MODELLING, SIMULATION AND TARGET TRACKING CONTROL OF TWO DEGREE OF FREEDOM (2 DOF) GUN TURRET SYSTEM

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Thesis submitted to the Center for Graduate Studies**, Universiti Pertahanan Nasional Malaysia,** in fulfillment of the requirement for the Degree of Master of Science (Mechanical Engineering)

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ABSTRACT

Weapon system is one of the most important components in an armored vehicle that plays a major role especially during enemy attacking missions. One of the important issues associated with a weapon system during firing is the system's inability to fire accurately towards an intended target due to the difficulty in controlling the elevation and platform angle in the gun system. The aim of this study is to develop an automatic target tracking system for a gun turret system. Therefore, a two degree-of-freedom gun turret simulator is developed which consists of the azimuth and elevation rotational motion. The automatic gun turret system is operated by a combination of software and hardware devices. A gun turret system involving a DC motor actuator is modeled mathematically and simulated within MATLAB/Simulink. The overall tracking system consists of target detection and target tracking elements. First, target detection module is developed using a motion detection method based on image processing technique. A control structure for the target tracking of the gun turret is proposed in this study, consisting of an outer and inner feedback loops. There are two types of controllers considered for the outer loop controller, namely Proportional Integral Derivative (PID) and Sliding Mode Control (SMC) controller, with the latter was found to be a more superior choice. The SMC controller is then further optimized using an optimization algorithm, Particle Swarm Optimization (PSO). Each controller strategy is evaluated in terms of its target tracking performance. The PSO-tuned SMC controller is proven to be the most suitable controller for this system due to the better performance results for tracking the target accurately compared to the PID and untuned SMC controllers. In order to validate the control strategy on the actual gun turret simulator, a hardware-in-the-loop (HiL) simulation is carried out. In conclusion, the proposed automatic gun turret system is able to detect and track targets in both static and moving positions which is proven from the experimental results.

ABSTRAK

Sistem persenjataan adalah salah satu komponen yang paling penting dalam sebuah kenderaan perisai, yang mana ianya memainkan peranan penting terutamanya semasa misi menyerang musuh. Salah satu isu penting yang berkaitan dengan sistem senjata adalah semasa menembak, sistem tersebut tidak berupaya untuk menembak tepat ke arah sasaran yang dikehendaki akibat daripada kesukaran untuk mengawal sudut pada sistem pengangkat dan pelantar yang terdapat dalam sistem senjata. Matlamat kajian ini adalah untuk menghasilkan sistem mengesan sasaran secara automatik bagi sistem senjata turet. Oleh itu, simulator senjata turret yang mempunyai dua darjah kebebasan dan dilengkapi dengan mekanisme azimut dan pengangkat telah direkabentuk. Sistem senjata turet automatik dikendalikan dengan menggunakan gabungan peranti perisian dan perkakasan. Model senjata turet yang melibatkan model motor *DC* dibangunkan secara matematik dan disimulasikan dalam *MATLAB/Simulink*. Struktur kawalan untuk mengesan sasaran bagi senjata turet telah dicadangkan dalam kajian ini, yang terdiri daripada maklum balas gelung luar dan dalam. Dalam kajian ini, terdapat dua jenis pengawal yang dipertimbangkan untuk pengawal gelung luar, iaitu pengawal *Proportional Integral Derivative (PID)* dan pengawal *Sliding Mode Control (SMC)* yang mana pengawal SMC telah terbukti sebagai pilihan yang lebih tepat. Seterusnya, Pengawal *SMC* dioptimumkan dengan menggunakan algoritma pengoptimuman, *Particle Swarm Optimization (PSO)*. Setiap strategi pengawal dinilai dari segi prestasi pengesanan sasaran. Pengawal *SMC* yang ditala oleh *PSO* telah terbukti menjadi pengawal yang paling sesuai untuk sistem ini kerana keputusan prestasinya lebih baik untuk mengesan sasaran dengan tepat berbanding pengawal *PID* dan pengawal SMC yang tidak ditala. Dalam usaha untuk mengesahkan strategi kawalan pada simulator senjata turet yang sebenar, simulasi *hardware-in-the-loop (HiL)* telah dijalankan. Kesimpulannya, sistem senjata turet automatik yang dicadangkan mampu mengesan dan menjejaki sasaran di kedua-dua posisi statik dan bergerak yang terbukti dari hasil eksperimen.

