DEVELOPMENT OF A CASCADE PID FUZZY LOGIC CONTROLLER FOR WALL FOLLOWING MOBILE ROBOT

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DEVELOPMENT OF A CASCADE PID FUZZY LOGIC CONTROLLER

FOR WALL FOLLOWING MOBILE ROBOT

by

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LIST OF SYMBOLS

D_c	distance of the center of the WMR has travelled
D_l	distance of the left wheel has travelled
$D_{l/r}$	distance travelled by left or right wheel
D_r	distance of the right wheel has travelled
D_w	distance between the wheels
H_0	Null hypothesis
H_A	Alternative hypothesis
K_d	Derivative gain
K_i	Integral gain
K_p	Proportional gain
K_u	Ultimate gain
P_u	Oscillation period
R_w	radius of the wheel
T_e	Torque developed
T_l	Load torque
i_a	Armature current
k_e	emf constant
k_t	Armature constant
v_b	Back emf voltage
x'	current x position of the WMR
y'	current y position of the WMR
δ_M	Degree of maneuverability
δ_m	Degree of mobility

δ_s	Degree of steerability
θ'	current orientation of the WMR
J	Inertial load
L	Inductance
N	total encoder count per revolution
R	Resistance
e	Error between actual output and desired output
t	Time or instantaneous time
u	Output
x	x coordinate of the WMR position
y	y coordinate of the WMR position
θ	orientation of the WMR
μ	Population mean
τ	Variable of integration, values from time 0 to the present t
ω	Angular velocity

LIST OF ABBREVIATIONS

3D	Three-Dimensional
AC-to-DC	Alternating Current to Direct Current
AGV	Automated Guided Vehicle
ANOVA	Analysis of Variance
BOM	Bill of Materials
DC	Direct Current
DOF	Degrees of Freedom
DDD	Dual Differential Drive
DMA	Decision Making Algorithm
emf	Electromotive Force
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
IC	Integrated Circuit
ICR	Instantaneous Center of Rotation
ICSP	In Circuit Serial Programming
IDE	Integrated Development Environment
PID	Proportional-Integral-Derivative
PLX-DAQ	Parallax Data Acquisition Tool
PWM	Pulse-Width Modulation
SLAM	Simultaneous Localization and Mapping
SMPA	Sense-Model-Plan-Act
TOF	Time-of-Flight
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus

WMR	Wheeled Mobile Robot

PEMBANGUNAN PENGAWAL LOGIK KABUR PID LATA BAGI ROBOT MUDAH ALIH MENGIKUT DINDING

ABSTRAK

Kajian ini membentangkan pembangunan mandiri sebuah sistem robot mudah alih beroda (WMR) dalaman dalam menyelesaikan masalah maze. Masalah maze diandaikan sebagai satu pemudahan kepada persekitaran untuk WMRs untuk digunakan dalam kehidupan harian sebagai kenderaan panduan automatik, seperti kenderaan pengangkutan dalam sebuah kilang. Pada masa kini, terdapat banyak pengawal dan algoritma yang dicadangkan untuk isu kawalan navigasi. Walau bagaimanapun, tiada reka bina gabungan yang sempurna dalam isu ini. Pergerakan sebuah WMR dihasilkan oleh motor. Namun, ia adalah sukar untuk mengawal dan meramalkan kelajuan motor. Kajian ini memberi tumpuan kepada pembangunan pengawal Berkadar, Kamiran dan Kebezaan (PID) lata untuk mengawal kelajuan motor dan Logik Kabur (FL) sebagai algoritma pembuat keputusan dalam mengikut dinding. Input untuk WMR adalah bacaan daripada pencari julat ultrasonik dan pengekod putaran. Unit pemprosesan pusat untuk WMR adalah Arduino Mega 2560. Hasil analisis statistik daripada *analisis varians faktor tunggal* pada pencari julat telah membuktikan bahawa semua penderia akan memberi bacaan yang sama dan konsisten jika semua penderia mengesan pada jarak dan hala tuju yang sama. Langkah yang dikira daripada pengekod putaran merupakan input sebenar untuk pengawal PID lata manakala input yang diingini pengawal adalah langkah kiraan yang dikehendaki. Keputusan menunjukkan bahawa pengawal PID lata telah menjanjikan prestasi yang baik, dengan 1.1% ralat dalam mengawal motor untuk mencapai kelajuan yang dikehendaki. Selepas bacaan daripada pencari julat direkodkan, bacaan-bacaan ini diproses oleh FL untuk menentukan hala tuju yang harus dituju WMR. Seterusnya,

