ASSESSMENT OF KINEMATIC PERFORMANCE OF A 4-WHEELS GROUND VEHICLE IN A STRUCTURED TERRAIN ENVIRONMENT

MUHAMMAD ZULHILMI BIN HARIS

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Faculty of Manufacturing Engineering

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ABSTRACT

This thesis deals with the assessment of kinematic performance of a 4-wheels ground vehicle in a structured terrain environment to overcome an obstacle, which this case, a stair of a building. This thesis studied the kinematic and dynamic movement of a 4-wheels ground vehicle and implement it on a real life rock crawler type 4-wheels ground vehicle. The dimension and definition of a rock crawler type 4-wheels ground vehicle was measured and analysed for the purpose understanding the way of a rock crawler type 4-wheels ground vehicle performed. The objective of this thesis is to change and develop the control system of a 4-wheels ground vehicle from radio remote control transmission to autonomous programmable electronics board. The other objective is to program the control system of a 4-wheels ground vehicle using programmable electronics Arduino board to climb a stair. The program code was developed by using Arduino software to autonomously control the movement of a 4-wheels ground vehicle overcoming a given obstacle. Range of PWM signal was measured to control the velocity and acceleration of DC motors and the turning angle of servo inside a 4-wheels ground vehicle. The movement analysis of a rock crawler type 4-wheels ground vehicle on a surface with and without an obstacle was analysed using the Tracker software to find a maximum, minimum and average value of velocity and acceleration of a 4-wheels ground vehicle. Comparison between two different situations was measured to analyse the performance of a rock crawler type 4-wheels ground vehicle on a surface with and without an obstacle.

ABSTRAK

Tesis ini memperkatakan tentang penilaian prestasi kinematik kenderaan darat 4-roda dalam persekitaran muka bumi yang tersusun untuk mengatasi halangan, dalam kes ini, tangga sesebuah bangunan. Tesis ini mengkaji pergerakan kinematik dan dinamik kenderaan darat 4-roda dan melaksanakannya pada kenderaan darat 4-roda sebenar jenis rock crawler. Dimensi dan definisi kenderaan darat 4-roda jenis rock crawler diukur dan dianalisis untuk tujuan memahami prestasi pergerakan kenderaan darat 4-roda jenis rock crawler itu dilakukan. Objektif projek ini adalah untuk mengubah dan membangunkan sistem kawalan kenderaan darat 4-roda daripada penghantaran kawalan jauh radio diubah kepada papan elektronik yang boleh diprogramkan iaitu Arduino. Objektif lain adalah untuk memprogram sistem kawalan kenderaan darat 4-roda untuk mendaki tangga menggunakan papan elektronik yang boleh diprogramkan iaitu Arduino. Kod program telah dibangunkan dengan menggunakan perisian Arduino untuk mengawal pergerakan kenderaan darat 4-roda mengatasi halangan yang diberikan secara automatik. Pelbagai rangkaian isyarat PWM diukur untuk mengawal kelajuan dan pecutan dua DC motor dan penukaran sudut tayar hadapan menggunakan servo dalam kenderaan darat 4-roda itu. Analisis pergerakan kenderaan darat 4-roda jenis rock crawler di atas permukaan berhalangan dan permukaan tanpa halangan dianalisis menggunakan perisian Tracker untuk mencari nilai maksimum, minimum dan purata kelajuan dan pecutan kenderaan darat 4-roda. Perbandingan antara dua situasi yang berbeza diukur untuk menganalisis prestasi kenderaan darat 4-roda jenis rock crawler di atas permukaan berhalangan dan permukaan tanpa halangan.

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LIST OF SYMBOLS

$\dot{X}, \dot{Y}, \dot{Z}$	Velocity in global frame of reference (m/s)
x, y, z	Body fixed axes of the ground vehicle (m)
v_x, v_y, v_z	Velocity measured in body x, y, z coordinates (m/s)
ϕ, θ, ψ	Euler angles – roll, pitch, yaw (rad)
w_x, w_y, w_z	Angular velocities about x, y and z axes (body axes) respectively (rad/s)
M_x, M_y, M_z	Total moment about x, y, z axes (Nm)
q	Velocity vector of the ground vehicle
p	Dynamic of translational motion of the ground vehicle
R	Turning radius of the ground vehicle
F_x, F_y, F_z	Overall longitudinal, lateral and normal force in the body frame (N)
δ	Angle of front tire turning
τ_e	Torque of the ground vehicle
J_w	Moment of inertia of the tire
f_k	Friction of coefficient force
F_{total}	Total force on the ground vehicle

LIST OF ABBREVIATIONS

DARPA-AI	Defence Advanced Research Projects Agency for Artificial Intelligence
TV	Television
DC	Direct Current
DoF	Degrees of Freedom
ICR	Instantaneous Center of Rotation
PWM	Pulse Width Modulation
RC	Remote Control
FM	Frequency Modulation
AM	Amplitude Modulation
PPM	Pulse Position Modulation
PCM	Pulse Code Modulation
ESC	Electronic Speed Controller
Li-Po	Lithium Polymer battery
IDE	Integrated Development Environment
USB	Universal Serial Bus
OSP	Open Source Physics

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

4-wheels ground vehicle can be referred to as an advance technology operate without the present of human nearby thus it is called as unmanned system. This technology emerged from a complex combination of artificial intelligence, computer technology and advanced processor developments. That complex combination give birth to a highly advance technology capable to operate on any extreme condition. This advance technology also classified as an intelligence vehicle as it put robotic technologies one step forward to the future.

