Control & Computing Laboratory (EE615) Report

Submitted by

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Group number: 5

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Experiment No: 4

Stabilization of an Inverted pendulum in the upright position

AIM

To implement a regulator for rotary inverted pendulum using LQR controller.

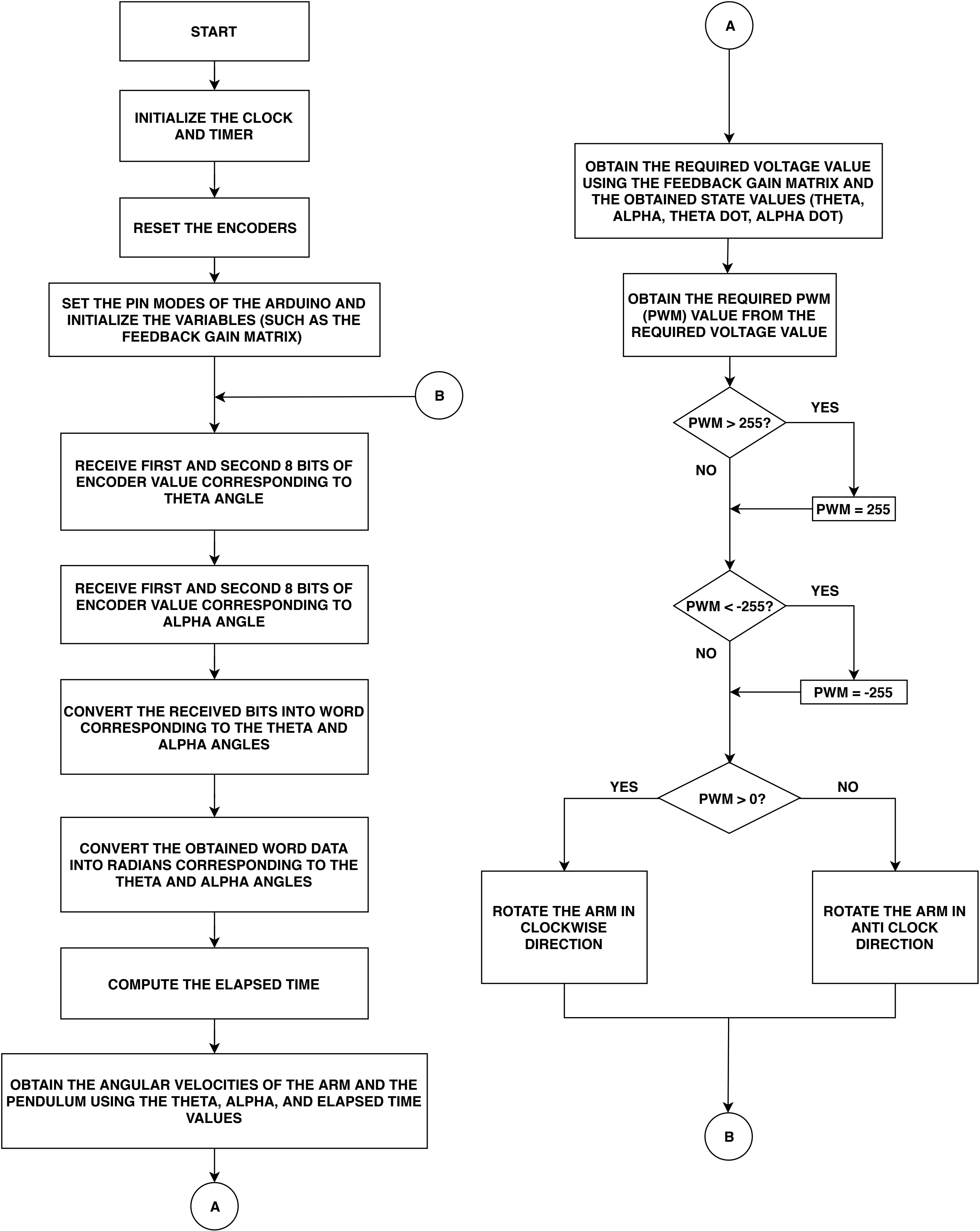
OBJECTIVE

1. To design and implement control action for maintaining a pendulum in the upright position (even when subjected to external disturbances) through LQR technique in Arduino Mega.
2. To restrict the pendulum vibration within ± 3 degrees and base angle oscillation within ± 30 degrees.

