THE PATH PLANNING CONTROL OF TWO WHEELED MOBILE ROBOT USING EXTENDED KALMAN FILTER TECHNIQUE

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DEDICATION

This report is devoted to my parents, who inspired me that the most ideal sort of knowledge to acquire is realizing it for the good of its own. It is additionally committed to my lovely wife, who instructed me that even the biggest undertaking can be achieved assuming it is done with extra efforts. Lastly, this report is dedicated to my son.

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ABSTRACT

The project proposes a model of path planning control for two-wheeled mobile robot using the Extended Kalman Filter (EKF) technique. The main objective of this work is to minimize the error in calculation for the robot's position, orientation, localization, and navigation. The results are compared to the past research using Linear Kalman Filter (LKF) technique. Due to the limitation of the LKF that is unable to handle non-linear dynamics measurement equations, makes the kinematics model of the robot is not accurate. The cause of uncertainty for the infinite precision of the distance between wheeled axes of the robot, noise from the sensor, and the slippage of the direction of motion in the perpendicular direction of the robot in the relative localization make it worse. This work is aimed to overcome the restraints of the path planning control of the robot by using a non-linear model with odometry and locomotion system using an optical encoder that can monitor the wheel position and speed. This is achieved by developing an estimator that recursively converges noise from sensor data with a model of the system dynamics of the robot. The distance between the robot and the desired landmark is set as input to EKF. To validate the accuracy of the proposed model, a simulation using MATLAB software is conducted. The initialization position is marked out at first, and the robot is programmed to navigate from point A to point B in a specific space. To verify the robot's position, prior knowledge of the environment is needed. The environment is set to be safe from obstacles therefore the robot doesn't have a behaviour of obstacle avoidance using external sensors. The results of the proposed model are expected to be achieved successfully where the robot can course itself according to the equation of motion that has been set at the initialization state as path planning to the desired destination. The EKF technique will be verified to be the best method for the localization and navigation of the robot with reliable estimation of position and orientation of the robot compared to the standard Kalman Filter.

ABSTRAK

Projek ini menawarkan sebuah model untuk kawalan perancangan laluan bagi robot dua roda mudah alih menggunakan teknik penapisan lanjutan Kalman (EKF). Objektif utama bagi usaha ini ialah untuk meminimumkan ralat dalam pengiraan posisi, oreintasi, lokaliti, dan navigasi bagi robot tersebut. Keputusan bagi projek ini dibandingkan dengan kajian-kajian lalu yang telah dibuat sebelum ini menggunakan teknik penapisan linear Kalman (LKF). Disebabkan oleh kekangan teknik LKF yang mana ianya tidak boleh digunakan dalam system tidak linear mengakibatkan model kinematik robot tersebut menjadi tidak tepat. Punca bagi permasalahan ini ialah ketidakpastian jarak antara paksi roda robot tersebut secara tepat, gangguan dari penderia dan pergelinciran arah tuju pergerakan robot tersebut. Kajian ini bertujuan untuk mengatasi isu-isu tersebut menggunakan sistem tidak linear. Perkara ini dapat dicapai dengan membangunkan satu penganggar yang bertumpu secara rekursif antara gangguan dari penderia dengan model sistem dinamik bagi robot tersebut. Jarak di antara robot tersebut dengan arah tuju yang diinginkan dijadikan sebagai input kepada algoritma EKF. Untuk mengesahkan ketepatan model yang ditawarkan, simulasi menggunakan perisian MATLAB perlu dijalankan. Posisi permulaan ditanda dan robot diprogram untuk bergerakan dari titik A ke titik B dalam ruang yang spesifik. Ruang tersebut ditetapkan agar ianya selamat tanpa sebarang halangan supaya robot tersebut tidak memerlukan penderia tambahan. Keputusan bagi model yang ditawarkan adalah dijangka untuk berjaya di mana root tersebut dapat bergerak secara sendiri menggunakan laluan yang telah diprogram kepada robot tersebut agar sampat ke destinasi yang dianggarkan. Teknik EKF adalah dijangka merupakan teknik terbaik bagi lokaliti dan navigasi robot berbanding LKF.

