LINEAR QUADRATIC REGULATOR (LQR) SPEED CONTROL FOR DC MOTOR USING MC68HC11

CHE KU MOHD FAIZUL BIN CHE KU MOHD SALLEH

UNIVERSITY MALAYSIA PAHANG

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This thesis is submitted as partial fulfillment of the requirement for the award of the Bachelor Degree of Electrical Engineering (Electronic)

Faculty of Electrical & Electronic Engineering
University Malaysia Pahang

NOVEMBER 2008

DECLARATION

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Signature : ______________________________

Author : CHE KU MOHD FAIZUL BIN CHE KU MOHD SALLEH.

Date : 12 NOVEMBER 2008.

DEDICATION

Specially dedicate to

My beloved parents, brothers and sisters.

ACKNOWLEDGEMENT

First and foremost, I am very grateful to the almighty ALLAH S.W.T throughout all His Almighty kindness and loveliness for giving me the key and opportunity to accomplish my Final Year Project.

In particular, I wish to express my sincere appreciation to my supervisor, Madam Haszuraidah Binti Ishak for encouragement, guidance, suggestions, critics and friendship throughout finishing this project. I am also very thankful to Mr. Ahmad Nor Kasruddin Bin Nasir for his guidance.

Secondly, I wish to thank lecturers, staff and technicians, for their cooperation, indirect or directly contribution in finishing my project. My sincere appreciation also to all my friends whose have involved and helped me in this project.

Most importantly, I wish my gratitude to my parents for their support, encouragement, understanding, sacrifice and love. For all of that, I am very thankful to the cooperation and contribution from everyone that has driven me to accomplished of this project. There is no such meaningful word then…. May Allah bless you all.

ABSTRACT

Linear Quadratic Regulator (LQR) control problems have been widely investigated in the literature. The performance measure is a quadratic function composed of state vector and control input. If the linear time-invariant system is controllable, the LQR control law will be obtained via solving the algebraic Riccati equation. The LQR tuning algorithm in microcontroller MC68HC11 is applied to the speed control of servo motor. The performance measure to be minimized contains output error signal and differential control energy. The LQR controller receives error signal only and it doesn't need to feedback full states. The Q matrix can be determined from the roots of the characteristics equation. Once the poles for the closed-loop system are assigned, the existence criteria of the LQR controller are derived. In the motor control systems, error detector signal are used to provide feedback information on the motor. This error comparator is used in the control loop and to improve the reliability by detecting fault conditions that may damage the motor.

ABSTRAK

Masalah pengendalian kawalan menggunakan cara Linear Quadratic Regulator (LQR) telah dikaji dengan meluas. Oleh sebab itu, perlu adanya pengendalian optimal. Pelaksanaan ukuran ini merupakan fungsi quadratik dengan gabungan state vector dan control input. Jika system linear time-invariant boleh dikontrol, prinsip kontrol LQR akan diperolehi melalui penyelesaian persamaan Riccati algebra. Applikasi kontrol halaju didalam terhadap motor servo adalah melalui pelarasan LQR algoritme didalam mikrokontroller,MC68HC11. Operasi ukuran yang diminimumkan , megandumgi perbezaan tenaga kontrol dan ralat signal. Kontroller LQR akan menerima ralat signal sahaja dan tidak perlu mendapatkan maklum balas pada full states. Matrix Q boleh diperolehi melalui punca bagi sifat persamaan tersebut. Apabila kutub bagi sistem rangkaian tertutup ditentukan, kriteria kewujudan pada kontroller LQR akan diperolehi. Didalam sistem kontrol motor, ralat pengesan digunakan untuk memberi maklum balas terhadap motor. Perbezaan ralat ini digunakan di dalam rangkaian kontrol dan untuk meningkatkan konsistensi dengan mengesan kesalahan pada sistem yang mungkin merosakkan motor.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW.

Linear Quadratic Regulator (LQR) control problems have been widely investigated in the literature. The performance measure is a quadratic function composed of state vector and control input. If the linear time-invariant system is controllable, the LQR control law will be obtained via solving the algebraic Riccati equation.

The LQR tuning algorithm in microcontroller is applied to the speed control of DC motor. The performance measure to be minimized contains output error signal and differential control energy. The LQR controller receives error signal only and it doesn't need to feedback full states. The Q matrix can be determined from the roots of the characteristics equation. Once the poles for the closed-loop system are assigned, the existence criteria of the LQR controller are derived.

In the motor control systems, error detector signal are used to provide feedback information on the motor. This error comparator is used in the control loop and to improve the reliability by detecting fault conditions that may damage the motor.