kelajuan kedua-dua motor di sebelah kiri dan kanan yang dikehendaki juga ditentukan dengan sewajarnya. Berdasarkan keputusan yang dipaparkan, ia dapat disimpulkan bahawa FL dapat berfungsi dengan baik dalam mengawal pergerakan WMR, dengan kejayaan yang berulang. Kesimpulan, sistem yang dibentangkan dalam tesis ini menjanjikan kejayaan dalam sistem pengawal WMR dalam mengikuti dinding. Sistem ini boleh diperbaiki dan dibangunkan dengan lebih ke hadapan untuk penggunaan di dalam aplikasi kehidupan harian yang lain.

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ABSTRACT

This study presents an indoor self-developed differential wheeled mobile robot (WMR) system in encountering the maze solving problem. The maze problem is assumed as a simplification of the environment for the WMRs to be applied as a real-life automated guide vehicles application, such as a transporting vehicle in a factory. Nowadays, there are many controllers and algorithms being proposed for the issue of navigation control. However, there is no unified and perfect architecture in this issue. The movement of a WMR is provided by the motors, however, it is hard to control and predict the motors' speed. The study focuses on the development of cascade Proportional, Integration, and Derivation (PID) controller to control the motors' speed and Fuzzy Logic (FL) as the decision making algorithm in wall-following. The inputs of the WMR are readings from ultrasonic range finders and rotary encoders. The central processing unit of the WMR is an Arduino Mega 2560. The statistical analysis, single factor analysis of variance on the range finders proved that all of the sensors will provide the same and consistent readings if they are sensing at the same distance and same direction. The step counts from the motors' rotary encoders are the actual inputs for the cascade PID controllers, while the desired inputs for the controllers are the desired step counts. The results show that the cascade PID controllers promise a good performance with 1.1% of error in controlling the motors to reach the desired speed. After the readings from the range finders are recorded, they are processed by the FL to decide where the direction of the WMR should be heading to and then the speed of both left and right motor are also determined accordingly. Through the results illustrated, it can be concluded that the FL is working fine in controlling the

movements of the WMR with repeated success. In conclusion, the system presented in this thesis promises a success in differential WMR control system in wall-following and it can be improved and further developed to be applied in other real-life application.

CHAPTER 1

INTRODUCTION

1.1 Overview

As a cutting-edge high technology, robotics reflects wide range of interdisciplinary, which includes automatic control, artificial intelligent, mechanical engineering, computer science, and many more. Robotics also involves numerous research topics, such as architecture, motion control, path planning, environment mapping and positioning, and etc. Besides, robots are suitable in any kind of working environment, even in dangerous, dirty, tedious, and difficult situation.

Robot is an autonomous machine. The difference between robot and normal machinery is that robot is equipped with a certain level of intelligence such as sensing capability, planning capability, moving capability, and collaboration capability. Mobile robot emphasizes more on the robot's moving capability, thus facing more complex and uncertain environment compared to the static robot and it also causes the design of intelligent system to be more complicated.

As one of the important branches, intelligent mobile robot emphasizes on mobility. Intelligent mobile robot is a kind of mobile robot uses information from sensors to have a perception of the environment and the robot's own state, in order to achieve the objective of an autonomous goal-oriented motion in an environment with obstacle and to accomplish certain tasks. Intelligent mobile robot not only provides great help for the industry and our personal life, but it also can be used as a research platform to study the complicated intelligent behavior and explore the human mindset.

Navigation is needed for a mobile robot to realize the objective of an autonomous goal-oriented motion in an environment with obstacle. Mobile robot navigation usually has to solve three basic questions: “Where am I?”, “Where is the goal?”, and “How to get to the goal?”. The first and second questions need the sensors on the robot, such as speedometer, gyroscope, camera, laser range distance sensor, and etc., to sense and interpret the environment in order to provide some information to answer the questions.

