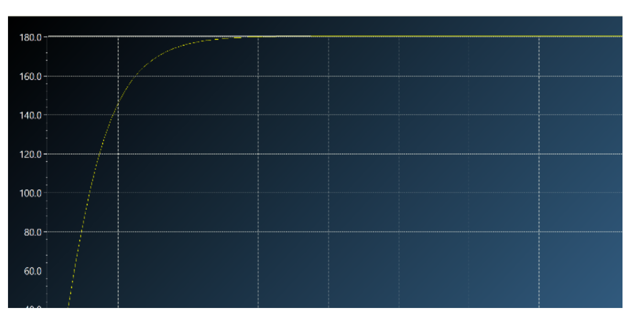


Figure 8 – Error with $K_i = 0.026$

Figure 9 – Motor Position with $K_i = 0.026$

The figures above are the graphs of various errors and motor positions from gain values we tested. **Figure 1** is the constant angle value that is given as input to the system. For all of these tests we used an angle value of 180 degrees. **Figure 2** and **Figure 3** show the error and motor position for our final system. We achieved this performance with the gain values $K_p = 0.5$, $K_d = 0.005$, and $K_i = 0.025$. **Figures 4-9** show the system output for different gain values that we tested throughout the experiment. When comparing the graphs it seems that adjusting K_p and K_i causes the error and motor position curves to take longer to settle out. Adjusting K_d has a similar effect on the error of the system, but less of an effect on the position of the motor.

Motor Prototype Design

The prototype maintains a series of gains that work with two outside signals allowing it to work with a motor. The model has a “Real Motor” and a “Simulated Motor” which can be switched to and from through the use of programming logic.

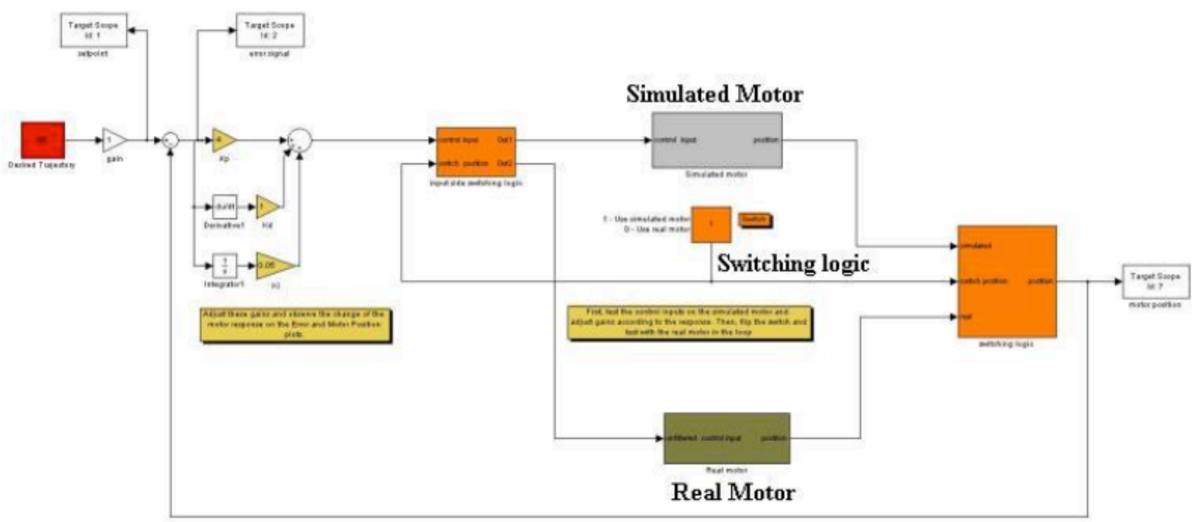


Figure M: Simulink design for the experiment

The simulated motor is constructed with blocks and tools in the Simulink application by combining integrator blocks with gains. Inductance of the motor is provided when a gain is added to an integrator block. Another gain is added to two series connected integrator blocks, providing the motor’s inertia. These two combinations run in parallel and are each connected to an Add block to account for proper sign values when applying Kirchoff’s equation.
Next the torques are accounted for, first the dampening torque, then the armature’s torque. The dampening torque has its block flipped, setting its gain and connecting it to the negative input of the Add block in front of the inertia gain. The armature will provide the current integrator and is connected to the k_t gain that leads the Add block previously mentioned. The voltages are then added and meters are placed to allow reading to ensure proper values.
Connecting a control input to one side of the Motor Loop can provide intial guidelines for motor performance. A feedback signal is connected to the other side of the loop. Using a potentiometer to close the loop on the feedback signal side will promote Real-time feedback and allow for accurate motor control during use.
After simulated motor construction is complete, the amplifier must be calibrated for use. The amplifier is needed to give the motor enough power for movement. With the amplifier gain adjusted to the properly measured setting (34 mA), attention could be placed on the various gains in the Simulink diagram. Manipulating the gains provided the motor with the proper settings to operate. Invalid gains disrupted the motor and provided annoying frequencies to be heard from the motor. There are two graphs that offer readings that allow motor placement to be compared against the set point. Attempting to reach zero error without crossing the zero overshoot required many attempts and “fine-tuning.” As the motor position would move away, the error signal grew proportionately in magnitude.
Manipulation included the summing of three gains, k_i, k_d, $k_{p,}$. Gain 1, k_p, has a constant gain set to 0.5. A derivative block is connected in series with Gain 2, k_d, and is set to 0.005. An integrator block is connected in series with Gain 3, k_i, and is set to 0.025. When simulating the model, the graph displays the set-point, error and motor position using the scopes on the xPC Target display.
The mounting system for our prototype was built with a small piece of plywood, a 2”x2” beam, small bolts, and a number of screws. The 2”x2” beam was cut into 5 small pieces that were used as legs at each

