# DESIGN AND DEVELOPMENT OF A NEW STABILIZATION MECHANISM FOR TWO-WHEELED WHEELCHAIR

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Mechatronic Engineering)

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# ABSTRACT

This research embarks on designing a new mechanism for transforming a four-wheeled wheelchair into a two-wheeled wheelchair. It is known that wheelchair system is a main means of mobility for the disabled and the elderly. A normal four wheels wheelchair has some limitations where the wheelchair user is too depending on the helper, which reduces their mobility if the assistance is not available. The standard wheelchair nowadays only caters for outdoor environment where the space is not a constraint. Therefore, the two-wheeled wheelchair is proposed to encourage independence where many common tasks such as pick and place things can be done independently and is suitable to be used in confined space i.e. home, office or library. The proposed two-wheeled wheelchair was modeled to mimics a double inverted pendulum scenario where Link2 was introduced to cater for the human weight. To increase the confidence level of the modeling stage, a virtual prototype of a two-wheeled wheelchair was developed with a human model. Analysis of the model was conducted and simulated to study the actuators requirement and response performance. The mathematical models were then derived to represent the two-wheeled wheelchair. It was achieved that the equations derived represents the system as a highly nonlinear and unstable system. The complexity of the system was reduced through the linearization of the equations. Both linearized and nonlinear equations of motions were tested with different control strategies, where the LQR was implemented on the linearized model and the fuzzy logic controller was designed to control the nonlinear model of the two-wheeled wheelchair. Upon satisfactory results of analysis on the virtual prototype and mathematical models with controllers, a full hardware prototype was developed. The controllers designed were tested experimentally and it provides promising results where the four-wheeled wheelchair was able to transform into a two-wheeled wheelchair and stabilized at the upright position as required.

# ملخّص البحث

هذا البحث يشرع في تصميم ميكانيكية جديدة لتحويل الكرسي من هيكلية 4 عجلات الي هيكيلية عجلين . من المعروف ان الكرسي المتحرك هو الوسيلة الرئيسية للتنقل عند المقعدين. الكرسي المتحرك العادي ذو الاربعة عجلات يوجد لديه بعض القيود حيث ان مستخدمية يعتمدون كثيرا على المساعدين مما يقلل حركتهم عندما يغيب المساعدين. الكرسي المتحرك القياسي في هذه الايام يمكن استخدامه في البئية الخارجية. وبالتالي, الكرسي المتحرك على عجلتين يهدف الي تشجيع الاعتماد على النفس حيث ان كثير من المهام الشائعه يمكن القيام بها بصورة منفردة وهو مناسب للاستخدام في المساحات الضيقة. الكرسي المتحرك المقترح تم تصميمه ليشبه ميكانيكية البندول الثنائي المقلوب. تم تصميم نموذج رقمي مع وزن الانسان. وتم تحليل ومحاكاه النظام من اجل التعرف علي متطلبات المحركات المطلوبة. المعادلات الرياضية الممثلة للنظام تم حسابها. تم التقليل من تعقيد النظام بواسطة تحويل المعادلات الرياضية غير الخطية الي خطية حول زاوية صغيرة لكل من Link1 and Link2 . كلا من المعادلات الخطية والغير خطية تم اختبارها مع متحكمات مختلفه. حيث ان LQR استخدم مع النظام الخطي و Fuzzy logic controller استخدم مع النظام الغير خطي. على الرغم من النتائج المرضية لكل من النموذج الرقمي و معادلات الحركة, تم تصميم نموذج حقيقي. النظام المصمم تك تطبيقه على هذا النموذج حيث اظهر ان الكرسي المتحرك على اربع عجلات قادر على التحول الي عجيلتين والتوازن عليهما فقط.

# APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Mechatronic Engineering).

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I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Mechatronic Engineering).

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Amir Akramin Shafie
Examiner

This dissertation was submitted to the Department of Mechatronics Engineering and it is acceptable as a fulfilment of the requirement for the degree of Master of Science (Mechatronic Engineering).

