SPEED TRACKING CONTROL OF IN-WHEEL MOTOR FOR SMALL SCALE TRACKED VEHICLE

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ABSTRACT

Generally, tracked vehicles are used on the ground for rough terrain swamp and snow field that a wheeled vehicle cannot go through. In this study, the basic control structure of the tracked vehicle system is developed based on a validated 3 degree-of-freedoms (DOF). The model is to control the turning radius capability of the vehicle in terms of vehicle speed, longitudinal, lateral and yaw motions. PID control is used to control the vehicle and optimized using Particle Swarm Optimization (PSO) algorithm. In order to verify the developed model, it is set to turn in 20 m radius with various speeds which are 10 km/h, 20 km/h and 30 km/h. The performance of PID control structure without optimization is compared to the performance of PID control structure optimized using PSO algorithm with respect to the desired travelling conditions. From the simulation results, it can be seen that the performance of optimized control structure is better compared with non-optimized control structure in terms of vehicle speed, longitudinal, lateral and yaw motions. From the simulation results, it also can be observed that the proposed tracked control structure with PID control is able to increase the performance of the tracked vehicle under medium speed at 20 km/h with maximum percentage of improvement 55%, 69%, 68% for longitudinal displacement, lateral displacement, and yaw angle respectively. Finally, tracked vehicle system with PID controller optimized by PSO is then tested experimentally through Hardware-in-the-Loop Simulation (HiLS) using an actuator namely in-wheel motor system. From the experimental results, a good agreement between HiLS and simulation is obtained with 14%, 19%, 18% and 9% in error reduction for longitudinal displacement, lateral displacement, and yaw motion respectively. It also indicates that the proposed control structure with PID controller optimized by PSO was proven to reduce the error by giving the desired speed and turning radius to maintain the desired direction of the vehicle during maneuvering.

ABSTRAK

Umumnya, kenderaan yang dilacak digunakan di lapangan untuk kawasan paya dan padang salji yang kasar bahawa kenderaan beroda tidak boleh dilalui. Salah satu aspek yang paling penting dalam kenderaan yang dikesan ialah sistem kawalannya untuk menentukan kecekapan dan kebolehgunaan kenderaan di atasnya akan memberi lebih banyak pembangunan sistem kawalan yang mencabar kerana lebih banyak halangan dari segi pelbagai rupa permukaan bumi dan juga halangan dalam penghantaran data tanpa wayar, seperti sebagai dinding, pelbagai bangunan dan keupayaan kelajuan terhad. Dalam kajian ini, struktur kawalan asas sistem kenderaan yang dikesan dikembangkan berdasarkan 3 darjah kebebasan (DOF) yang disahkan. Model ini adalah untuk mengawal keupayaan jejari pusingan kenderaan dari segi kelajuan kenderaan, gerakan memanjang, lekukan dan celah. Kawalan PID digunakan untuk mengawal kenderaan dan dioptimumkan menggunakan algoritma Pengoptimuman Swarm Partikel (PSO). Untuk mengesahkan model yang dibangunkan, ia ditetapkan untuk menghidupkan radius 20 m dengan pelbagai kelajuan 10 km/j, 20 km/j dan 30 km/ j. Prestasi struktur kawalan PID tanpa pengoptimuman dibandingkan dengan prestasi struktur kawalan PID dioptimumkan menggunakan algoritma PSO berkenaan dengan keadaan perjalanan yang dikehendaki. Dari hasil simulasi, dapat dilihat bahawa prestasi struktur kawalan yang dioptimumkan lebih baik berbanding dengan struktur kawalan yang tidak dioptimumkan dari segi kelajuan kenderaan, memanjang, gerak sisi dan gerakan. Dari hasil simulasi, juga dapat diperhatikan bahawa struktur kawalan yang dicadangkan dengan kawalan PID dapat meningkatkan kinerja kendaraan yang diperiksa di bawah kecepatan menengah pada 20 km / jam dengan peningkatan maksimum 55%, 69%, 68% untuk anjakan membujur, anjakan sisi, dan sudut curang. Akhir sekali, sistem kenderaan yang dikesan dengan pengawal PID yang dioptimumkan oleh PSO kemudiannya diuji secara percubaan melalui Simulasi Perkakasan-dalam-Loop (HiLS) menggunakan penggerak iaitu sistem motor roda. Dari hasil eksperimen, satu perjanjian yang baik antara HiLS dan simulasi diperoleh dengan 14%, 19%, 18% dan 9% dalam pengurangan ralat untuk anjakan membujur, anjakan sisi, dan gerakan yaw masing-masing. Ia juga menunjukkan bahawa struktur kawalan yang dicadangkan dengan pengawal PID yang dioptimumkan oleh PSO terbukti dapat mengurangkan kesilapan dengan memberikan kelajuan yang dikehendaki dan jejari pusing untuk mengekalkan hala yang diinginkan kenderaan semasa bergerak.