After the information of its environment is extracted, the mobile robot tries to answer the third basic question: “How to get to the goal?”. To reach its destination, the decision making algorithm (DMA) comes into play. Through the sensors onboard, the mobile robot knows what option that it has when it reaches a junction and with the DMA, the mobile robot can decide its next step and then takes the most suitable action.

Since the introduction of maze solving competition using micromouse by the IEEE Spectrum Magazine in 1977 (Harrison, 2010), many similar maze solving robotic competitions have been held. Maze solving robot is a category of mobile robot that requires the mobile robot to answer all three basic questions frequently so that it will not become lost in the maze and reach the desired destination. Through the process of building a maze solving robot, the robot’s builder will have better understanding on how to answer the three basic questions. With the better understanding, the builder can easily extend his knowledge to build a mobile robot with localization or mapping or both localization and mapping technologies. Thus, the maze solving robot can be recognized as a stepping stone to build a more advanced mobile robot.

1.2 Problem Statements

In the mobile robot navigation control theories and methods, there are a lot of researches for the navigation control in a known environment that have been carried out and the results are satisfactory. There are also some researches for the navigation control in unknown environment and several methods have been proposed. However, there is still no unified and perfect architecture for unknown environment as there are still some critical theories and technical problems that have to be solved and improved, for example, lack of *a priori* knowledge and the uncertainty of an unknown environment (Wang & Liu, 2008). Only when the mobile robot knows its own location and the location of the obstacle precisely in the working environment, then it can move around safely and automatically.

The sensors on the mobile robot play important roles in obtaining the information of its surrounding. Therefore, inconsistent data from the sensor will mislead the mobile robot from its initial destination (Ganapathy, Soh, & Ng, 2009). Although the issue of inconsistent data can be solved by allowing 'settling down' period after performing every action to ensure the readings collected are not fluctuating, this is a time consuming process (Ganapathy, Soh, & Joe, 2009; Soh, Parasuraman, & Ganapathy, 2013). Furthermore, it is difficult to know the exact time needed for the sensor to 'settle' down. In addition, even from the same manufacturer, the settling time can also be different for the same model of sensors.

The difference between a wheeled mobile robot (WMR) and other categories of mobile robot is its mobility with the help of wheels attached on the motors on the robot's base. To power up a motor, it only needs a power source with positive and negative terminal. With the help of a motor driver, such as integrated circuit (IC)

L293D, rotation speed of the motor can be easily varied by input pulse-width modulation (PWM) to the driver (Agung, Huda, & Wijaya, 2014). Even though it is easy to drive a motor, it is hard to maintain a constant speed for a period of time. Furthermore, due to the internal resistance inside a motor is different for every motor, the motors' speed also varied for each motor even with the same PWM (Brian, 2014). These two issues have caused difficulties and complications if the motor is required to run in a specific speed. This situation is clearly seen if a differential drive wheel mobile robot is required to move in a straight path. Without the constant and synchronous speed between two motors, the mobile robot cannot move in a straight path (Correll, 2014; Goris, 2005).

There are several controller types proposed to control motor's speed such as proportional-integral-derivative (PID) controller, fuzzy logic controller (FLC), neural network, fuzzy-neural networks and fuzzy-genetic algorithm (Allaoua, Abderrahmani, Gasbaoui, & Nasri, 2008; Antar, Allu, & Ali, 2013). Conventional controllers such as PI and PID controllers are sensitive to variation in the motor parameters and load (Hammed & Mohamad, 2012). FLC can be used as motor controller but it has a major disadvantage which is insufficient analytical technique design with respect to the selection of the rules, the membership functions and the scaling factors (Allaoua et al., 2008). A fuzzy system can explain the knowledge it encodes but cannot learn or adapt its knowledge from training examples, while a neural network has the ability to learn and adaptation but cannot explain what it has learned (Khuntia, Mohanty, Panda, & Ardil, 2009). As a result, hybrid fuzzy-neural controllers have been developed to take the advantage of strong points of both (Antar et al., 2013; Hammed & Mohamad, 2012; Mustafa, Ali, Bashier, & Elrahman, 2013; Tipsuwan & Aiemchareon, 2005). These works control the speed of a DC motor with intelligent controllers, which are