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Md. Noor Bin Salleh
Dean, Kulliyyah of Engineering

# DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not previously or concurrently submitted as a whole for any other degree at IIUM or other institutions.

Tareq ALTalmas

Signature……. Date: ……

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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## DESIGN AND DEVELOPMENT OF A NEW STABILIZATION MECHANISM FOR TWO-WHEELED WHEELCHAIR



Affirmed by Tareq ALTalmas

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…….….. Date

# ACKNOWLEDGEMENTS

In the name of Allah, the most Gracious, the most Merciful. Praise be to the Almighty Allah s.w.t, the God of the universe, for his mercy and blessings that have been granted to the author. Peace and blessings be upon His messenger Muhammad s.a.w, his families and companions.

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I would like to dedicate this work to my family. My special thanks for my father Maher and my mother Sanaa for their Doaa'. Also for my brothers Hossam, Khalel, Abdullah and Mohammed. And finally for my sister Areej.

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| | |
|---|---|
| $J_R$ | Moment of Inertia of the Right Wheel |
| $J_L$ | Moment of Inertia of the Left Wheel |
| $K_R$ | Kinetic Energy of the Right Wheel |
| $K_L$ | Kinetic Energy of the Left Wheel |
| $K_1$ | Kinetic Energy of Link1 |
| $K_2$ | Kinetic Energy of Link2 |
| $K_t$ | Total Kinetic Energy of the System |
| $L_1$ | Length of Link1 |
| $L_2$ | Length of Link2 |
| $M_R$ | Mass of the Right Wheel |
| $M_L$ | Mass of the Left Wheel |
| $M_1$ | Mass of Link1 |
| $M_2$ | Mass of Link2 |
| $r$ | Radius of the Wheels |
| $\theta_R$ | Angular Displacement of the Right Wheel |
| $\dot{\theta}_R$ | Angular Velocity of the Right Wheel |
| $\ddot{\theta}_R$ | Angular Acceleration of the Right Wheel |
| $\theta_L$ | Angular Displacement of the Left Wheel |
| $\dot{\theta}_L$ | Angular Velocity of the Left Wheel |
| $\ddot{\theta}_L$ | Angular Acceleration of the Right Wheel |
| $\theta_1$ | Rotation Angle of Link1 |
| $\dot{\theta}_1$ | Angular Velocity of Link1 |

| | |
|---|---|
| $\ddot{\theta}_1$ | Angular Acceleration of Link1 |
| $\theta_2$ | Rotation Angle of Link2 |
| $\dot{\theta}_2$ | Angular Velocity of Link2 |
| $\ddot{\theta}_2$ | Angular Acceleration of Link2 |
| $U_R$ | Potential Energy of the Right Wheel |
| $U_L$ | Potential Energy of the Left Wheel |
| $U_1$ | Potential Energy of Link1 |
| $U_2$ | Potential Energy of Link2 |
| $U_t$ | Total Potential Energy of the System |
| $x$ | Linear Position of the Wheelchair |
| $X_R, Y_R$ | The Position of the Right Wheel in the x-y Plane |
| $\dot{X}_R, \dot{Y}_R$ | The Velocity of the Right Wheel in Regard to the x-y Plane |
| $X_1, Y_1$ | The Position of the Link1 in the x-y Plane |
| $\dot{X}_1, \dot{Y}_1$ | The Velocity of the Link1 in Regard to the x-y Plane |
| $X_2, Y_2$ | The Position of the Link2 in the x-y Plane |
| $\dot{X}_2, \dot{Y}_2$ | The Velocity of the Link2 in Regard to the x-y Plane |

# CHAPTER ONE

# INTRODUCTION

## 1.1 INTRODUCTION AND MOTIVATIONS

Wheelchair is a device used for mobility of the people for whom walking is difficult or impossible, due to illness or disability. Wheelchairs have many types and versions, where some wheelchairs are propelled manually (manual wheelchair), while others move by actuating motors (electric wheelchair).