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LIST OF ABBREVIATIONS

BFSL	-	Best Fit Straight Line
DOF	-	Degree of Freedom
EKF	-	Extended Kalman Filter
FAQ	-	Frequently Ask Question
GA	-	Genetic Algorithm
GUI	-	Graphical User Interface
LQG	-	Linear Quadratic Gaussian
LQR	-	Linear Quadratic Regulator
NFOC	-	Nonlinear Freezing Optimal Control
PID	-	Proportional Integral Derivative
PSO	-	Particle Swarm Optimization
SOP	-	Standard Operation Procedure
SFLC	-	Same Fuzzy Logic Controller
TWMR	-	Two Wheeled Mobile Robot
UTM	-	Universiti Teknologi Malaysia

CHAPTER 1

INTRODUCTION

1.1 Research Background

Since the word ‘Robot’ is introduced by Karel Capek, a Czech writer in 1921, scientist and engineers realized it and transformed it to reality from imagination. From then, robot have been a part of human life to ease the daily tasks and upgrade the standard of living for mankind. From industrial robots where they usually have manipulator arms to perform specific tasks to mobile robots that also be used commercially, they are part of our norms nowadays. It is undoubtedly that robot can fulfil their programmed task more efficient in a way compared to human. Robot is faster, stronger, and durable. In business perspectives, owning robots and machines are adding to their assets. Since the 3rd industrial revolution i.e., the era of electronics, it is where the beginning of robot in many applications. There lies a thin line to differ an autonomous robot and an automated machine. An automated machine can perform simple tasks assigned to it. In contrast, an autonomous robot can accomplish multiple complex tasks at a same time and has the ability to decide action accordingly either reactively or deliberatively. In a simpler word, a robot can think logically like human.

Nowadays in 21st century where the era of information and internet of things, the term robot may also be referred to not only a physical robot but also a virtual robot which related to artificial intelligence. Machine learning algorithm is used for analysis and prediction is implemented in a virtual robot. For example, there is a robot that can predict the trends of trading stocks, robot that can entertain customer FAQs for certain products, and also robot that can have a dialog with human for example Apple’s Siri and many other examples of virtual robot. When we throwback several decades back, the same application mentioned before were done by involvement of a lot of people with SOPs and bureaucracies. Currently, robot is trustworthy to convey the tasks without wariness. In conclusion, robots have become noteworthiness in part of our daily life.

There are lots of behaviors of robots. It depends on either the robot is industrial robot or mobile robot. For mobile robot, stability and navigation are parts of the behaviors. In order for the mobile robot to be able to move from point A to point B, the robot itself must be stable enough before it can navigate to desired location. To put in an analogy, in order for a baby to walk from a starting point to and ending point, the baby ought to have the capability to stand with stable first before proceeding with the ability to walk with his/her two feet. In more advance application, the mobile robot also be able to avoid obstacle along the path of the navigation. Then obstacle avoidance is another set of mobile robot behavior. The more behavior a mobile robot possesses, the more complex and perfect the robot will be ideally. In practice, there is no such thing as perfect system per se. More and more work has been done by engineers in previous years in order to add new behavior to a mobile robot and to bring to perfection of the algorithm for the behavior.

In this project, there are two behaviors focused on the mobile robot i.e., stability and navigation. Because the robot is a two-wheeled mobile robot, of course the stability behavior must be there. When the stability behavior of the robot is attained, the next behavior of robot is navigation. The estimation for the wheeled mobile robot’s position with respect to external world is elementary to navigation behavior. The modelling of the current environment is essential. By that, the robot will have the ability to operate in the environment fluently. As for the stability of the robot, the modelling of the equation of motion of the robot is the fundamental. The crucial part of the stability of two-wheeled mobile robot is to balance the pitch angle of the robot so that the robot will not fall forward or backward. The accelerometer sensor is the key sensor to this behavior of stability. There are lots of algorithm developed for the behavior of mobile robot and will be discussed more in next chapter. There are gaps to be filled in the current implementation of the algorithm for both stability behavior and navigation behavior. In shorts, two wheeled mobile robot is a robotic application which required a complex control algorithm because it modelled from an inverted pendulum application. One example of a commercial two-wheeled mobile robot is Segway robot invented by Dean Kamen and his team in 2001. Since then, many other self-balancing robot applications is made by this remarkable inspiration.

1.2 Problem Statement

Two-wheeled mobile robot (TWMR) is a hot research area in the past 5 years for implementation of control algorithm in order to balance the upright position of the robot in static as well as while moving condition. Another aspect to be look into is the path planning of the TWMR. This is one of the fundamental operations where the navigation of the robot is guided so that the robot will reach desired destination from trajectory planning via sequence of action. TWMR is an unstable system by default which implement the concept of inverted pendulum. Because of that instability factor, many algorithms were designed, applied, and tested for the benefit of control the stability and path planning of the TWMR. However, there were gaps in both the stability control and the path planning of the TWMR that can be filled in order to improve the current studies and practices.