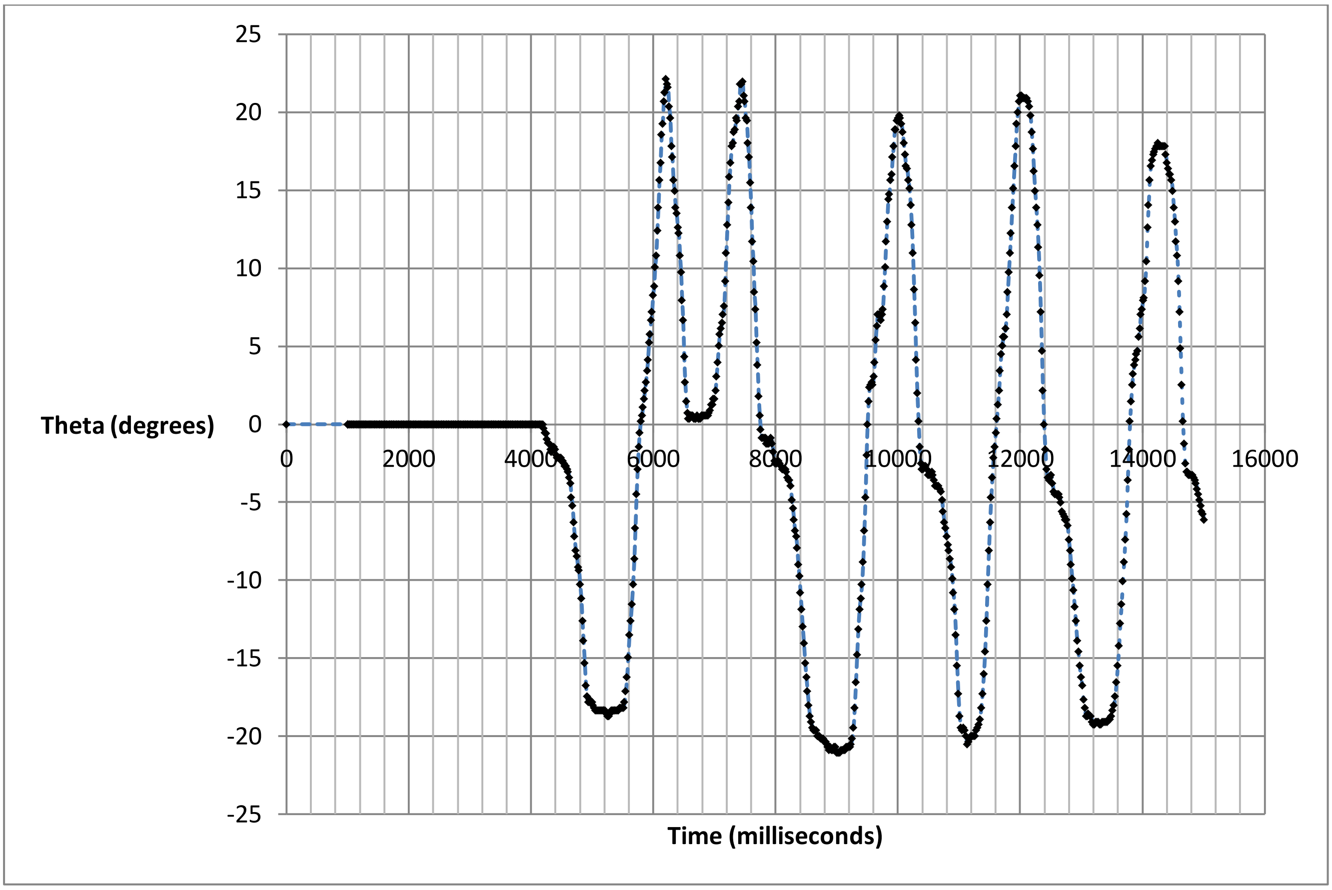
CHALLENGES FACED

1. The controller performance is very much dependent on the data types of the variables used, the number of print statements, and the amount of floating point computations. This results in change in the optimized feedback gain matrix for every significant change in the Arduino program. Hence retuning of the system is required for new optimized feedback gain matrix every time the Arduino program is improved or modified.
2. Simulating the model of the system in the Simulink to identify the parameters of the system response for different values of the Q matrix.

