MODELLING AND CONTROL OF TWO-LINK FLEXIBLE MANIPULATOR

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"This thesis is dedicated to my wife for her endless love, support and encouragement"

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ABSTRACT

Flexible link manipulators have caught the interest of many researchers due to the limitations of their rigid counterparts. However, Flexible manipulators introduces undesired vibrations which is not easy to control due to its high-non linearity. In order to keep the advantages associated with the lightness and flexibility of the manipulators, accurate modelling of the system and efficient reliable controller have to be developed which is the focus of this study. The two-link flexible manipulator is split into 4 models, the Hub angle and endpoint vibrations of both links of the Two-Link Flexible Manipulator. Input and output data were obtained from an experimental rig. Each model was obtained through system identification techniques within MATLAB simulation environment, namely conventional Recursive Least Square and Cuckoo Search Algorithm. Comparison was made between models developed using the two algorithms and this study shows that Cuckoo Search Algorithm is superior than Recursive Least Square Algorithm based on Mean Square error (MSE). RLS developed models MSE are $5.6321 \times 10^{-5}, 0.0018, 0.0129$ & $0.0078\mathrm{e}$ for hub angle 1, hub angle 2, deflection 1 and deflection 2 respectively. CSA developed models MSE are $2.7164 \times 10^{-5}, 1.1546 \times 10^{-5}, 6.0404 \times 10^{-4}$ & 0.0026 respectively. Correlation tests showed that the hub angle models are biased, while the deflection models are unbiased for both algorithms. Finally, controllers intelligently tuned by Cuckoo search optimization algorithm were introduced to control the hub angle position and the endpoint vibrations. The rise time and maximum overshoot are 0.5 seconds and 0 rad for hub angle 1 and 0.5 seconds and 0.2 rad for hub angle 2. The setting time and maximum overshoot are 2 seconds and 0.01 rad for deflection 1 and 2 seconds and 0.007 rad for deflection 2.

ABSTRAK

Link fleksibel manipulator telah menarik minat ramai penyelidik disebabkan oleh batasan tegar bahagian tersebut. Walau bagaimanapun, manipulator fleksibel memperkenalkan getaran yang tidak diingini yang sukar dikawal oleh sebab sifatnya yang tidak linear. Dalam usaha untuk mengekalkan kelebihannya yang ringan dan fleksibel, pemodelan tepat mengenai sistem dan pengawal yang berkesan berkesan perlu dibangunkan yang juga merupakan tumpuan kajian ini. Dua-link manipulator fleksibel terdiri kepada 4 model, sudut Hub dan titik akhir getaran kedua-dua pautan Dua-Link fleksibel Manipulator. Input dan output data diperolehi daripada pelantar eksperimen. Setiap model telah diperolehi melalui teknik pengenalpastian sistem dalam persekitaran simulasi MATLAB iaitu konvensional *Recursive Least Square* dan *Cuckoo Search Algorithm.* Perbandingan dibuat antara model yang dibangunkan alah dengan menggunakan kedua-dua algoritma dan kajian ini menunjukkan bahawa *Cuckoo Search Algorithm* adalah lebih baik daripada *Recursive Least Square Algorithm* berdasarkan *Mean Square error* (MSE). RLS menghasilkan model MSE $5.6321 \times 10^{-5}, 0.0018, 0.0129$ & 0.0078 untuk sudut hab 1, sudut hab 2, pesongan 1 dan pesongan 2. CSA menghasilkan model MSE $2.7164 \times 10^{-5}, 1.1546 \times 10^{-5}, 6.0404 \times 10^{-4}$ & 0.0026. ujian korelasi menunjukkan bahawa model sudut hub adalah berat sebelah, manakala model pesongan adalah tidak berat sebelah untuk kedua-dua algoritma. Akhirnya, pengawal bijak ditala oleh *Cuckoo search optimization algorithm* telah diperkenalkan untuk mengawal kedudukan sudut hab dan getaran titik akhir. masa naik dan terlajak maksimum adalah 0.5 saat dan 0 rad untuk sudut hab 1 dan 0.5 saat dan 0.2 rad untuk sudut hab 2. Masa penyediaan dan terlajak maksimum adalah 2 saat dan 0.01 rad untuk pesongan 1 dan 2 saat dan 0.007 rad untuk pesongan 2.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Robotic manipulators are devices that are used to manipulate materials without direct contact with it, usually referred to as robotic arms. They are electronically controlled mechanisms consisting of segments that interact together to perform a desired task. Nowadays, robotic manipulator are extensively used in industries and other engineering related disciplines, however, the original application of robotic manipulators was to perform tasks in inaccessible places that requires dealing with radioactive and biohazardous materials which is too dangerous to be handled my man.

Further development of robotic manipulator systems widened their applications to robotically-assisted surgery and space applications. A robotic manipulator can be single-link with single degree of freedom or multiple link system with multi degrees of freedom, making multiple link manipulator more preferable as it is more reliable and can be applied more widely.

Manipulators can be used for pick up tasks, assembly operations, handling machines tools, different welding techniques, painting and soldering of cars. Alongside their wide applications in industrial sector, they are used for more advances applications including servicing of nuclear power plants, deep water applications such as repairing pipelines on the ocean floor. Moreover, space manipulators supports astronauts during their spacewalks, it can explore planets and moons without endangering human’s life as it is operated remotely and provided with cameras. Other applications include electric mobility, logistics, search and rescue, security and agriculture.