For the stability control of TWMR, there are three types of linear control technique which are Proportional Integral Derivatives (PID) control, Linear Quadratic Regulator (LQR) control and Fuzzy Logic control. All these three types of controllers have drawbacks. Since there are linear controllers, there are impractical to apply in real physical environment compared to simulation environment. This is due to the fact that in real application, perturbation and disturbances are inevitable and it is hard to predict the consistency of the noises. In contrast, simulation environment has deterministic and specific noise that can be introduced to the system modelling. Furthermore, studies had shown that linear controllers mentioned have limited operation range of the pitch angle of TWMR. The pan movement along the pitch axis of the TWMR is bounded to smaller range of angle compared to the nonlinear control method which might have wider operating pitch angle. In summary, it is obvious that the gaps that need to be filled are the stability control method which results in impracticality in physical environment of the robot and poor operating range of pitch angle of the pan movement of the robot. Because of that, this research has been focused to infuse the gap with suitable control method.

As for the path planning algorithm of TWMR, the research has been conducted since 1960. At that time, only wheeled mobile robot were used. After year 2001, the first TWMR called JOE were introduced by Laboratory of Industrial Electronics Swiss Federal Institute of Technology Lausanne. There were two type of path planning technique in the past ten years research i.e., classical, and intelligent path planning. Both classical path planning as well as intelligent path planning has gaps that can be ample. For classical path planning method, the problems are that the result was poor performances, and the robot will be entrapped in local optima due to NP-hard complete of nature where at least as hard as the hardest NP-problem. As for the problem of intelligent path planning, the method will decrease the accuracy of the pat trajectory which eventually will result in non-optimal path due to discretization and pre-processing. Researchers are still improving the path planning methods in order to achieve robust algorithm. This research is aimed to fill the gap regarding current implementation of path planning algorithm.

1.3 Research Goal

The aim of the research is to improve the control stability and path planning of TWMR to more stable and robust within the period of project timeline. In order to reach this goal, several objectives are required to achieve.

1.3.1 Research Objectives

The objectives of the research are:

(a) To implement a PID controller to stabilization of TWMR.

(b) To design a path planning control algorithm using Extended Kalman Filter Technique (EKF).

(c) To validate the performance of path planning algorithm of Extended Kalman Filter using Pure Pursuit controller.

1.4 Research Scopes

The scope of the research are as follows:

i. The experiment is conducted in a controlled and safe environment where all the perturbations and disturbances were manipulated variables.

ii. The trajectory path of the TWMR is clear from any obstacle – No obstacle avoidance behaviour.

iii. The simulation of the experiment is conducted using MATLAB software toolbox.

1.5 Summary

The research is organized as follows. Chapter 1 introduces the background of the project, the gaps within the past 5 years research related with the stability and path planning of TWMR. The research aim and objectives are clearly stated as well as the scope of the research. In chapter 2, the literature review related to the research topic will be discussed. The control method of stability of TWMR and path planning methods utilized by recent studies will be examined and a section for critical review of selected topic will be elaborated. In chapter 3, the research methodology for the project will be explained thoroughly. The Gantt chart, project milestone and research flowchart will be discussed methodically. Chapter 4 discusses the expected result and discussion. The preliminary result of experiment will be plotted and tabulated regarding the stability and path planning of TWMR. In chapter 5, the conclusion and recommendation for future work will be discussed and how the project contribute to knowledge and reflect with the objectives of the research. Lastly, the appendix that list the MATLAB source code will be written and the reference of the literature is indexed.

REFERENCES

Aouf, A., Boussaid, L., & Sakly, A. (2019). Same Fuzzy Logic Controller for Two-Wheeled Mobile Robot Navigation in Strange Environments. *Journal of Robotics*, *2019*. https://doi.org/10.1155/2019/2465219

Chang, Y. C., & Yamamoto, Y. (2008). On-line path planning strategy integrated with collision and dead-lock avoidance schemes for wheeled mobile robot in indoor environments. *Industrial Robot*, *35*(5), 421–434. https://doi.org/10.1108/01439910810893590

Chang, Y. C., & Yamamoto, Y. (2009). Path planning of wheeled mobile robot with simultaneous free space locating capability. *Intelligent Service Robotics*, *2*(1), 9–22. https://doi.org/10.1007/s11370-008-0033-4

