ADAPTIVE SUP-PID-SMC CONTROLLER FOR UNMANNED TRACKED VEHICLE (UTV) BASED ON PATH FOLLOWING CONTROL

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ABSTRACT

Tracked vehicle can be referred as a type of vehicle that have two sets of metal/rubber track on each side of the vehicle instead of wheels. It is a well-known system used widely in military, agriculture and constructions to complete a difficult tasks and mission. Due to importance of tracked vehicle, a lot of researchers have been studying it in many aspects such as power system, suspension system and its prospect in autonomous vehicle technology. The latter demands the development of the path following controller that allows the vehicle to follow a specified path autonomously. However, the parameter of path following controller needs continuous tuning for each set of predefined paths on various tracked vehicle speed. In order to overcome this weakness, an adaptive mechanism is proposed to the modified Sup's controller so that the controller's parameters will be adjusted automatically based on predefined path and driving condition. The work presented in this thesis focuses on the design an adaptive path following control of fuzzy supervisory system and evaluate the proposed path following controller using Hardware-In-Loop Simulations (HILS). In development stage, the proposed adaptive path following controller was compared against the original controller in terms of tracked vehicle global coordinates and its lateral error. The results show that by applying adaptive controller, the tracked vehicle can follow the desired path with up to 41% of improvement in terms of lateral error. Then, for the validation through HILS, the result shown that the tracked vehicle was able to follow the predefined path with the actual actuation by the tracked vehicle motor with the control signals generated by the proposed controller.

ABSTRAK

Kenderaan penjejak dapat disebut sebagai sejenis kenderaan yang mempunyai dua set trek logam/getah pada setiap sisi kenderaan menggantikan roda. Ia adalah sistem yang banyak digunakan dalam aplikasi ketenteraan, pertanian dan pembinaan untuk menyelesaikan tugasan dan misi. Oleh kerana kepentingan kenderaan penjejak ini, banyak penyelidik mempelajarinya dari pelbagai aspek seperti sistem kuasa, sistem suspensi dan prospek terhadap teknologi autonomi kenderaan. Mutakhir ini menuntut kepada perkembangan kawalan laluan pengikut yang membenarkan kenderaan mengikut jalan tertentu secara autonomi. Walau bagaimanapun, parameter kawalan laluan pengikut memerlukan penalaan berterusan untuk setiap set jalan pada pelbagai kelajuan kenderaan penjejak. Bagi mengatasi kelemahan ini, mekanisma adaptif telah dicadangkan kepada kawalan ubahsuai Sup agar parameter kawalan boleh diubah secara automatik berdasarkan laluan dan pemanduan yang telah ditetapkan. Kerja yang dibentangkan dalam tesis ini memfokuskan kepada mereka bentuk kawalan laluan adaptif berdasarkan system penyeliaan *Fuzzy* dan menilai kawalan laluan yang dicadangkan melalui *Hardware-In-Loop Simulations* (HILS). Pada peringkat pembangunan, kawalan yang dicadangkan dibandingkan dengan kawalan asli dari segi kordinat global kenderaan dan ralat lateral. Hasilnya menunjukkan dengan menggunakan kawalan adaptif, kenderaan penjejak dapat mengikuti laluan yang diinginkan dengan 41% penambahbaikan dari segi ralat lateral. Kemudian, untuk pengesahan melalui HILS, hasilnya menunjukkan bahawa kenderaan penjejak dapat mengikuti laluan yang telah ditentukan dengan penggerak motor kenderaan penjejak di mana kawalan *signal* dihasilkan oleh kawalan yang dicadang.

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The Examination Committee has met on **09th November 2021** to conduct the final examination of **Muhammad Akhimullah Bin Subari** on his degree thesis entitled **'Adaptive Sup-PID-SMC Controller for Unmanned Tracked Vehicle (UTV) Based on Path Following Control'**.