Conventionally, robotic manipulators have rigid arms which are large and heavy in weight, as a result, their usage are limited and their movements are slow and is more difficult to transport especially to outer space and off shores. Since the links are heavy, large power input is required to run the manipulator because much power is expended to move the heavy arms and resist gravity. Moreover rigid robotic arms are slow in motion and have low maneuverability.

As a result of these limitations of rigid manipulators, flexible link manipulators (FLM) has become a research interest nowadays, with an attempt to solve limitations of rigid manipulators. There are a lot of benefits from the development of flexible manipulators, they are light in weight, less material is required for their construction, they consume less power, improved characteristics as it has higher dexterity, better maneuverability, easier to transport, safer to operate and cost-effective.

1.2 Problem statement

Flexible manipulators introduces undesired vibrations which is not easy to control due to its high non-linearity. Ongoing research focuses on improving the control methods in order to suppress these vibrations. In order to keep the advantages associated with the lightness and flexibility of the manipulators, accurate modelling of the system and efficient reliable controller have to be developed.

Suppressing the vibration on flexible structures of is very important. The vibration of the structure will significantly affect the performance such as tracking errors, lags between tasks and reduced efficiency and accuracy. Moreover, excessive and continuous vibrations will cause early deterioration and possible deformation of the system.

Developing and accurate dynamic model that can describe the true behavior of the structure is crucial to ensure the effectiveness of the control system. In earlier research, high number of analytical model based approaches has been developed to establish the physical behavior of two link flexible manipulator (TLFM). There are a lot of mathematical models which were based on assumptions and approximations to make the derivation easier leading to inaccuracy of the system. A new methodology will be introduced, incorporating real input and output data of the system

Controllers of FLM has been widely established, proving successful results. As a result, none of the researchers use evolutionary algorithms to tune the parameters of the system. So the main focus in this study will be on the dynamic modelling of TLFM. However, the model derived from the new methodology will be incorporated with conventional PID controller to ensure the effectiveness and accuracy of the model and compare the results with previous work.

1.3 Objectives of Study

This thesis focuses on modelling and control of TLFM, the main objectives are:

1. To develop an accurate model describing the dynamics of TLFM via system identification techniques using actual experimental input and output data of the system.

2. To develop and simulate intelligent proportional-integral-derivative controller to suppress the vibration of the flexible manipulator.

1.4 Scopes of the study

1. To model TLFM through parametric system identification techniques using cuckoo search algorithm (CSA) and conventional recursive least square (RLS) method.

2. The developed models are validated via mean square error (MSE) and correlation tests.

3. Acquiring input-output data using data acquisition system (DAQ) from an experimental rig.

4. Simulation and evaluation of an intelligent fixed proportional-integral-derivative (PID) controller for vibration reduction in TLFM system based on the developed model. The controller will be tuned using metaheuristic algorithms.

5. Comparative study between the developed and conventional algorithm.

1.5 Significance of the study

This research is very important because it contributes in developing the model of TLFM. Parametric system identification approach is used which utilizes input and output data from the experiment in TLFM based on auto regressive with exogenous input (ARX) structure model. Two different system identification approaches are implemented, cuckoo search algorithm (CSA) and recursive least square (RLS).

The models are verified through mean squared error (MSE) and correlation test in order to determine which one is better.

Another significant importance of this study, its attempt to eliminate the vibration in TLFM. The methodology developed in this study can also be applied to other flexible structures in industries and many related engineering discipline applications. In order to suppress the vibrations, PID controller is applied to structure. The model is controlled within the simulation environment to determine the appropriate gains for PID controller. Later, the performance of the simulation is validated experimentally.

1.6 Thesis organization

Chapter 1: The present chapter is an introduction to this research, briefing the research background. The problem statement, objectives and scopes of the study is identified. The reader should be able to have a general idea about the project goals, significance and how the research is going to be implemented.

Chapter 2: Literature review, this chapter discusses the latest and trending literature about modelling and system identification of flexible link manipulators. It also cover literature on the control strategies. Moreover, some literature of the algorithms adopted (CSA) and (RLS) modelling are also included.

Chapter 3: Research methodology, it explains in details how the project will be carried out. It starts with explaining how the experimental rig works and how data are collected, followed by the procedures of system identification and how each step is carried out by using RLS and CSA algorithms. Finally, introduction to PID controller and how it is going to be implemented in control of Two-Link-Flexible-Manipulator (TLFM)

Chapter 4: Results and discussions, this chapter illustrates the results obtained from processing the experimental data into MATLAB to model the hub angle and deflection of Link 1 & Link 2. The mean squared error (MSE) is evaluated. Other results are graphically represented for better interpretation. It includes the relationship between actual and predicted output, error, auto-coloration and cross-coloration validation. The second part of this chapter is the discussion, where the results and the findings from these results are discussed.

Chapter 5: Conclusion and Recommendations. Firstly, the conclusions from the carrying out the project and interpreting the results are discussed. The findings and the achievement of the project as well as the drawbacks are mentioned. Secondly, recommendations for researchers who would wish to pursue the project and further development are explained.

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