# ADAPTIVE CONTROL OF ONE-DOF PORTABLE REHABILITATION ROBOT FOR WRIST TRAINING

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*Especially dedicated to my beloved parents, wife,*

*siblings, nephews, and nieces.*

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# ABSTRACT

Stroke is one of the leading causes of severe disability. The application of rehabilitation robots is increasing rapidly to help in recovering this disability through rehabilitation training. By using robot, the patient may perform the training more frequently. Various rehabilitation robots have been developed with a set of rehabilitation training programs with different haptic modalities. Different controllers were applied to provide accurate motor control for the rehabilitation robot and PID controller is one of the commonly used controllers. A robot named CR2-Haptic, which is used to train upper limbs, was developed in UTM with a set of rehabilitation training programs with PID controller that was designed for the patients having standard weight and wrist flexibility. The robot is successfully being used for training of stroke patients. One of the limitations for the PID controller is that it is not able to adapt its controller if the load is over its capability, since the robot controller is tuned based on a set standard weight. Therefore, the robot controller was not able to adapt itself to rotate the patient's hand for patient with high muscle stiffness which is common in stroke patient. Thus, it limits the use of the device to only patient with low muscle spasticity. Whenever the unknown and inaccessible load torque is imposed, the system will have the steady-and/or transient-state error. Therefore, in this project, a model reference adaptive controller (MRAC) which is able to adapt itself based on different patient conditions has been designed using Lyapunov method and implemented on the CR2-Haptic device to reduce the positioning error and make it more beneficial for wide range of stroke patients. The controller has been tested on subjects of different muscles stiffness. It has performed better for accurate positioning of the end effecter for patients with different weight and muscle stiffness. The results show that the designed controller is able to cope with the variations in limb's stiffness of the patients without the aid of any additional stiffness detection sensors.

# ABSTRAK

Strok adalah salah satu penyebab utama ketidakupayaan yang teruk. Penerapan robot pemulihan meningkat dengan pesat untuk membantu memulihkan kecacatan ini melalui latihan pemulihan. Dengan menggunakan robot, pesakit boleh melakukan latihan tersebut dengan lebih kerap. Pelbagai robot pemulihan telah dibangunkan dengan satu set program latihan pemulihan dengan modaliti haptic yang berbeza. Pengawal yang berbeza digunakan untuk memberikan kawalan motor yang tepat untuk robot pemulihan dan pengawal PID adalah salah satu pengawal yang biasa digunakan. Robot bernama CR2-Haptic, yang digunakan untuk melatih paras atas anggota badan, telah dibangunkan di UTM dengan satu set program latihan pemulihan dengan pengawal PID yang direka untuk pesakit yang mempunyai berat badan standard dan fleksibilitasi pergelangan tangan. Robot ini berjaya digunakan untuk latihan pesakit strok. Salah satu batasan untuk pengawal PID ialah ia tidak dapat menyesuaikan pengawalnya jika beban melebihi tahap keupayaannya, ini kerana pengawal robot ditala berdasarkan set berat badan yang standard. Oleh itu, pengawal robot tidak dapat menyesuaikan dirinya untuk memutar tangan pesakit bagi pesakit yang mengalami kekakuan otot yang tinggi yang biasa terjadi bagi pesakit strok. Oleh itu, ia mengehadkan penggunaan peranti itu dengan hanya boleh digunakan untuk pesakit yang mempunyai kelembutan otot yang rendah. Apabila tork beban yang tidak diketahui dan tidak dapat dicapai berlaku, sistem akan mempunyai kesilapan dari segi keadaan mantap dan / atau sementara. Oleh itu, dalam projek ini, pengawal penyesuaian rujukan model (MRAC) yang dapat menyesuaikan diri berdasarkan keadaan pesakit yang berbeza telah direka dengan menggunakan kaedah Lyapunov dan dilaksanakan pada peranti CR2-Haptic untuk mengurangkan kesilapan posisi dan menjadikannya lebih bermanfaat untuk pelbagai jenis pesakit strok. Pengawal telah diuji ke atas subjek otot kekejangan yang berlainan. Ia telah meghasilkan nilai yang lebih baik untuk kedudukan yang tepat dari effecter akhir bagi pesakit dengan berat badan yang berbeza dan kekakuan otot. Hasilnya menunjukkan bahawa pengawal yang direka dapat mengatasi variasi kekakuan anggota pesakit tanpa tambahan bantuan sensor pengesanan kekakuan.