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APPROVAL

I certify that an Examination Committee has met on **27TH APRIL 2017** to conduct the final examination of **ABDUL MUHAIMIN BIN IDRIS** on his degree thesis entitled **'MODELLING, SIMULATION AND TARGET TRACKING CONTROL OF TWO DEGREE OF FREEDOM (2 DOF) GUN TURRET SYSTEM'**. The committee recommends that the student be awarded the degree of Master of Science (Mechanical Engineering).

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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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

2D	Two Dimensional
ADRC	Active Disturbance Rejection Control
AR	Auto-regressive
DC motor	Direct Current Motor
DOF	Degree of Freedom
EP	Evolutionary Programming
FOPID	Fractional order Proportional Integral Derivative
FoSMC	Fractional order Sliding Mode Control
GA	Genetic Algorithm
HDS	Human Detection for Surveillance
HIL	Hardware in the Loop
MPC	Model Predictive Control
PID	Proportional Integral Derivative
PSO	Particle Swarm Optimization
RGB	Red Green Blue
SMC	Sliding Mode Control
UAV	Unmanned Aerial Vehicle
xPC	Target PC
σ	Sliding Surface Design
p_{best}	Particle Best

g_{best}	Global Best
$E_{k\alpha}$	kinetic energies for lateral motion
$E_{k\theta}$	kinetic energies for vertical motion
E_p	Potential energy
I_g	Moment of Inertia for Gun
I_p	Moment of Inertia for Platfrom
I_α	Total of the moment inertia for lateral motion
R_p	Radius of Inertia for Platform
k_t	Torque constant
k_v	Electromotive-force constant
l_2	Length from the rotation axis to the centre of gravity of gun
m_g	Mass of Gun
m_p	Platform Mass
t_D	Dead Time
t_r	Rise Time
v_b	Electromotive-force
α_a	Alpha Actual
α_d	Alpha Desired
θ_a	Theta Actual
θ_d	Theta Desired
A	Cross Section of Gun Barrel
C	Constant Value

C	weights trading off the impact of the local best solutions
L	Inductance
R	Distance between z-axis and the centre of gun for lateral motion
R circuit	Resistance
U	Control input
$U[0,1]$	samples of uniform random distribution from 0 to 1
i	Motor Current
l	Length of gun
s	weights trading off the impact of the global best solutions
t	relative time index
w	weight of inertia impact for each particle
α	Elevation angle
ε	Error rate
θ	Azimuth angle
ρ	Material Density of gun
ω	Angular Velocity

CHAPTER 1

INTRODUCTION

1.1 Introduction

An armored vehicle is used in military application as a ground combat vehicle equipped with weapons which is operated either mechanically or electronically. Most of recent advance system and active protection system has been implemented in the armored vehicle to provide protection for the soldiers during battle. However, the improvement in the current technologies has increased the performance of the armored vehicle especially in terms of stability and safety system of the armored vehicle (Ahmadian, 2001). One of the major active systems which have been improved in the armored vehicle is the weapon platform system. Weapon platform, on the other hand, is known as a firing mechanism to attack towards the enemy which is mounted on top of the armored vehicle as shown in Figure 1.1. The weapon platform has the ability to rotate 360 degrees in azimuth angle as well as increase up to 30 degrees in bearing direction. Besides, the weapon platform also used as projectile-firing mechanism which gives the ability to fire in various directions. (Ahmadian and Poynor, 2001).

Generally, the weapon platform consists of a gun turret which is used to launch a missile towards the target point. The weapon platform is divided into two mechanisms, which are gun turret and weapon base. Both mechanisms are actuated using hydraulic system where in azimuth plane is used for weapon base meanwhile elevation plane for gun turret. However, the hydraulic systems have drawbacks to track a moving target due to the springing effect on hydraulic oil properties which causes lag in the system and reduce the firing accuracy. Therefore, many researchers have improved their weapon systems by introducing an electrical system with control algorithm to replace the hydraulic system. In the modern army technology, mechanical, electric and electronic systems are combined to improve the performance of gun turret system. The combinations of mechanical, electric and electronic system are able to provide fast response for a gun turret in tracking the moving target.