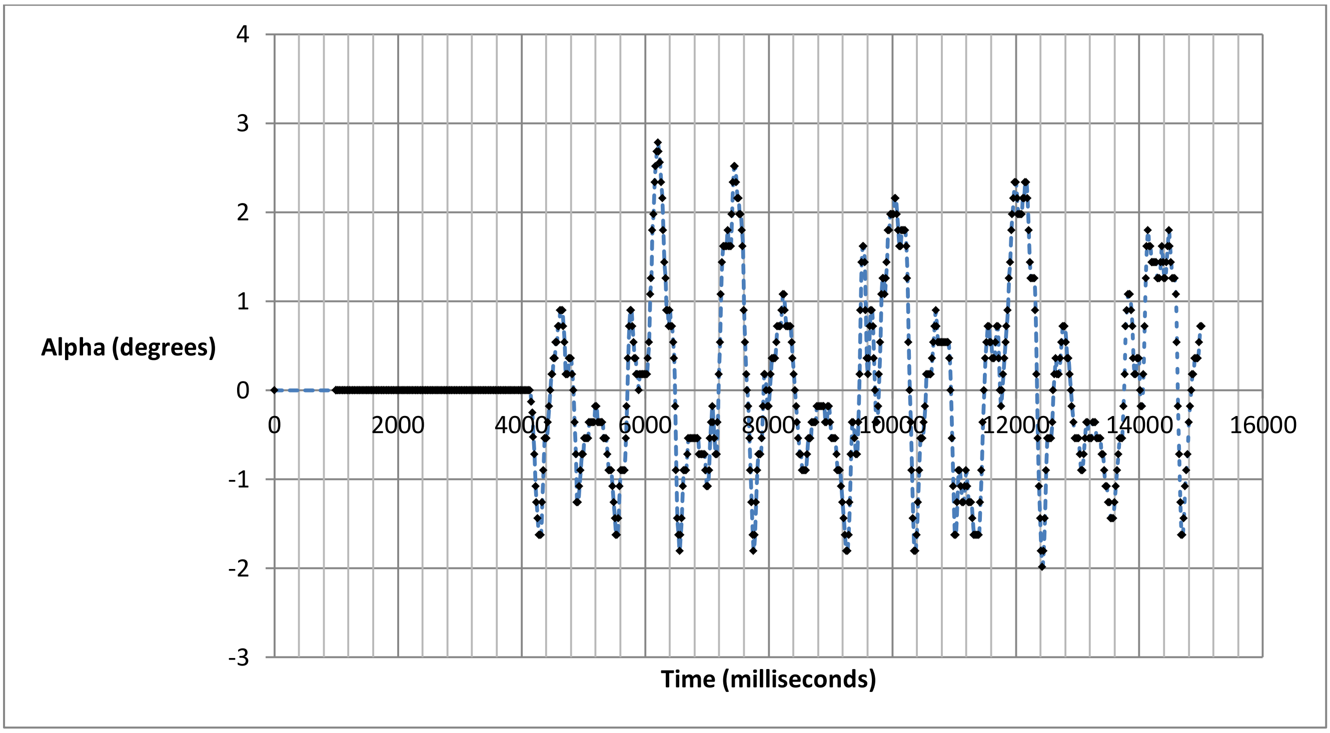
FLOWCHART


START
INITIALIZE THE CLOCK AND TIMER
RESET THE ENCODERS
SET THE PIN MODES OF THE ARDUINO AND INITIALIZE THE VARIABLES (SUCH AS THE FEEDBACK GAIN MATRIX)
B
RECEIVE FIRST AND SECOND 8 BITS OF ENCODER VALUE CORRESPONDING TO THETA ANGLE
RECEIVE FIRST AND SECOND 8 BITS OF ENCODER VALUE CORRESPONDING TO ALPHA ANGLE
CONVERT THE RECEIVED BITS INTO WORD CORRESPONDING TO THE THETA AND ALPHA ANGLES
CONVERT THE OBTAINED WORD DATA INTO RADIANS CORRESPONDING TO THE THETA AND ALPHA ANGLES
COMPUTE THE ELAPSED TIME
OBTAIN THE ANGULAR VELOCITIES OF THE ARM AND THE PENDULUM USING THE THETA, ALPHA, AND ELAPSED TIME VALUES
A
A
OBTAIN THE REQUIRED VOLTAGE VALUE USING THE FEEDBACK GAIN MATRIX AND THE OBTAINED STATE VALUES (THETA, ALPHA, THETA DOT, ALPHA DOT)
OBTAIN THE REQUIRED PWM (PWM) VALUE FROM THE REQUIRED VOLTAGE VALUE
PWM > 255?
YES
NO
PWM = 255
PWM < -255?
YES
NO
PWM = -255
PWM > 0?
YES
NO
ROTATE THE ARM IN CLOCKWISE DIRECTION
ROTATE THE ARM IN ANTI CLOCK DIRECTION
B

PLOT



25
20
15
10
5
0
-5
-10
-15
-20
-25
Theta (degrees)
0
2000
4000
6000
8000
10000
12000
14000
16000
Time (milliseconds)



4
3
2
1
0
-1
-2
-3
Alpha (degrees)
0
2000
4000
6000
8000
10000
12000
14000
16000
Time (milliseconds)

RESULT

$$Q = \begin{bmatrix} 500 & 000 & 000 & 000 \\ 000 & 700 & 000 & 000 \\ 000 & 000 & 20 & 000 \\ 000 & 000 & 000 & 20 \end{bmatrix}$$