1.2 OBJECTIVE RESEARCH

The main core objective of the project is to explore about the quadratic optimal control or LQR and design a system and programming to control speed of servo motor using LQR controller, so it can move based on pulse by using microcontroller. The system and the programming will be able to control the motor speed so motor will move according the speed needed.

1.3 PROJECT SCOPE

In order to achieve this project, there are several scopes had been outlined:

i. To choose the optimal value of feedback gain in order to grab the stable system.
ii. The error speed signal is used to provide feedback information to the LQR controller in microcontroller.
iii. The servo motor will be as output that generates the mechanical energy from electrical energy in microcontroller.
iv. To describe how a MC68HC11 can be used to implement a speed Linear Quadratic Regulator feedback control in the unstable system.

1.4 PROBLEM STATEMENT

The problem statement in this project is about how to determine the LQR gain matrix for the unstable system and how to apply the feedback control to the microcontroller. To find the LQR gain, need to consider Riccati equation and eigenvalues and find Q using optimal cost function. Build control block diagram to find the equation of error signal and program it to the microcontroller.

1.5 THESIS ORGANIZATION

This thesis will consist five chapters. For the chapter 1 it discuss the background

of the system, the objective of these project, scope, problem statement and the summary of work. In chapter 2 it will discuss more on the literature review that have been done. It will discuss about the Linear Quadratic Regulator (LQR), Clifton Precision Servo Motor, Motor Drive G340 and Motorola MC68HC11 microcontroller. In chapter 3, the discussion will be on methodology hardware of the project and so as the software implementation of the project. The result, analysis and discussion will be on the chapter 4. Finally, chapter 5 will discuss the conclusion of the project and future work can be done to this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION.

In this chapter include the study of linear quadratic regulator (LQR), servo motor, dc servo motor driver, microcontroller, and also about maxim RS233.

2.2 LINEAR QUADRATIC REGULATOR (LQR).

Linear quadratic regulator or LQR is commonly used technique to find the state feedback gain for a closed loop system. This is the optimal regulator, by which the open-loop poles can be relocated to get a stable system with optimal control and minimum cost for given weighting matrices of the cost function. On the other hand, by using the optimal regulator technique, that freedom of choice is lost for both discrete-time and continuous-time systems, because, in order to get a positive-definite Riccati equation solution, there are some areas where the poles cannot be assigned.

A crucial step in the LQR design process is the selection of the quadratic weighting matrices. These matrices determine the Kalman steady state gain and ultimately the state response. Algorithms which aid in the selection of the quadratic weights based on some specified criteria are very desirable since they eliminate a trial and error weight selection process. The LQR problem can be solved for either the continuous or discrete time case. Each method yields an optimal gain. These gains are not interchangeable.

CONTINUOUS TIME LQR PROBLEM

The problem presented by the infinite horizon LQR formulation is given a linear n-dimensional state variable system of the form: $\dot{}(\;) = \;(\;) + \;(\;)$ Compute the m-dimensional control input vector u(t), such that the performance index is minimized. Quadratic weighting matrices Q and R are selected by the designer to give appropriate state responses. It is well known that the solution is $(\;) = -\;(\;)$, where the Kalman gain, ***K*** *,* is given by $=$,with ***P*** being the solution to the algebraic Riccati equation,$0 = \; + \; - \; + \;$.

The most important step in the LQR design process is the selection of the weights ***Q*** and ***R.*** Since no clear relationship exists between the weights and the system state response, any algorithm that can select weights based on state response specifications is very desirable. The easily implemented algorithm selects weights to place closed loop eigenvalues in a specified region of the s-plane.

This is a specification that is easily related to state response. The method is straightforward and easy to implement. It ultimately produces a continuous time Kalman steady state gain which cannot be incorporated in digital controller applications. By relating the continuous closed loop system to its discrete equivalent, a relationship between the gains can be determined.

DISCRETE EQUIVALENT STEADY STATE GAIN

For a continuous time linear system modeled by $\dot{}(\ ) = \ (\ ) +$, (the) discrete equivalent system is given by $= \ + \Gamma$,with the discrete system matrices, and Γ, computed as $=$, $\Gamma = \int$,where T is the sample period of the discrete system. If the LQR problem is solved for the discrete system above, the closed loop system equation becomes; $= (\ - \Gamma \ )$ where is the discrete Kalman steady state gain.