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APPROVAL

The Examination Committee has met on **21th JUNE 2019** to conduct the final examination of **MOHAMMAD HAKIM BIN AHMAD SIDI** on his degree thesis entitled '**SPEED TRACKING CONTROL OF IN-WHEEL MOTOR FOR SMALL SCALE TRACKED VEHICLE'.** The committee recommends that the student be awarded the degree of Master of Science (Mechanical Engineering).

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APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science (Mechanical Engineering). The members of the Supervisory Committee were as follows.

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DECLARATION OF THESIS

Student's full name	: Mohammad Hakim bin Ahmad Sidi
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Academic session	: March 2017 – March 2019

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LIST OF ABBREVIATION AND SYMBOLS

V_o	Velocity of the outer track
V	Vehicle speed
V_i	Velocity of the inner track
w_o	Angular velocity of the outer track
w_i	Angular velocity of the inner track
i_o	Longitudinal slips of the outer track
i_i	Longitudinal slips of the inner track
t	Time
B	Tread of the vehicle
K_s	Sprocket angular velocity ratio
R	Turning radius
F_o	Thrusts for the outer track
F_i	Thrusts for the inner track
R_o	Longitudinal motion resistance that acting at outer track

R_i	Longitudinal motion resistance that acting at inner track
CF_{long}	Component of centrifugal force in longitudinal direction
M_r	The moment of turning resistance of the vehicle
a_y	The centrifugal acceleration
l	Length of the tracked vehicle
μ_t	Coefficient of resistance in lateral direction
g	Gravitational force
μ_r	Coefficient of longitudinal resistance
A	Base area of the vehicle
c	Cohesion of the ground
ϕ	Angle of internal shearing of ground
DOF	Degrees of freedom
PID	Proportional, integral and derivative controller
RMS	Root mean square
SIL	Software-in-Loop

xPC	PC target
DOF	Degrees of freedom
G	PID controller
GA	Genetic algorithm
HiL	Hardware in the Loop

CHAPTER 1

INTRODUCTION

1.1 Introduction

On the battlefield, tracked vehicles (TVs) can perform many tasks such as detect threats,transport items, explore minefields, bomb disposal and search and rescue~~s~~ mission. For example~~s~~, Packbot from iRobot has been used in Iraq, Afghanistan and another battlefield by US military (Wong and Chiang 2001).

In the nuclear industry, a tracked vehicle can work in areas where the radiation levels are too high for human. Packbots were the first robots to enter the damaged Fukushima nuclear plant after the Tohoku earthquake and tsunami occurred in 2011. Another example is the *HERMIES* series of mobile robots from the Center for Engineering Systems Advanced Research (CESAR) at Oak Ridge National Laboratory (ORNL), where the robots were applied in radioactive environments (Brian 2004).

This study aims to design the tracked vehicle for searching and rescuing operation. This tracked vehicle also can perform activities in a disaster area or dangerous places Then, the tracked vehicle should not only move but to obtain information but also complete the tasks for manipulation.

At the end of this study , a new design of tracked vehicle is proposed and developed. Furthermore, one can expect a new understanding-on the unmanned vehicle control system and new development of expertise in national military technology beneficial to UPNM as a learning institution and also Malaysia's defense industry. In addition, this technology can be applied in the civilian industry of remote-controlled cars.

1.2 Background of the study

Vehicles driven by a track drive, as shown in Figure 1.1, are referred to as tracked vehicles or tracked equipment. In contrast to wheel drives, which generate forward thrust through a rotational motion, a track drive generates thrust via a translating motion. In theory, two different types of track drives can be categorized; known as flexible and rigid track belts. The rigid track belts are governed by steel linked tracks. The operational behavior of both types is different, so it is important to know how to select the correct belt type. The main criteria to identify a track belt type is the ratio between the road wheel spacing and the track link length.

The track driven vehicles can be equipped with or without a suspension system. If a suspension system is applied, it could be one suspension for the entire track frame or a separate suspension for each road wheel. The presence of a suspension system has an impact on the interaction between the track and the soil which depends on the number of parameters.

Figure 1.1 Example of tracked vehicles

Before looking at the different types of tracks and their behavior, the main components and general theory are introduced. The track drives are applied in a wide range of applications. Figure 1.2 shows a simple track where the essential components are the track frame, track belt assembly, sprocket, idler, road wheels and carrier rollers.