Dirik, M., Kocamaz, A. F., & Castillo, O. (2020). Global Path Planning and Path-Following for Wheeled Mobile Robot Using a Novel Control Structure Based on a Vision Sensor. *International Journal of Fuzzy Systems*, *22*(6), 1880–1891. https://doi.org/10.1007/s40815-020-00888-9

Fantian, K., Youping, C., Jingming, X., Gang, Z., & Zude, Z. (2006). Mobile robot localization based on Extended Kalman Filter. *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, *2*(60474021), 9242–9246. https://doi.org/10.1109/WCICA.2006.1713789

Grasser, F., D’Arrigo, A., Colombi, S., & Rufer, A. C. (2002). JOE: A mobile, inverted pendulum. *IEEE Transactions on Industrial Electronics*, *49*(1), 107–114. https://doi.org/10.1109/41.982254

Haj Darwish, A., Joukhadar, A., & Kashkash, M. (2018). Using the Bees Algorithm for wheeled mobile robot path planning in an indoor dynamic environment. *Cogent Engineering*, *5*(1). https://doi.org/10.1080/23311916.2018.1426539

Iwendi, C., Alqarni, M. A., Anajemba, J. H., Alfakeeh, A. S., Zhang, Z., & Bashir, A. K. (2019). Robust Navigational Control of a Two-Wheeled Self-Balancing Robot in a Sensed Environment. *IEEE Access*, *7*, 82337–82348. https://doi.org/10.1109/ACCESS.2019.2923916

Kokkrathoke, S., & Xu, X. (2021). Implementation of Nonlinear Optimal Control of Two-wheel Robot with Extended Kalman Filter. *2021 IEEE International*

Conference on Automatic Control and Intelligent Systems, I2CACIS 2021 - Proceedings, *June*, 19–25. https://doi.org/10.1109/I2CACIS52118.2021.9495859

Manasee, Sudheesh, P., & Jayakumar, M. (2016). Indoor robot localisation using Kalman filter. *Indian Journal of Science and Technology*, *9*(38). https://doi.org/10.17485/ijst/2016/v9i38/101945

Martins, R. S., & Nunes, F. (2017). Control system for a self-balancing robot. *Proceedings of 2017 4th Experiment at International Conference: Online Experimentation, Exp.at 2017*, *Project I*, 297–302. https://doi.org/10.1109/EXPAT.2017.7984388

Philippart, V. Y., Snel, K. O., De Waal, A. M., Jeedella, J. S. Y., & Najafi, E. (2019). Model-Based Design for a Self-Balancing Robot using the Arduino Micro-Controller Board. *2019 23rd International Conference on Mechatronics Technology, ICMT 2019*, 1–6. https://doi.org/10.1109/ICMECT.2019.8932131

Prakash, K., & Thomas, K. (2017). Study of controllers for a two wheeled self-balancing robot. *2016 International Conference on Next Generation Intelligent Systems, ICNGIS 2016*. https://doi.org/10.1109/ICNGIS.2016.7854009

Prasetio, B. H. (2016). Ensemble Kalman filter and PID controller implementation on self balancing robot. *Proceedings - 2015 International Electronics Symposium: Emerging Technology in Electronic and Information, IES 2015*, 105–109. https://doi.org/10.1109/ELECSYM.2015.7380823

Shrotriya, A. (2010). *ROBOT PATH PLANNING AND TRACKING OF A MOVING TARGET USING KALMAN FILTER* (Issue July).

Shubhank Sondhia, Ranjith Pillai. R, Sharat S. Hegde, S. C. & V. V. (2017). Development of Self Balancing Robot With PID Control. *International Journal of Robotics Research and Development (IJRRD*, *7*(1), 1–6. http://www.tjprc.org/view-archives.php

Vidhyaprakash, D., Karthikeyan, S., Periyasamy, M., Kalaimurugan, K., & Navaneethasanthakumar, S. (2019). Positioning of two-wheeled mobile robot to control wheelslip by using the wheel rotate planning technique. *Journal of Scientific and Industrial Research*, *78*(12), 879–884.

Wu, W., Chen, H., & Woo, P. Y. (2000). Time optimal path planning for a wheeled mobile robot. *Journal of Robotic Systems*, *17*(11), 585–591. https://doi.org/10.1002/1097-4563(200011)17:11<585::AID-ROB1>3.0.CO;2-7