Similarly, solving the LQR problem for the continuous case, the closed loop system becomes $\dot{}(\ ) = (\ - \ ) \ (\ )$ where is the continuous time Kalman steady state gain. If the closed loop continuous system is discretized using sample period ***T,*** the discrete equivalent closed loop system is given by; $= {}^{(\ )}$ .Equating the two representations of the discrete closed loop system gives $- \Gamma \ = {}^{(\ )}$.

The right side of the above equation is the closed loop state transition matrix and its value can readily be computed using a truncated Taylor series. Every element of the equation is known except *,* the discrete equivalent Kalman steady state gain. The equation can be put into the familiar form, Cy = d, Using the pseudo inverse technique, the unknown vector can be determined by; $= (\ )$. This technique can be used to obtain a discrete equivalent gain.

2.2 DC SERVO MOTOR

Servo motors are used in closed loop control systems in which work is the control variable, figure 2.1. The digital servo motor controller directs operation of the servo motor by sending velocity command signals to the amplifier, which drives the servo motor. An integral feedback device (resolver) or devices (encoder and tachometer) are either incorporated within the servo motor or are remotely mounted, often on the load itself. These provide the servo motor's position and velocity feedback that the controller compares to its programmed motion profile and uses to alter its velocity signal. Servo motors feature a motion profile, which is a set of instructions programmed into the controller that defines the servo motor operation in terms of time, position, and velocity. The ability of the servo motor to adjust to differences between the motion profile and feedback signals depends greatly upon the type of controls and servo motors used.

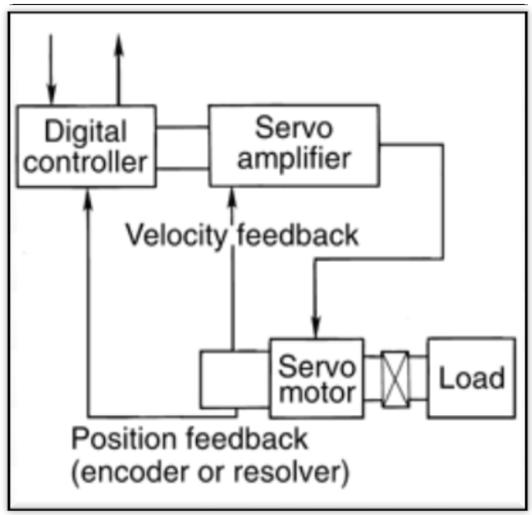

Figure 2.1: Typical dc servo motor system with either encoder or resolver feedback. Some older servo motor systems use a tachometer and encoder for feedback.

Servo motor is one of the devices that have the applications where precise positioning and speed required. The big advantage of the servo motor is that servos are operated "closed loop". This means feedback is required from the motor, that's why this system is sensitivity to disturbances and have ability to correct these disturbances.

The other advantages of servo motor are:

i. High output power relative to motor size and weight
ii. Encoder determines accuracy and resolution
iii. High efficiency. Can approach 90% at light loads
iv. High torque to inertia ratio. Can rapidly accelerate loads
v. Has reserve power. Two to three times continuous power for short periods
vi. Has reserve torque. Five to ten times rated torque for short periods
vii. Motor stays cool. Currently draw proportional to load

viii. Usable high speed torque. Maintains rated torque to 90% of No load RPM
ix. Audibly quiet at high speeds
x. Resonance and vibration free operation

Permanent-magnet DC motors are widely used in servo-systems. For the type of servo motor, permanent-magnet JDH-2250 Clifton Precision motor was chosen.

Figure 2.2: Clifton Precision Servo Motor

The characteristics of Clifton Precision Servo Motor are:

i. Torque Constant: 15.76 oz-in. / A
ii. Back EMF: 11.65 VDC / KRPM
iii. Peak Torque: 125 oz-in.
iv. Cont. Torque: 16.5 oz-in.
v. Encoder: 250 counts / rev.
vi. Channels A, B in quadrature, 5 VDC input (no index)
vii. Body Dimensions: 2.25" dia. x 4.35" L (includes encoder)
viii. Shaft Dimensions: 8 mm x 1.0" L w/flat

2.3 DC SERVO MOTOR DRIVER

The G340 servo drive is a monolithic DC servo motor controller providing all active functions necessary for a complete closed loop system. This device consists of an on-chip op amp and window comparator with wide input common-mode range, drive and brake logic with direction memory. Power H-Switch driver capable of 1.0 A, independently programmable over-current monitor and shutdown delay and over-voltage monitor. This part is ideally suited for almost any servo positioning application that requires sensing of temperature, pressure, light, magnetic flux or any other means that can be converted to a voltage.