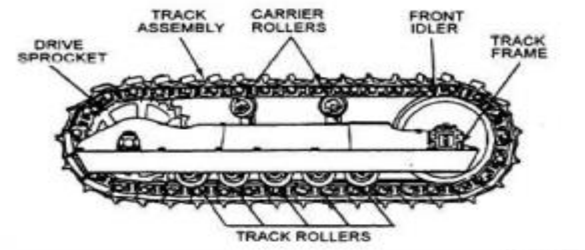

Figure 1.2 Main components of general track drive

The frame provides the track drive with structural strength–and most of the components are mounted on the frame. A track drive contains one or more sprocket, where it can be an actual gear or a custom build roller. The sprocket is connected to a drive train, where it provides the chain attached to the belt with the motion mechanism. The main function of the idler is to create and maintain sufficient pre-tension in the track. In general, the idler is a big roller, connected to the frame via a cylinder. The desired pre-tension can be set by operating the cylinder. The function of the track and carrier rollers is to support the track over the horizontal lengths between the sprocket and idler. In general, a track drive contains more track rollers then carrier rollers because the track rollers have to secure the contact area between track and soil.

1.3 Problem Statement

The importance of a tracked vehicle in various operations cannot be denied. The tracked vehicle has been used for USAR (Urban Search and Rescue) activities such as searching for victims, searching paths through the rubble that would be quicker than to excavate, inspecting the structural and detecting of the hazardous materials.

Recently, vehicle platforms are proposed in rough terrain and high-risk missions for law enforcement and military applications (e.g., Iraq for IEDs – Improvised Explosive Devices), hazardous site clean-ups, and planetary explorations (e.g., Mars Rover). These missions require a vehicle to perform difficult locomotion and dexterous manipulation tasks. During the operations, loss of traction, leading to entrapment-loss of stability,– and leading to flip-over, might occur, which resulting in mission failure.

In the civilian industries, tracked vehicles have been used thoroughly, such as airborne weather viewing and deep-sea explorations mainly to minimize human resources and to gain access to regions beyond human capabilities. In military applications, unmanned vehicles are essential to minimize the risk of compromising soldiers while gathering data during reconnaissance missions.

One of the most critical aspects in the tracked vehicles is the control system. The effectiveness of the control system will determine the efficiency and usability of the vehicles. The ground tracked vehicles will give more challengers in the control system development due to a lot of obstacles exist on the ground surface and also the obstacles in the wireless data communication such as walls, buildings and limited speed capability.

Therefore, this will put limitations on the communication range between the controller and the units.

This study will be considering several options in communication methods and choosing the best method for the final implementation. Also, several aspects of vehicle design will be studied and analyzed, by considering different surface terrains and the best structure will be chosen for the final product.

Currently, limited studies can be found on the implementation of the tracked vehicle in Malaysia. Due to the confidential nature of this field, specific studies are difficult to find. Therefore, this study proposes a study to further exploring the possibility of introducing this technology into the military industry in Malaysia.

1.4 Objectives and scopes of the study

The main aim of this study is to develop a control system for a small scale of the tracked vehicle. Several objectives have been planned to achieve along the process of completing this study.

1. To develop a mathematical model for the tracked vehicle in longitudinal and lateral directions.
2. To develop a small scale tracked vehicle using in-wheel motor system.
3. To develop a speed tracking control structure based on straight and turning radius trajectories.
4. To implement the developed speed tracking control structure via hardware-in-the-loop simulation (HiLS) technique.

Scope of the study:

1. The tracked vehicle is developed based on a three degree-of-freedom vehicle model.
2. Design and fabrication of a new prototype of tracked vehicle.
3. The parameters of the tracked vehicle model are obtained based on the new prototype tracked vehicle.
4. Evaluation of the actuator performance of the tracked vehicle is carried out using speed tracking control.
5. Develop the controller design for the tracked vehicle model.
6. Evaluate the performance of the tracked vehicle using HiLS-technique.

1.5 Methodology

In this study, a control system for a tracked vehicle is developed. The development process of the control structure will be carried out using simulation method and applied a MATLAB/SIMULINK software. After that, separate control sub-systems are then developed in parallel for a tracked vehicle. These systems are developed, simulated and optimized iteratively until the best performance can be achieved. Then, the integrated control systems will be implemented and tested on a tracked vehicle in UPNM via hardware-in-the-loop implementation as shown in Figure 1.3.

The stages involved in this study can be explained in detail as follows:

1) **Literature reviews on existing control structure for a tracked vehicle**

   The first stage focused on literature review regarding the classification of tracked vehicle system technology. Then, all background theories and basic principles of tracked vehicle models were studied. Modelling and analysis on the dynamics of the tracked vehicle model as well as the configuration of the control structure were carried out.

2) **Design and develop tracked vehicle prototype.**

   A prototype of small-scale tracked vehicle is developed using CAD software. The dimensions of each component for the tracked vehicle obtained from the developed mathematically model are used to fabricate the prototype of tracked vehicle.