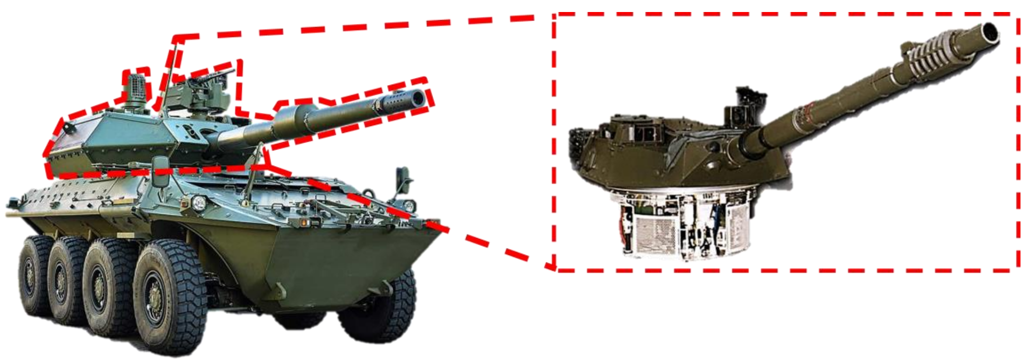


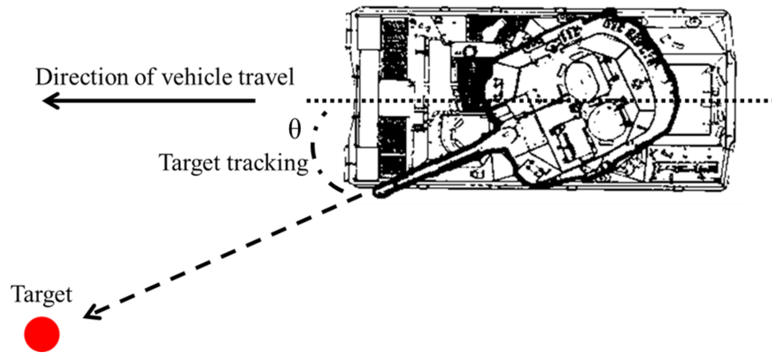
Figure 1.1 Conventional gun turret system on the armoured vehicle

1.2 Problem Statement

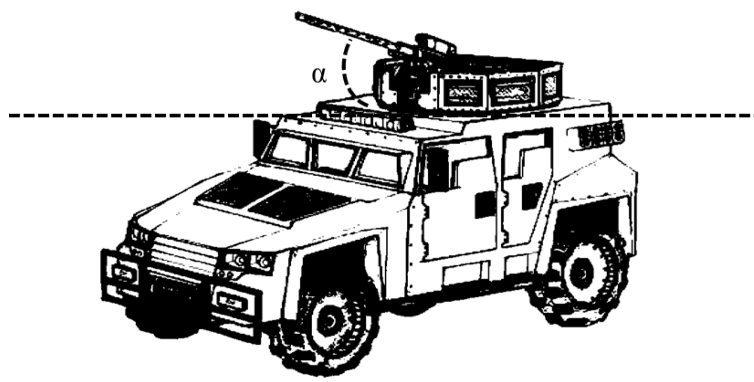
The major problem concerned in armored vehicles is an inefficient target tracking system of the conventional gun turret. This problem has occurred due to the time delay occurred in hydraulic system in order to track the target while the vehicle is in dynamic condition. The shortcoming of the hydraulic system which requires more time to track the target has affected the accuracy in target locking. Commonly, soldiers required to rotate the gun turret manually using hydraulic mechanism in order to track the desired target. However, due to the time delay on tracking process, the armoured vehicle expose to an extreme danger in the battle ground. Therefore, an automated gun turret trajectory is proposed in this study to enhance the performance of firing accuracy of the gun turret. This system is proposed to aim the desired target accurately and more efficiently in tracking a moving target. In order to increase firing accuracy performance, a camera sensor is utilized as the feedback actual trajectory. In this study, a control strategy is developed for the actuator of the gun turret to achieve optimum performance to track the moving target.