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LIST OF ABBREVIATIONS

UGV	Unmanned Ground Vehicle
USAR	Urban Search and Rescue
AGV	Autonomous Ground Vehicle
TGV	Teleoperated Ground Vehicle
LCA	Lane Centering Assist
BSM	Blind Spot Monitoring
ACC	Adaptive Cruise Control
HETVs	Hybrid Electric Track Vehicle
MTB	Multibody System
DOF	Degree of Freedom
STV	Seafloor Tracked Vehicle
PID	Proportional, Integration, Derivative controller
CMU	Carnegie Mellon University
UPNM	Universiti Pertahanan Nasional Malaysia
SMC	Sliding Mode Controller
BLDC	Brushless Direct Current Motor
PSO	Particle Swarm Optimization
ODE	Ordinary Differential Equation
FIS	Fuzzy Inference System
MF	Membership Function
HIL	Hardware-In-the-Loop
SUP	Sup Hong [1]

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Unmanned ground vehicle (UGV) is a well-known system used in military technology to complete a difficult task [1]. Normally, a UGV can be described as a vehicle that controls autonomously based on the targeted road and trajectory profiles without any human interactions [2,3]. There are several elements need to be considered in developing a UGV, such as the objective of development, its potential application (on road or an off road), and finally designing the path algorithm. Currently, UGV have been used for various applications such as in military application [4-6], mining application [7,8], and agriculture application [9,10]. Besides that, application of UGV also can be found in an operation during natural disasters for urban search and rescue (USAR) and as bomb disposal agent [11], Other than that, UGV also have been used for humanitarian efforts and emergency assists such as providing necessities of food, water and first aid to rural, hard to reach regions [12].

In UGV, one of the most familiar vehicle types that have been used on an off-road terrain is known as tracked vehicle. Tracked vehicle is a class of high mobility vehicle using a set of tracked wheel for maneuverability which mostly used in heavy terrain in order to access difficult environments [13]. It has the capability to operate in this condition due to larger contact area between the track and road surfaces, and is able to provide a better traction force for the stability during maneuvering [14]. It is widely used for military purpose such as to carry equipment, surveillance and enhancing the combat efficiency [15,16].

Autonomous ground vehicle (AGV) and teleoperated ground vehicle (TGV) can be referred as a big subset under UGV category. TGV can be described as a working mechanism using a machine or robot which is remotely control the vehicle from a distance. Meanwhile, AGV can be defined as an intelligent vehicle that have the capability to maneuver and navigate itself based on the specific task given. Carnegie Mellon University (CMU) researchers in 1980s, were the first group that have been successfully developed autonomous ground vehicle [17]. Due to this successful development, it has ignited researchers to further explore on AGV capabilities [18,19] which resulted the SAE-J3016 [20] to outline the automated vehicle system in several level as listed below.

- **Level 0: No Automation** – Vehicle control fully depend on human operator and automated system may issue warnings.

- **Level 1: Driver Assistance** – Several systems were introduced in order to assist the driver automatically such as Lane Centering Assist (LCA), Blind Spot Monitoring (BSM) and Adaptive Cruise Control (ACC).

- **Level 2: Partial Automation** – The automated vehicle system can accelerate, brake and steer. However, it can be deactivated once the driver took an action.

- **Level 3: Conditional Automation** – The vehicle can be maneuvered by autopilot in a limited environment.

- **Level 4: High Automation** – The automated vehicle system can be maneuvered autonomously in various driving condition when the driver enables it. During the process, driver attention is not required.

- **Level 5: Full Automation** – The automated vehicle system can be maneuvered autonomously in various driving condition without any driver input.

1.2 Problem Statement

Tracked vehicle was developed for its flexibility and mobility to maneuver on various driving conditions. It is commonly driven by human during battlefield and USAR missions to complete the task given. This situation will directly expose the life of person in charge in danger since they will become one of the targets by their enemies. The person in charge might severely injured or risking their life while driving the tracked vehicle. Hence, a non-direct involvement of people in conducting the tracked vehicle need to be developed as a solution to overcome this problem which known as autonomous tracked vehicle. Here, one of the important aspects in autonomous tracked vehicle is the path following control. This path following control will allow the vehicle to follow a predefined path or trajectory in lateral and longitudinal directions.

In this study, a geometric/kinematic type of controller is chosen for the path following control where it bargains simple configuration and have various application [21]. However, this type of controller had several weaknesses such as difficulties to control sharp cornering and needs continuous tuning of its control parameter for each set of predefined path on various tracked vehicle speed [22,23]. Therefore, in order to overcome this weakness, an improvement is proposed in this study by adding an adaptive algorithm to the existing geometric/kinematic controllers so that the controller’s parameters will be adjusted automatically based on predefined path and driving condition.

