LQR CONTROLLER TUNING BY USING PARTICLE SWARM OPTIMIZATION

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To my beloved mother and father and sisters and brothers

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ABSTRACT

LQR is an optimal controller. Optimal in that it is defined so as to provide the smallest possible error to its input. Q and R matrix of LQR usually selected by trial and error. In two wheeled inverted pendulum robot, the most important variable to control is tilt angle. Therefore in this thesis, the value of Q is firstly set and then R the identity matrix is set. For small rising time and low overshoot for the overall control. After getting good value of Q, the feedback gain K is obtained. By using MATLAB simulink, we simulated new PSO algorithm for the LQR control to select the best Q control matrix. The selection is based on the smallest integral of absolute error of the random Q. From the simulation results, the very challenging controller design for the TWIP control system has been realized by the PSO-based LQ regulator. It is our firm belief that the proposed method is use useful not only for the control of TWIP robot problem but also for other difficult problems.

ABSTRAK

LQR merupakan pengawal optimum. Ia merupakan pengawal optimum kerana berupaya meminimumkan ralat berkadaran dengan input yang diberi. Istilah optimal didefinasikan sebagaiuntuk memperoleh ralat sekecil mungkin berbanding masukan yang diberi seperti satu atau lebih keluaran daripada sistem terkawal (atau "loji") digabungkan, justeru meminimumkan keluaran pengawal. Matriks Q dan R di dalam LQR biasanya diperolehi daripada kaedah "cuba jaya". Kaedah ringkas adalah dengan memilih matrik tersebut sebagai matrik pepenjuru dan nilainya adalah nombor positif yang besar untuk pelbagai pembolehubah perlu kecil dalam domain masa. Robot bandul dua roda, misalnya pekali yang perlu diambilkira ialah nilai sudut condong. Robot bandul dua roda (TWIP) misalnya, Pembolehubah yang paling penting untuk dikawal ialah nilai sudut condong. Justeru didalam tesis ini, matriks Q akan dicari dahulu diikuti dengan matriks identiti,R. Justeru didalam tesis ini, matriks Q akan ditentukan dahulu diikuti dengan matriks identiti,R. Nilai yang lebih besar pada pemberat pepenjuru diberikan untuk pencapaian yang baik. Masa rising yang kecil dan overshoot yang rendah untuk keseluruhan kawalan. Masa menaik yang kecil dan lampau lajak yang rendah untuk keseluruhan kawalan nilai gandaan feedback,K diperolehi setelah hasil optimum matriks Q dikira. Nilai gandaan suapbalik, Kdiperolehi setelah mendapatkan nilai matriks Q yang bagus/sepadan. Menggunakan MATLAB Simulink, algoritma PSO baru untuk pengawal LQR disimulasikan untuk memilih nilai matriks pengawal,Q. Pengiraan adalah berdasarkan smallest integral dari ralat absolute dari nilai random Q. Dari keputusan simulasi,LQ regulator dengan algoritma PSO berjaya mengatasi masalah yang paling mencabar iaitu rekabentuk pengawal untuk sistem pengawal TWIP. Kami yakin degan kaedah yang diperkenalkan berguna bukan sahaja untuk mengatasi masalah kawalan robot TWIP tetapi jugak beberapa masalah lain yang susah.

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LIST OF ABBREVIATIONS

LQR	-	Linear Quadratic Regulator
TWIP	-	Two-wheels Inverted Pendulum
PSO	-	Particle Swarm Optimization
IAE	-	Integral Absolute Error

LIST OF SYMBOLS

Q	-	Non-Negative Definite Matrix
R	-	Positive Definite Matrix

CHAPTER 1

INTRODUCTION

In a nutshell, linear quadratic regulator design methods involve the determination of an input signal that will take a linear system from a given initial *state* $x(t0)$ to a final *state* $x(tf)$ while minimizing a quadratic cost functional. The cost functional in question is the time integral of a quadratic form in the state vector x and the input vector u such as $x^TQx + u^TRu$ where Q is a non-negative definite matrix and R is positive definite matrix. With this basic definition in place, various flavors of the quadratic linear regulator design problem can be posed; e.g., finite horizon (tf finite), infinite horizon (tf infinite), time-varying (the system, Rand Q matrices themselves, or both) etc. Also, the final state itself may or may not contribute to the cost functional as a separate term.