$$R = [11]$$

$$K = [-6.7420 \quad 84.5149 \quad -3.3334 \quad 11.1641]$$

INFERENCE

1. In order to reduce the amount of error in a state variable during the control action, the corresponding state variable is more penalized by increasing its corresponding coefficient present in the Q matrix.
2. The feedback gain (K) matrix which is the solution of an Algebraic Riccati Equation is obtained using the lqr command in MATLAB.
3. The inverted pendulum initially has a positive eigenvalue (10.1974) at the equilibrium point which makes the system unstable. The resultant system with feedback has all its eigenvalues in the left half plane $(-84.3407, -6.7343 + 1.0986i, -6.7343 - 1.0986i, -5.2876)$
4. The sensitivity of the system decreases when the controller program uses values of the angles by converting them into radians in comparison to using the values received directly from the encoder (without conversion) for computing the required output voltage for the DC motor.

CONTROL & COMPUTING LAB
RESULT SHEET

	Student Name	Roll No
1	R.V. SATWIK	193079009
2	ALLEN RUJIS	193079008
3		

Group No - 5

$$Q = \begin{bmatrix} 500 & 0 & 0 & 0 \\ 0 & 700 & 0 & 0 \\ 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 20 \end{bmatrix}$$

$$R = 11$$

$$K = \begin{bmatrix} -6.7420 & 84.5149 & -3.3334 & 11.1641 \end{bmatrix}$$

	TA Name	Date	Signature
1	Devang	23/10/'19	Devang
2	Tarun S.	23/10/19	Tarun