The population of wheeled mobility device users has increased by 4.3% per year, and there are about 3.3 million adults using these devices (LaPlante and Kaye, 2010). The use of wheelchair has helped disabled people to be more independent in their life, which increases the vocational and educational opportunities, reduces dependence on caregivers and family members, and promotes feelings of self-reliance (Simpson, 2005). On the other hand, it is very obvious that the user of a normal wheelchair needs an assistant for their mobility, thus the contributions of those normal people in the society are affected (Simpson, 2005). There are many types of wheelchairs that have been designed with special functions. Some of the designs give the ability to climb over step and curbs (Cooper, et al., 2012), while, others are designed to help user's mobility in the society. In particular, there was a wheelchair designed to help user to have face to face conversation with people by lifting the seat (INDEPENDENCE® iBOT® 4000 Mobility System, 2013). This two-wheeled wheelchair was invented to give the user the ability to maneuver in confined space. The lifting mechanism that was designed has the ability of increasing the seat level

help the user to act independently, for instance to pick and put things on the shelves in the library and home.

Disabled and aged people have been using wheelchairs widely for the sake of mobility since the wheelchairs have become an important assistive tool for them. The works on invention wheelchairs with extra features have grown rapidly as the industry of wheelchairs evolve. The field of improving the wheelchair's features focuses particularly on thewheelchair's features such as design, traveling range, style, control, maneuverability, seating, suspension system, and other functions. In fact the increasing number of wheelchair users with different needs has been motivating the researches and industry to produce more new designs with extra features.

Two-wheeled wheelchair system is proposed in this research having a unique function to fulfill the needs among the wheelchair users. The system is designed such that it has the mechanism of converting its original four-wheeled wheelchair to the two-wheeled wheelchair with the ability of lifting the seat to give the wheelchair users more independence during their daily activities and the user may have face-to-face conversation with other normal people, which indirectly has significant effect on their emotional and psychology.

## 1.2 PROBLEM STATEMENT

As mentioned that the number of wheelchair users increases day by day. Therefore, the need of producing improved products that offer a greater independence and greater participation in the family and community is also increased. The proposed design will give the disabled people the desired independence in their daily life.

Nakamura & Murakami, (2009) listed three problems in the structure of the available four-wheeled wheelchairs. Firstly, the requirement space to turn and move

the manual wheelchair needs more space and to make 360 degree turn it need go forward and backward. Second problem is the resistance of the front wheels. Thirdly, the seat level which it is not provided face to face conversation with normal people. (Why Choose Genny, 2012) listed some difficulties for traditional wheelchair users. Firstly, the casters problem which the users have to take care constantly to prevent it stuck into little holes or cracks in the pavement. Moreover, the normal wheelchair users have to keep holding the wheels. The iBOT design has some limitations. It has the ability to work and balance on two wheels, reach face to face conversation level and climb stair. But unfortunately, this product is not available currently on the markets. Genny mobility is another two wheeled vehicle but it doesn't have the ability to maintain the seat level.

Consequently, the need for two-wheeled mobile vehicle has grown and attracted many researchers to conduct their researches in this field to come out with new products that help wheelchair users to be independent as much as possible. These products have the ability to move and balance on two wheels and maintain the height of the seat which gives wheelchair users much independence in their daily life. Therefore, this research on the design and development of a new mechanism of two-wheeled wheelchair for disabled.

## 1.3 AIMS AND OBJECTIVES OF THE RESEARCH

The objectives of this research are as follows:

1. To model and develop prototype of a wheelchair system that mimics a double inverted pendulum scenario.
2. To design a new mechanism for transforming a normal four-wheeled wheelchair into a two-wheeled wheelchair.

3. To design suitable lifting mechanism to increase the height of the seat.
4. To confirm stability of the wheelchair during its motion.
5. To perform hardware implementation of the wheelchair system and evaluate the performance experimentally.

## 1.4 METHODOLOGY

To achieve the goal, this research started with conducting reviews and surveys on the previous designs and works that have been done on the similar issue. Then, different modeling techniques were used to model the new mechanism for converting a normal wheelchair on four wheels onto a two-wheeled wheelchair. Then the analyzing stage takes place where the system's mechanism designed in the virtual 3D environment is tested. The wheelchair hardware is then realized based on the designed parameters of the model. Then, the hardware design tested with fuzzy logic controller. This research intends to help wheelchair users to act independently in their life. Figure 1.1 shows the research methodology flowchart.

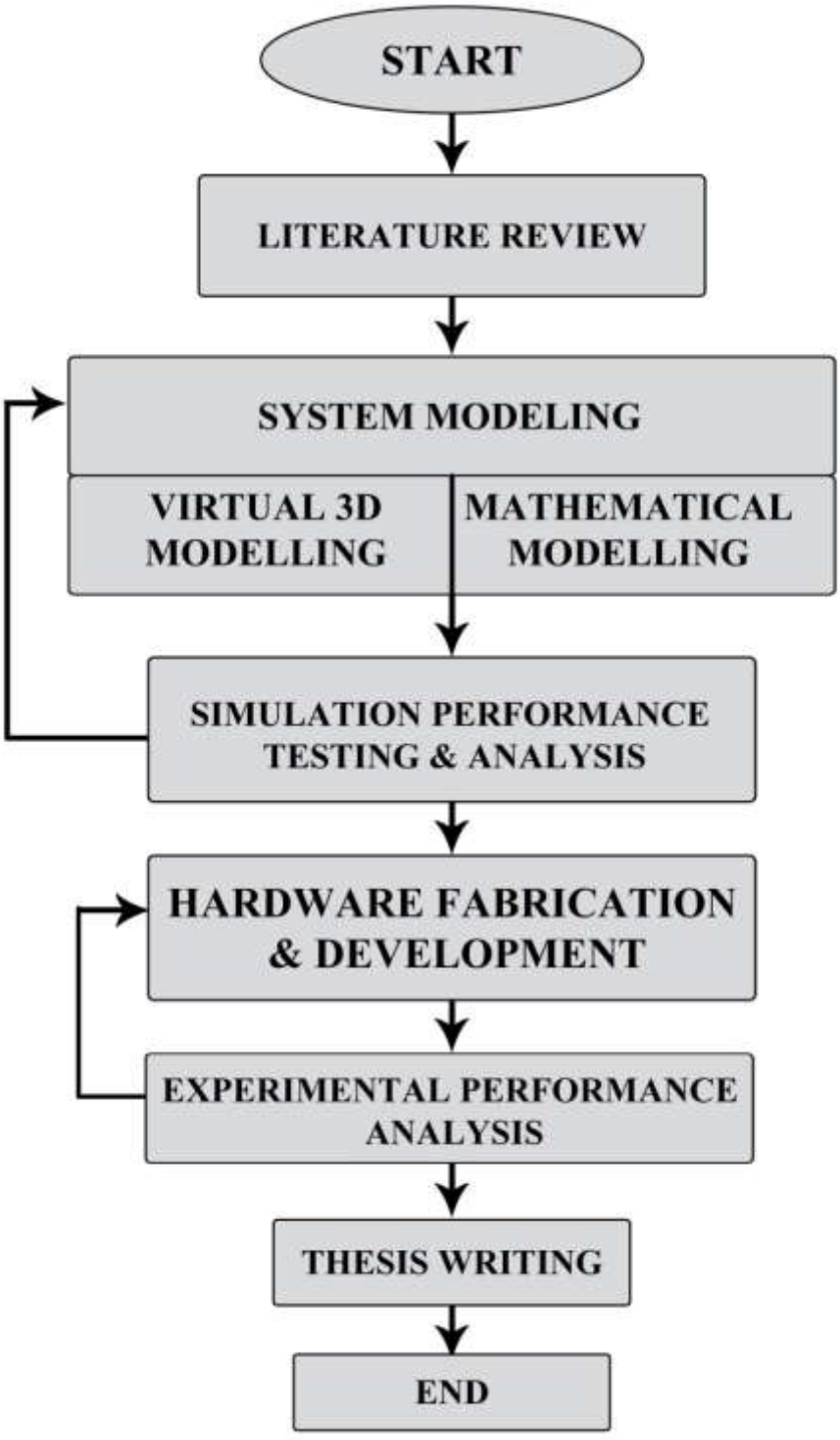


Figure 1.1 Research methodology flowchart

## 1.5 PROPOSED TWO-WHEELED WHEELCHAIR

Two-wheeled wheelchair is a complex, highly nonlinear but yet is an interesting and challenging system to be designed and controlled. It is important to build a proper design and control strategy to keep this complex system balanced, stable and perform as similar as normal wheelchair does. Two-wheeled wheelchair is aimed to be suitable for domestic areas and confined spaces that it will take less space comparing to the normal four-wheeled wheelchair, particularly during steering process. This is due to its ability to turn into spot, similar to any mobile robot on two wheels.

This research focuses on developing a new design and mechanism for transforming normal four-wheeled wheelchair onto a two-wheeled wheelchair by rising up the front wheels (casters) of the wheelchair. Furthermore, a scissor mechanism is introduced to change the seat's height to reach higher level of heights. This research is aimed to assist the wheelchair users to have independent life. The encouragements on the proposed wheelchair on two wheels, which mimics a double inverted pendulum scenario, are:

1. To provide the wheelchair users the ability to maneuverable in confined spaces such as house, library or offices particularly during the sharp cornering.
2. To equip the user with the ability to reach higher level of height that will help them in picking and placing things on shelves and allowing them to have an eye-to-eye level during conversation with a standing normal people.

## 1.6 THESIS OUTLINES

The outlines of the thesis are explained as follows;

**Chapter One:** This chapter introduces and explains the importance of the wheelchair for disabled and elderly people as a tool for mobility. Then it covers the problem statement, aims and objectives, methodology, and the proposed design.

**Chapter Two:** This chapter summarizes a list of previous works that is related to this research. Inverted pendulum, double inverted pendulum, rotary inverted pendulum, and then previous researches, and designs have been discussed in this chapter.

**Chapter Three:** This chapter discusses a wheelchair 3D model. The process of 3D modelling from part building until full assembly has also been described. This chapter further presents the mathematical modelling of the proposed two-wheeled wheelchair system based on Lagrangian approach. Non-linear equations of motion have been derived then they have been linearized to get the linear state space model.

**Chapter Four:** This chapter presents the SolidWorks motion simulation, that simulation has been used to show the turning diameter of the design and system behavior when raising the casters. It is used also to calculate the required torques from the Link2 and the effect of using the Link2 in the system. The effects of removing the casters have also been explained. The open loop step responses of the linear state space model. Control system requirements have been explained. Moreover, system controllability has also been tested. The system has been tested with pole placement approach and linear quadratic regulator (LQR). Further, it is discusses the implementation of fuzzy logic control on the nonlinear model.

**Chapter Five:** This chapter describes the physical prototype of the two-wheeled wheelchair system. Then the actuator, power sources and the sensor system have been discussed as well. In addition, the used data acquisition system and interfacing has been presented. It is also shows the system behavior after implementing two independent fuzzy logic controller for each link.

**Chapter Six:** The conclusions of this work, contribution of research and the recommendations for further work and improvement have been explained in this chapter.

## 1.7 SUMMARY

This chapter has briefly described the introduction and the motivations of the research of the two-wheeled wheelchair. Then a brief explanation about the proposed design has been written with the benefits of using two-wheeled wheelchairs system with the ability of changing the seat's height. The aims, objectives, problem statement and research methodology of the research have been described.