1.3 Objective of the Research

The objectives of this research work are:

a) Develop tracked vehicle model and to validate its lateral and longitudinal dynamic characteristics.

b) Design an adaptive path following control of fuzzy supervisory system by modified Sup’s controller with PID and SMC controller for tracked vehicle.

c) Evaluate the proposed path following control using Hardware-In-Loop Simulation for tracked vehicle.

1.4 Scope of the Research

The scope of this study can be defined as follows:

a) The tracked vehicle model is developed to observe the vehicle maneuvering in local and global coordinates.

b) The parameters of tracked vehicle model are obtained from the real tracked vehicle developed at Automotive Laboratory, Universiti Pertahanan Nasional Malaysia.

c) The tracked vehicle electric motor is developed using a non-parametric approach that will act as a power unit to the vehicle.

d) Path following algorithm and controller is developed to maneuver the tracked vehicle autonomously to follow the predefined path.

e) The predefined path chosen are straight line path and hook path as the tracked vehicle tend to experience this kind of driving behavior in real situation.

f) The performance of path following control is evaluated at the speed of 0.5 m/s and 2 m/s on straight path and hook path respectively.

1.5 Methodology

This research involves seven tasks that need to be carried out over a period of 36 months. For the first 12 months, the research focusing on the literature review and development of simulation model for tracked vehicle based on mathematical equation. For the 12 months, an experimental work such as design and fabrication of tracked vehicle. Other than that, the simulation model that has been developed in the first 12 months was validating with the real tracked vehicle. Then, 12 months on the design of control algorithm based on previous study with several modifications to adapt with tracked vehicle system. Here, the control algorithm proposed were optimized to obtain the optimum parameter value of the controller. Lastly, the controller will be implemented into the actual tracked vehicle and its performance will be analyzed based on the project objectives through Hardware-In-Loop Simulation. The flow chart of the work can be seen through Figure 1.1 meanwhile the seven tasks must be done in order to complete this work, which are:

a) **Literature review and patent search**

   Literature study and patent search on establish tracked vehicle model was conducted. The review was concentrated on the structure of control strategy used and its performance.

b) **Development of mathematical model of tracked vehicle**

   The mathematical model of tracked vehicle was derived which consist of five sub-models namely velocity model, local coordinate model, global coordinate model, turning radius model and dynamic model.

c) **Development and verification of tracked vehicle**

The simulation model of tracked vehicle developed in MATLAB/Simulink software was verified at the speed of 0.5 m/s and 2 m/s at turning radius of 10 m and 20 m respectively.

d) **Development of path following controller model for tracked vehicle during maneuvering**

The path following controller and its algorithm was developed by using a geometric/kinematic approach. This controller is then will undergo an improvement by introducing an adaptive approach to the existing path following controller.

e) **Implementation of path following controller into tracked vehicle**

Verified MATLAB/Simulink model of tracked vehicle was merged with a path following controller model.

f) **Performance evaluation of the path following control of the tracked vehicle**

The performance of the proposed path following controller for the tracked vehicle was analyzed in terms of its global coordinate and lateral error.