1.3 Background of Research

Automated gun turret trajectory is a modern army technology to aim towards the enemy direction either in stationary or moving condition. To track the target, a sensor is used to follow the target and give feedback response to an electric motor. The electric motor actuated the weapon base and gun turret in azimuth and elevation plane. The motor can achieve optimum performance by rotating the weapon base and elevating the gun turret using a suitable control algorithm. Hence, the usage of an electric motor to control the weapon platform reduced the requirement of hydraulic system. Figure 1.2 shows that the rotational angle of gun turret system on armoured vehicle.



(a)



(b)

Figure 1.2 (a) Azimuth and (b) elevation angle of the armoured vehicle gun turret system

The first automated gun turret target tracking in battleships was in the 19th century and played a vital role in mechanical gunnery in World War II (Getting, 1990). These automated gun turret target tracking systems were electro-mechanical gun aiming computers fitted in armoured vehicle. These analog systems were relatively cumbersome and slow, which were unsuitable for armored vehicles because due to the lack of agile systems, the gunner had to rely on his sight reticle, skills and expertise with numerous drawbacks (Higgins *et al*., 1982; Jia *et al*., 2011; Gao *et al.,* 2013).

Due to the rapid advancement in these technologies, electrical and computing components are more compact, reliable and affordable to implement automated gun turret in armored vehicle to overcome the first problem for these technology and simultaneously, computers offered the only realistic means of achieving the speed and accuracy of engagement for battlefield survival (Zhang & Li, 2011; Ji-Hong & Hong-Yan, 2011; Venkatakrishnan & Sundaresh, 2003). The technologies are interfaced with sensors, which are optical sensor, temperature sensor, binocular sensor and wind sensor. The sensors are used for sending feedback or signal to the gun turret control system.

Currently, gun turret systems have been developed with many sophisticated technological capabilities. For example, a day and night vision enables a high firing accuracy in various conditions. Besides that, another capability of the gun turret is automatic target tracking, which increases the firing accuracy of gun turret especially on moving targets. This capability is greatly required for the development of gun turret system because of the high speed and manoeuvring abilities of a moving target. This capability is obtained by using a gun stabilization and target tracking system. These systems are used to hold and lock the orientation of the gun stationary point, which is relative to a reference on the ground. Thus, the gun turret is less affected even under random disturbance generated by vehicle mobility on an unconstrained terrain (Gourley, 1998).

In order to achieve precise firing accuracy and stability for the gun turret system, a control algorithm is highly required in order to control the actuator of the gun turret. The control algorithm is imperative for the gun turret actuator to track the target according to the desired trajectory. Many researchers have developed various types of intelligent control strategies for an automatic gun turret trajectory to achieve the optimum performance on gun turret actuator in tracking trajectory. The existing controllers, such as PID, fuzzy logic, sliding mode control and also other advance controllers were implemented to control the gun turret actuator.

There are a number of researches that have been done on automated gun turret trajectory control for armoured vehicle in the military industry and also for academic purposes (Iflachah *et al*., 2011; Liu, 2011; Purdy, 2006; Arambel *et al*., 2001). Previous researchers also focused on improving firing accuracy performance and fire control system, such as Tao & Ma (1999), who proposed optimal control scheme to control gun turret system. The control scheme is employed for backlash compensation. Kemao *et al*., (2004) introduced the back stepping sliding mode control with nonlinear disturbance that provided robustness to friction and uncertainties to obtain stabilization on the close loop system.

Besides, Ji-Hong & Hong-Yan (2011) employed the back stepping sliding mode control on the tank gun control system to solve the tracking control with friction on low speed. Meanwhile, Galal *et al*., (2009) applied the fuzzy logic control strategy to assess the achievable performance of the gun turret system in precision control. Recently, Munadi *et al*., (2014) constructed the fuzzy logic control for gun turret control system for controlling the angle of azimuth and elevation movement of barrel to provide high