Figure 2.3: External of G340

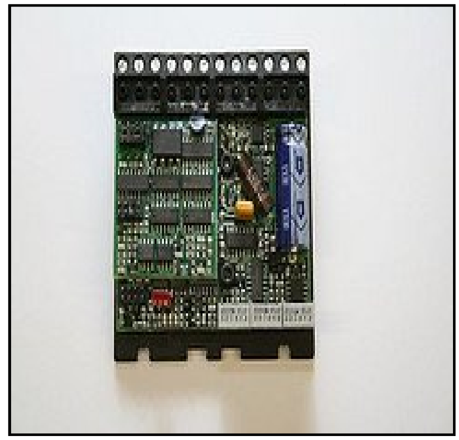

Figure 2.4: Internal of G340

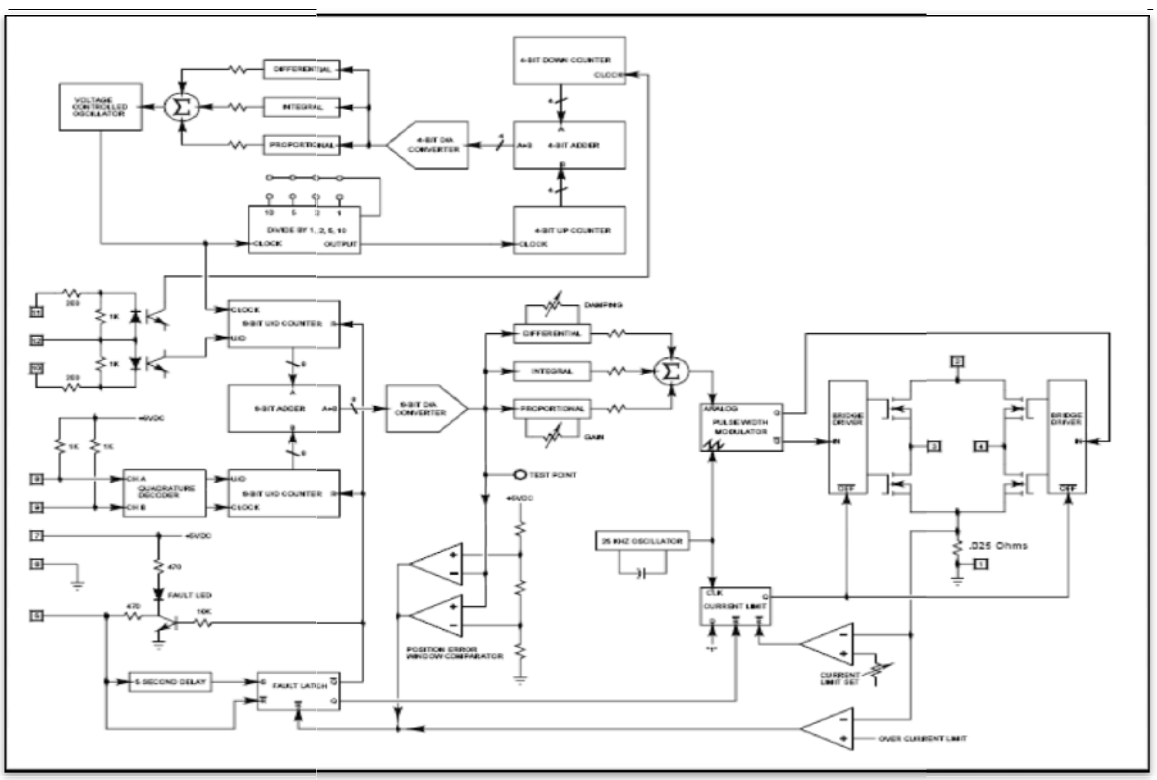

Figure 2.5: G340 Block Diagram

The several characteristics of Servo Drive G340 are:

i. Run PM DC servos with stepmotor software.
ii. PLL step pulse multiplier.
iii. 20A motor output,
iv. 18V to 80V power supply.
v. PID closed loop operation,
vi. Step and Direction control inputs.
vii. Quadrature encoder feedback.
viii. Anti-dithering circuit keeps motor silent.
ix. Onboard +5VDC, 50mA encoder supply.
x. Pulse by pulse motor current limiting.
xi. 0 to 20A current limit adjust range.
xii. +/- 128 count servo lock range,
xiii. No tachometer feedback needed.
xiv. 250 kHz max step rate,
xv. Latched Fault protection, LED Fault indicator
xvi. Small size: 2.5" by 2.5" by 0.82",
xvii. (63mm by 63mm by 21mm)
xviii. Light: 3.6 oz (100gm)
xix. Anodized aluminum package,
xx. Modular 2-piece main connector.