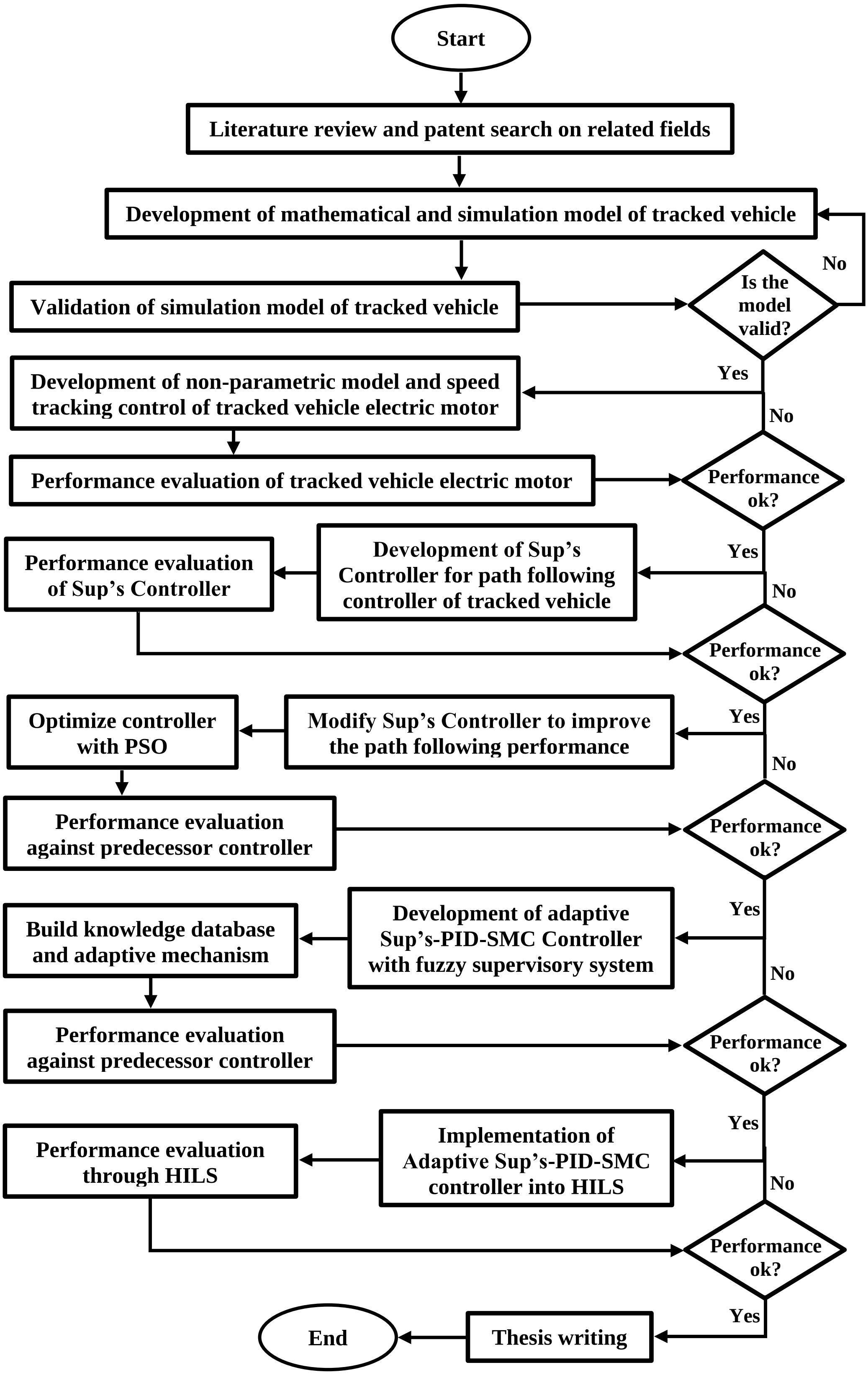

Figure 1.1 Flow Chart of research

1.6 Summary of Research Contributions

At the end of this study, the primary research contributions can be summarized as follows:

a) Mathematical modelling of tracked vehicle electric motor

A non-parametric model of tracked vehicle electric motor is developed by using a second order transfer function method. This mathematical model is then used to verify the speed tracking control for Hardware-In-Loop simulation. ***(Publication 2, List of Publication)***

b) Basic controller for path following of tracked vehicle

A basic path following controller of tracked vehicle namely Sup's controller was developed to automatically guide the tracked vehicle in following the desired path. Then, the basic controller was modified by adding Proportional-Integral-Derivative (PID) and Sliding Mode Controller (SMC) in order to improve the controller performance. However, the controller parameters need to be tuned where Particle Swarm Optimization (PSO) was chosen as the optimization tools. ***(Publication 3, Publication 4, List of Publication)***

c) Adaptive controller with fuzzy supervisory system for path following of tracked vehicle

The development of adaptive controller with fuzzy supervisory system. This adaptive controller is combined with the geometric/kinematic controllers used in this study for path following control. Thus, by combining it, the tracked vehicle can