corner of the plywood and 1 at the center back which was used as a support to mount the stand for the camera. The plywood was an inch bigger in length and width than a piece of paper. The plywood was raised with the legs so that the motor could be mounted underneath the center of the plywood with a hole being drilled in the center of the plywood for the shaft. The motor was mounted with 4 nuts and bolts up through the plywood. Other pieces of the plywood were cut so that they covered up the front left and right side openings and so that they extended above the normal plywood so that there was room to have back lighting. This allowed us to put a piece of Plexiglas on top so that we could mount LEDs below the paper and have a backlight board. The last step of the mounting design was cut a piece of the beam that can be mounted on the back that allows the camera to be mounted 16" above the plywood along with another piece attached to the top that lets the camera sit perfectly center above the shaft of the motor.

The connections for the motor design were the motor's power being connected to the amplifier which then went from the amplifier to the analog output. There was also a connection from the motor to the encoder on the Quanser board. We also wired LEDs to the mount so that we could always have lighting. Even in dark or shadowing situations. The LEDs were wired to the power supply with 12V. The last connection we had was the camera to the computer.

The code used the camera to take pictures and remove everything except the dots that were populated. It then determined the colors of these locations and spun to the correct color specified by calculating the location of the pixels in relation to the center of the shaft. It determined this angle from the starting position then sent the angle to the Simulink model allowing it to turn to the correct dot and so on until all the dots were stopped on. The Simulink model was downloaded from the ECE 495 website and the gain values were adjusted so that the motor moved at the correct speed and smoothness we determined.

Safety Analysis

DFMEA: Design Failure Modes and Effects Analysis

Our safety analysis is testing the closed loop motor control of our system.

Description of Component or Subsystem	**Failure Mode (Hazard)**	**Symptom**	**Effect**	**Probability of Failure**	**Severity of Effect**	**Risk Index**
Too much power given to the motor	Too High level of Volts	Motor not responding to commands	The product has no function if it won't respond	C	II	I-B
	Revolutions per minute incorrect	Inaccurately spinning of the aperture	Picks the wrong sticker or no sticker at all	A	III	III-C
Improper motor hand	Not durable material	Fails after certain amounts of use	Won't last for multiple runs of the device	C	III	III-C
	Incorrectly fastened onto the aperture of the motor	Hand detaches from the motor	No indication of what sticker is being pointed to	A	I	I-B
	Allows for high amount of slip	The hand doesn't move with the motor	Incorrect distinction of sticker	B	I	II-A
Non-functioning light source	Not enough Volts supplied	LED strip too bright or dim	Camera can't find all the objects	C	II	II-B
	Camera can't identify images on the board	The amount of stickers on the board aren't the same amount that	The motor hand won't know where to go if the sticker that	B	I	I-A

		were picked up	is picked isn’t noticed by the camera			

After performing the DFMEA table on our product it was shown to us that there needed to be several changed made to our product or it would not function properly. It was decided that the amount of volts supplied to the motor needed to remain constant the entire time and continuously monitored for any change. Next the motor hand had to be securely fastened to the aperture of the motor, so that it would not fly off during the spinning and that no unwanted slip was taking place. This effect, if not wasn’t fixed, would have led to many inaccurate results. Finally, the LED light source was a crucial component of the overall design because if the board was not lit up properly then the camera couldn’t find all of the stickers and the motor wouldn’t know where to spin to. But, overall at the conclusion of the project it was declared that with these new changes made to our design that our product could be called safe. There would be no adverse effects that could occur during the running of our motor, and all hazards were accounted for from the use of the DFMEA table and Risk Assessment Matrix.

Summary

In this project a closed-loop motor control system that could be controlled using the xPC/Quanser Real-Time Control workstation was designed and tested. The system was fine-tuned using Hardware-in-the-loop simulation and evaluated for its safety level. Many aspects of this project can be used in the final project. Hardware-in-the-loop simulation will need to be used in order to design a control system effectively. It will also be necessary to use real-time PID control in order to control the actuator used in the final project. The safety evaluation techniques learned will also need to be used in the final project in order to ensure that the system meets safety requirements.

Group Number__________ ***ECE495 - Project 5: Closed-loop Motor Control***

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	5	General Report Format - Professional Looking Document/Preparation (whole document) a) Fonts, margins (11pt, times new roman, single spaced. 1" margins on all sides). Follows the page limitations below. b) Spelling and grammar are correct. c) Layout of pictures – all figures need captions and must be referenced in text. d) References. Use IEEE reference format	g