The main advantage is that the optimal input signal u(t) turns out to be obtainable from full state feedback; i.e. u = Kx for some K matrix. The feedback matrix K in question is obtained by solving the Ricatti equation associated with the particular LQR problem you have at hand. One of the disadvantages of the LQR controller is that obtaining an analytical solution to the Ricatti equation is quite difficult in all but the simplest cases. I can summaries the advantages of LQR as listed:

Stability is guaranteed when the systems have:

- all of the states in the system available for feedback and

- A really good model of your system. In fact, not only is stability guaranteed but the stability _margins_ are guaranteed.
- The controller is automatically generated by simply selecting a couple of parameters (no need to do loop-shaping).

The main potential problem is that a 'plant' is hardly ever linear with precisely known parameters. Therefore, you have to build in some robustness against parameter variations/uncertainty during your control design. Also, you may have to do some gain-scheduling or switching between single controllers to account for changes in operating condition (e.g. aircraft speed or altitude). As noted above, the implementation of LQR controllers requires some effort. I can summaries the disadvantages of LQR as listed:

LQR is an optimal controller. Optimal in that it is defined so as to provide the smallest possible error to its input, i.e. one or more of the outputs of the controlled system (or 'plant'), combined with minimizing the control output. Compared to LQR, controller simply creates a stable system, without explicitly optimizing anything (Advantage #1). LQR is also straightforward to use for multivariable systems; the design procedure is essentially the same as for single-input-single-output systems (Advantage #2).

LQR control is calculated based on a linear model of the plant under control. If the linear model represents plant exactly, then the controller is optimal. However, if there is a mismatch due to model inaccuracy (i.e. in the parameters of the linear model), plant changes (e.g. changes in vehicle or machine speed or power level in a power plant) or nonlinearities (i.e. the real system is not actually linear) then the resulting controller will degrade and the system may even become unstable (Disadvantage #1).

The LQR is a state feedback controller. The states of a system can have some physical meaning (e.g. velocity, acceleration), but sometimes they have no physical interpretation at all. Consequently there may be difficulty in obtaining the states to use for feedback. To get around this another function is needed, called an observer, which estimates the values of the state. This makes the system even more complex (Disadvantage #2).

Aside from these abstract concerns, there are more practical problems with implementation:

- Full state feedback is hard to come by: you are more than likely to have a few output measurements from which I need to "infer" the state information via state observers. Put the resulting observer-based feedback in the context of LQR design, and things get complicated real quick!
- The standard LQR design does not put any restrictions on the input signal u(t) amplitude. My optimizing input might well turn out to have amplitudes that are well above the signal generation/carrying capacities of my real system.

And not to put down optimal control or anything, but optimizing the system performance with respect to one single criterion (such as the quadratic cost functional you are trying to minimize in the LQR design)usually means sacrificing the overall system performance with respect to other criteria. The LQR filter will do precisely what it has been designed to do: minimize a cost metric. Whether this is enough for my design purposes is something you will have to decide as the design engineer. Stability is guaranteed if you have.

1.1 Problem Background

Q and R matrix of LQR usually selected by trial and error. A simple guideline is to choose these matrices to be diagonal and make the diagonal entry positive large for any variable need to be small in the time domain. In two wheeled inverted pendulum robot, the most important variable to control is tilt angle. Therefore the value of Q is firstly set and then R the identity matrix is set. More weight is given to diagonal term for good performance. For small rising time and low overshoot for the overall control. After getting good value of Q, the feedback gain K is obtained.

1.2 Objectives

In this project following objectives shall be achieved:

- Tuning LQR Controller that applied to 2-Wheel Mobile Robot by using Particle swarm optimization.
- Control and Simulate the system two-wheel inverted pendulum mobile robot by using LQR controller.

1.3 Problem Statement

The output of any control system that designed using LQR controller has percentage of error and overshoots which are undesirable. A lot of efforts have been made to tune LQR controller parameters for better system’s performance since its indispensable in industry and very difficult to get an optimal parameters.

1.4 Project Scope

The scopes of this project are:

- The projects propose PSO to tune the LQR to get good results.
- Utilizing mat lab program to simulate the system that we want to develop it.
- Enhancing the performance of any system by minimizing the overshoot and steady state error is considered a real addition to industry field.