This technology is a land-based vehicle so it can only be applied to an operation while in contact with ground counterpart to unmanned aerial vehicles and remotely operated underwater vehicles. The special about this advance technology vehicle is it capability to move on a clear road to an uneven road with ease. Typical field conditions include urban road, meadow, sand, forest, rocky area, mountainous area, watery area and muddy terrain. This piece of technology can also withstand the possibility of being heavily impact from an extreme condition.

As this robotic vehicle can withstand any extreme condition, it will be paid more attention in future combat field and play a far more important role as a military support. When the robotic technologies become more mature, more and more advanced ground vehicle will be designed and produced for military operations, in order to reduce casualties. Ground vehicle will be even more widely used in some other new area, such as new weapon testing, pollution elimination, military production, and electronic warfare.

1.2 PROBLEM STATEMENT

The student will program the control system of a 4-wheels ground vehicle using Arduino board. The program of control system must be able make a ground vehicle to climb a standard height of stairs. Every parts and components involves inside a ground vehicle must be considered precisely in order to make a ground vehicle to operate perfectly according to the program and able to climb stairs successfully without any error or malfunction happened during the operation time.

The student also will improve the part of a ground vehicle so it can be able to climb a stair successfully. For example, the chassis of the ground vehicle need to be improvise according to the movement of the ground vehicle so it can climb a stair without any problem. Any part involved with the movement of the ground vehicle while climbing a stair need to be analyse in order for the ground vehicle to climb a stair smoothly.

1.3 OBJECTIVES

The main objectives that need to be fulfilled to finish this project is:

i. To change the control system of a 4-wheels ground vehicle from using radio remote control transmission to using programmable electronics board.
ii. To program the control system of a 4-wheels ground vehicle using Arduino board to climb a stair.

1.4 SCOPE OF PROJECT

To fulfil the objectives specified above, the scope of project study is to use a standard rock crawler radio remote control as a model 4-wheels ground vehicle. After that, program the movement of a 4-wheels ground vehicle climbing a stair using Arduino UNO. Then, simulate using Tracker software to analysis the movement of a 4-wheels ground vehicle climbing a stair. Lastly, the project required to be accomplished within the 6 month of period based on the Gantt chart schedule proposed (Appendixes A).

CHAPTER 2

LITERATURE REVIEW

2.1 WHAT IS 4-WHEELS GROUND VEHICLE?

There are a question that must be answered first in order to design a full functioning 4-wheels ground vehicle to climb a stair which is the purposes of a machine categorized as 4-wheels ground vehicle as well as it usage to the surrounding. 4-wheels ground vehicle is a vehicle that operates while in contact with the ground and without human presence inside it. It can be used for many outdoors applications located on inconvenient, dangerous, or impossible condition which not require to have a human operator present as it will harm them. For a field ruggedized 4-wheels ground vehicle such as rock crawler, it have a capability to withstand any extreme environment which make this vehicle more superior to human capability in certain condition. Usually, most of a 4-wheels ground vehicle will have a set of sensors to observe the surrounding environment, and will either autonomously make decisions about its behaviour or pass the information to a human operator at a different location who will control the vehicle through radio remote control.

A 4-wheels ground vehicle is a successful products with a combination of artificial intelligence, computer technology and advanced processor developments. As a field ruggedized vehicle, a 4-wheels ground vehicle are being actively developed for military use to perform a variety of dull, dirty, and dangerous activities on clear or uneven grounds. Which is why a lot of 4-wheels ground vehicle applications used for military operation. There are two classes of 4-wheels ground vehicle in terms of their basic handling which are remote operated and autonomous. Remote operated is controlled by a human operator via a communications link such as radio transmission. All actions are determined by the operator based upon either direct visual observation or remote use of

sensors such as digital video cameras. Autonomous handling is operated using artificial intelligence program without the need of a human controller. Currently, the main usages of the 4-wheels ground vehicle are

a) Mine Sweeping – To detect and dispose all of the remaining mines on a battlefield.
b) Bomb Disposal – To dispose an abandoned bomb before it harming the civilian.
c) Surveillance and Patrol – To observe the surrounding from any dangerous encounter
d) Weapon Platform – To stored and delivered weapon to another location through dangerous condition.
e) