THE INTELLIGENT CONTROLLER FOR SPHERICAL ROBOT

BY

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ABSTRACT

This research sought to design the intelligent controller for a spherical robot. Spherical robot is a ball-shaped mobile robot that capable to move from one place to another to perform the desired tasks. A error driven Fuzzy Logic Controller (FLC) which consist of two Proportional-Derivative type FLC and Proportional-Integral type FLC are designed to control the position of the spherical robot, angle of the pendulum and the angular velocity of the spherical robot. The intelligent controller like FLC is proposed to reduce the dependency on its mathematical model, FLC is a knowledge-based controller which can be design without using a complex mathematical model. Then, the designed controller is optimized with tuning the input and output gain of the controller with Particle Swarm Optimization (PSO) method. Besides, the effect of different type of membership function (MF) and number of variables used for MF are also been studied by heuristically tuned these two parameters. As a result, five variable of triangular and trapezoidal MF are selected as the best MF to be used in both PD-type FLC for position controller while gaussian and sigmoidal are selected to be used in PI-type FLC to control the angular velocity of the spherical robot. With PD-type FLC, rise time and settling time of the position control of the robot managed to be reduced by 84% and 87% respectively. In addition, PD-type FLC also capable to eliminate the overshoot and reduce the settling time of the pendulum control by 60 % compared to when the robot run without the controller. The optimized PI-type FLC used to control the angular velocity of the spherical robot manage to eliminate the steady state error and achieved its desired setpoint in 1.47s. Finally, the spherical robot with monitoring devices like camera, temperature sensor and the gas sensor are successfully developed, and the designed controllers are integrated to control the position, angle of pendulum, and the velocity of the spherical robot. The experimental performance analysis is studied and show that the integration of the controller managed to control the position with settling time 60% faster than simulation. While the PD-type FLC used to control the angle of pendulum managed to control its angle to it desired setpoint but having some problem on maintaining the angle due to the rotation of the spherical robot. For PI-type FLC, the experimental value achieved 83% of its desired angular velocity and need to be optimized to really achieved it desired setpoint velocity. Therefore, it concluded that the objective of the research is achieved to design and studies the integration of the intelligent controller for the developed monitoring and surveillance spherical robot.

خلاصة البحث

سعى هذا البحث إلى تصميم جهاز التحكم الذكي لإنسان آلي كروي. الروبوت الكروي هو روبوت متحرك على شكل كرة قادر على الانتقال من مكان إلى آخر لأداء المهام المطلوبة. تم تصميم وحدة التحكم المنطقي Fuzzy Logic Controller (FLC) التي تعتمد على الأخطاء والتي تتكون من نوعين مشتقين متناسبين من نوع FLC والنوع النسبي المتكامل FLC للتحكم في موضع الروبوت الكروي وزاوية البندول والسرعة الزاوية للروبوت الكروي. تم اقتراح وحدة التحكم الذكية مثل FLC لتقليل الاعتماد على نموذجها الرياضي ، FLC هي وحدة تحكم قائمة على المعرفة والتي يمكن تصميمها دون استخدام نموذج رياضي معقد. بعد ذلك ، يتم تحسين وحدة التحكم المصممة من خلال ضبط كسب الإدخال والإخراج لوحدة التحكم باستخدام طريقة Particle Swarm Optimization (PSO). إلى جانب ذلك ، تم أيضًا دراسة تأثير نوع مختلف من وظيفة العضوية (MF) وعدد المتغيرات المستخدمة في MF من خلال الضبط الإرشادي لهاتين المعلمتين. نتيجة لذلك ، تم اختيار خمسة متغيرات من MF المثلث وشبه المنحرف كأفضل MF لاستخدامه في كل من PD-type FLC للتحكم في الموضع بينما يتم اختيار gaussian و sigmoidal لاستخدامهما في PI من النوع FLC للتحكم في السرعة الزاوية لل روبوت كروي .مع PD-type FLC ، تم تقليل وقت الصعود ووقت الاستقرار للتحكم في موضع الروبوت بنسبة 84٪ و 87٪ على التوالي. بالإضافة إلى ذلك ، فإن PD-type FLC قادر أيضًا على التخلص من التجاوز وتقليل وقت الاستقرار للتحكم في البندول بنسبة 60 ٪ مقارنةً بوقت تشغيل الروبوت بدون وحدة التحكم. يتم استخدام FLC من نوع PI المحسَّن للتحكم في السرعة الزاوية للروبوت الكروي الذي يعمل على التخلص من خطأ الحالة المستقرة وتحقيق نقطة الضبط المطلوبة في 1.47 ثانية. أخيرًا ، تم تطوير الروبوت الكروي المزود بأجهزة مراقبة مثل الكاميرا ومستشعر درجة الحرارة ومستشعر الغاز بنجاح ، وتم دمج وحدات التحكم المصممة للتحكم في موضع وزاوية البندول وسرعة الروبوت الكروي. تمت دراسة تحليل الأداء التجريبي وتبين أن تكامل وحدة التحكم تمكن من التحكم في الموضع بزمن الاستقرار أسرع بنسبة 60٪ من المحاكاة. في حين أن PD-type FLC المستخدم للتحكم في زاوية البندول تمكن من التحكم في زاويته إلى نقطة الضبط المرغوبة ولكن هناك بعض المشاكل في الحفاظ على الزاوية بسبب دوران الروبوت الكروي. بالنسبة لـ PI-type FLC ، حققت القيمة التجريبية 83 ٪ من السرعة الزاوية المرغوبة وتحتاج إلى التحسين لتحقيق السرعة المحددة المرغوبة. لذلك ، خلص إلى أن الهدف من البحث قد تحقق لتصميم ودراسة تكامل وحدة التحكم الذكية للروبوت الكروي للمراقبة والمطوّر.

APPROVAL PAGE

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

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DECLARATION

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

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θ_p	Angle of the pendulum
θ_s	Angle of sphere
ω_p	Angular velocity of pendulum (rad/s)
ω_s	Angular velocity of spherical robot (rad/s)
B	Rotor damping
e_{ss}	Steady-state error
g	Gravitational force (N.m)
I_s	Moment of Inertia of the spherical robot
I_p	Moment of Inertia of the pendulum
J	Rotor Inertia ($kg.m^2$)
K	Kinetic energy
K_b	Back-emf constant (rad/s)
k_p	Proportional gain
k_d	Derivative gaib
k_i	Gain where i = 1,2,3,4,5,6,7,…..,n
L	Lagrangian
L_i	Armature Inductance (H)
L	Distance between center of spherical robot to center of the pendulum. (m)
m_p	Mass of pendulum (kg)
M_s	Mass of the spherical robot (kg)
M_T	Total mass of the Spherical robot
p_s	Position of the spherical robot on plane (m)
R	Radius of the spherical robot (m)
R_0	Inertial reference frame
R_1	Reference frame 1
R_2	Reference frame 2
$R_{m,}$	Armature resistance (ohm)
P	Potential energy
P_o	Percentages Overshoot
Q_i	Generalized force
q_2	Generalized coordinate
S	Viscous friction
t_r	Rise time
t_s	Settling time
v_p	Velocity of the pendulum
$X_{0,}$ Y_0	X-axes and Y-axes of reference frame 0
X_1 Y_1	X-axes and Y-axes of reference frame 1
$X_{2,}$ Y_2	X-axes and Y-axes of reference frame 2
Ξ	Damping coefficient

LIST OF ABBREVIATIONS

FLC	Fuzzy Logic Control
UAV	Unmanned Aerial Vehicle
PSO	Particle Swarm Optimization
AVG	Autonomous Guided Vehicle
IDU	Internal Driven Unit
CPU	Central Processing Unit
COM	Center of Mass
COG	Center of gravity
CMG	Control Moment Gyroscope
P	Proportional
PD	Proportional-Derivative
PI	Proportional-Integral
PID	Proportional-Derivative-Integral
3D	3-Dimensional
2D	2-Dimensional
ADAMS	Automated Dynamic Analysis of Mechanical Systems
FAT	Function approximate technique
MRAC	Model Reference Adaptive Controller
2DOF	2-Degree of Freedom
DC	Direct Current
MF(s)	Membership Function(s)
NB	Negative Big
NS	Negative small
Z	Zero
PS	Positive Small
PB	Positive Big
N	Negative
P	Positive
SISO	Single-input single-output
MISO	Multiple-input single output
CAD	Computer-aided design
RAM	Random-access memory
Wi-Fi	Wireless fidelity
ADC	Analog-Digital Converter
IC	Integration circuit
PPM	Parts per millions
LAN	Local area network
BLE	Bluetooth Low Energy
HDMI	High-definition multimedia interface
USB	Universal serial bus
HATs	Hardware attached on top
CSI	Camera serial interface
LPG	Liquefied petroleum gas
CMOS	Complementary metal-oxide semiconductor

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

A mobile robot is a robot that is capable of having its own locomotion about the surrounding environment. Those mobile robots are widely used in many areas of applications such as surveillance, search, and rescue, education and entertainment. Mobile robots can be categorized into several types; wheeled, legged, unmanned aerial vehicle (UAV), spherical mobile robot and others. These different types of mobile robots move using different types of motion principles. For instance, legged robot may crawl, slide, run, or walk. Spherical robot may roll, jump or bounce, while some other robots may even fly, swim and roll. The types of mobile robots and their motions are designed based on their environment and application's requirements. As compared to other mobile robots, a spherical robot possesses unique advantages due to its shaped, contact point and design. The shape of this robot allows it to roll naturally and change its direction easily. It's non-edged shaped reduced the overturned risk and increases its ability to recover from the collision with obstacles. Due to that reason, this kind of mobile robot is believed to be suitable to handle the rough and tough environment. Rolling is the main type of motion of the spherical robot, and there are a lot of enhancement that has been developed to improve this motion. Integrating the rolling mechanisms can improve the mobility of the spherical robot but may increase the nonlinearity and complexity of the overall system. Usually, a spherical robot is only able to roll on the ground or bounce when hitting the obstacle and change its direction naturally. When rolling mechanism is implemented in the spherical robot, the motion of the spherical robot can be controller. Instead of rolling and meanuver naturally around the place, the position and motion of the spherical robot can be specifically generated by its rolling mechanism to perform its desired tasks.

Besides, the spherical robot can perform better tasks in monitoring, surveillance, exploration, and navigation if it can move smoothly when it is equipped with suitable sensing elements according to the environment of concerns. For instance, Hernández, Barrientos, Del Cerro, Barrientos, & Sanz, 2013, developed the spherical monitoring robot equipped with temperature, humidity and GPS called ROSPHERE. Besides, GroundBot, an amphibious spherical robot has been programmed with navigation algorithm, camera and GPS has shown a remarkably result in exploring the potential of the spherical robot (Kaznov & Seeman, 2010). However, the control system can be very critical to handle different kinds of mechanisms of a spherical robot. Due to its complexity and nonlinear characteristic, the classical control method can be difficult to be designed and implemented. The classical controller requires an understanding of the dynamic behavior of the system. It requires mathematical model to represent the system. The fact is that nonlinearity and unmodeled parameters can be disadvantages in designing the control system. In contrast, intelligent control has been designed in many complexes and nonlinear applications like mobile robots (Chen et al., 2017). From the review, it can be said that the popular intelligent controllers that have been proposed and used in the mobile robot were neural network and fuzzy controllers. Both controllers required training data and knowledge-based system for the controller to be designed on the designated system. The controller design does not require rigid model and solution since knowledge and intelligence lie in the algorithm developed using suitable software where the robots are expected to decide based on the sample training data or input knowledge that has been required by the designer.

In particular, fuzzy logic control (FLC) is designed based on human reasoning and knowledge of the experts. The idea is to match the input of the controller to the knowledge of the system and produce the best output to achieve the desired input. Linguistic variables used in FLC make it more flexible to handle uncertainty and nonlinearity. Because of those reasons, recommendations and the suitability of this type of intelligent controller for a nonlinear system like spherical robot, therefore the fuzzy logic controllers were designed as the main control strategy in the rolling mechanism of the spherical robot that was discussed in details throughout the thesis.

1.2 PROBLEM STATEMENT

A mobile robot is a type of robot which can move around in their environment. The important element of the mobile robot is locomotion. Wheeled and legged are the common mobile robot that has been developed in the robotics area, but they are still limited in certain aspect especially mobility. Wheeled are suited on the flat ground but inefficient on the soft and bumpy area, while legged required complex leg configuration in different surface area. In comparison, spherical robot possesses significant advantages due to its geometrical shape. Its symmetrical shape allows it to roll naturally in any type of terrain including rough and uneven terrain. Besides, it has no edge or side which eliminates the risk of overturning and allows it to bounce when hitting the obstacle. This improves its capability to recover from the collision. In addition, the spherical robot can be designed with totally seal and enclosed with a spherical shell to protect its inner circuitry. This allowed a spherical robot to be used in many applications like education, entertainment, navigation, exploration, monitoring and surveillance.

However, for the spherical robot to smoothly manoeuvre in any environment, it should be able to control its motion precisely. So a controller must be design for the spherical robot to control itself in any situation and environment. A conventional controller like a PID controller is designed based on mathematical modelling of the system. Unfortunately, spherical robot is a nonholonomic, highly nonlinear and complex system that makes the derivation of its mathematical modelling is very challenging. Spherical robot especially the one with pendulum driven method will naturally roll and change its direction easily when the equilibrium of the system is disturbed. The motion of spherical robot can be influence by its mechanical structure, motor performance and external disturbance which make complication in designing its mathematical model. Error in mathematical modelling may lead to error in controller design.

Therefore, the intelligent controller is proposed to reduce the error due to the dependence on mathematical modelling as an intelligent controller can be designed without its mathematical model. An intelligent controller like Fuzzy logic controller does not require any deep knowledge of its mathematical model, since it requires an understanding of the designers about the system in achieving the required system performances. This research will be aim to design an intelligent controller like Fuzzy Logic Controller (FLC) to control the position of the spherical robot, the angle of the pendulum, and angular velocity of the spherical robot.

1.3 RESEARCH OBJECTIVES

The studies aim to achieve the following objectives:

1. To design an intelligent controller for the rolling mechanism of the spherical robot and perform simulation performance analysis.
2. To develop the spherical robot that is capable to roll and equipped with environmental sensors.
3. To study the performance of the spherical robot with designed controllers.

1.4 RESEARCH METHODOLOGY

A research methodology is a way to conduct, process and analysis the research. It is a method and a complete plan to achieve the objective of the research. For this research, the methodology or the flowchart of the research process is constructed as Figure 1-1.