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| | | |
|---|---|---|
| ANN | - | Artificial Neural Networks |
| CR2 | - | Compact Rehabilitation robot 2 |
| DC | - | Direct Current |
| DOF | - | Degree Of Freedom |
| FBME | - | Faculty of Bio-Medical Engineering |
| IDE | - | Integrated Development Environment |
| KVL | - | Kirchhoff's Voltage Law |
| LQG | - | Linear Quadratic Gaussian |
| LQR | - | Linear Quadratic Regulator |
| MIT | - | Massachusetts Institute of Technology |
| MRAC | - | Model Reference Adaptive Control |
| PI | - | Proportional Integral |
| PID | - | Proportional Integral Derivative |
| PWM | - | Pulse Width Modulation |
| QEI | - | Quadrature Encoder Interface |
| SMC | - | Sliding Mode Control |
| UTM | - | Universiti Teknologi Malaysia |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| V | - | Input Voltage to DC motor |
| $\theta$ | - | Angular position of end effecter |
| α | - | Adjustable controller parameter |
| i | - | Current through armature circuit |
| R | - | Resistance of Armature Circuit |
| L | - | Inductance of Armature |
| E | - | Back emf Voltage |
| T | - | Torque generated by DC motor |
| $K_t$ | - | Motor Torque Constant of DC motor |
| $K_b$ | - | Back emf constant of DC motor |
| $\dot{\theta}$ | - | Angular velocity of end effecter |
| $J$ | - | Moment of Inertia |
| $\ddot{\theta}$ | - | Angular acceleration of end effecter |
| b | - | Viscous friction constant |
| e | - | Difference between actual and reference model output |
| $Y_m$ | - | Reference Model output |
| Y | - | Actual output |
| $R$ | - | Reference input |
| U | - | Control signal |
| $\theta_1$ | - | Adjustable controller parameter for designed MRAC |
| $\theta_2$ | - | Adjustable controller parameter for designed MRAC |
| $\theta_3$ | - | Adjustable controller parameter for designed MRAC |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Stroke is one of the leading causes of severe disability. Rehabilitation robots are used to assist and improve motor function in the patients after stroke [20]-[22]. The application of rehabilitation robots is increasing rapidly to help in recovering post stroke disability through rehabilitation trainings. They provide automated therapy and enable intense and longer duration repetitive task practice [22], [23]. Moreover, by using a robot, the patient may perform training more frequently and easily at home. Various rehabilitation robots have been developed with a set of rehabilitation training programs with different haptic modalities [24]. They consist of actuators to produce desired movement of the end effecter that holds the patient's affected limb for the training. DC motors are the commonly used actuators for this purpose. Different control techniques have been applied to control the actuators accurately according to the desired movement. PID controller is one of commonly used controllers.

## 1.2 Problem Statement

One of the limitations for the PID controller is the low adaptability to external disturbance or load. As the PID controller is tuned based on a preset standard load and parameters, if the robot uses the PID controller, it may not be able to adapt itself to rotate the patient's limb for patient with heavy weight or high muscle stiffness which is common in stroke patient. Thus, it limits the use of the device to only patient with low muscle spasticity. Whenever the unknown and inaccessible load torque is imposed, the system will have the steady-and/or transient-state error. Advanced techniques such as fuzzy logic, artificial neural network, self-Tuning control requires heavy computation for their complex algorithms. Many other techniques such as optimal control and LQR (Linear Quadratic Regulator) do not take in consideration the change in parameters due to external loading or require sensors for all states of the system.

Therefore, in this project, an adaptive controller which is able to adapt itself based on different patients condition is designed to control the movement of end effecter of CR2-Haptic, a one-DOF rehabilitation robot that is used to train wrist and forearm movements. The purpose is to rotate wrist of patients with desired response for training and make it more beneficial for a wide range of stroke patients.

## 1.3 Objectives

The objectives of this project can be outlined as follows:

1. To design an adaptive controller for one-DOF rehabilitation robot that can adapt the variation in wrist stiffness of the patients.

2. To evaluate the performance of the controller using simulink.

3. To implement the designed controller on CR2-Haptic, a rehabilitation robot.

## 1.4 Scope of the project

The scope of the research is listed as follows:

1. The proposed control algorithm is designed for the robot with one-DOF for supination and pronation training in passive mode.

2. Implementation has been done on CR2-Haptic, a rehabilitation robot.

3. Previously deployed PID controller is reference for testing the designed controllers.

## 1.5 Thesis Outline

This thesis consists of five chapters. Chapter 1 is the introduction of the project. It covers a brief background of the project, problem statement, objectives, and scope of the research. Chapter 2 is a literature review of some previous research that was helpful to support the project. It classifies Rehabilitation Robots and controller's types for controlling the Robots and DC motors. Chapter 3 is research methodology that consists of the system selection, model of the system, controller design and flow chart of the research. Chapter 4 presents the simulation and experimental results together and discusses the obtained results for this research. The last chapter which is Chapter 5 summarizes the conclusion of the project with future recommendation to extend the research in future.

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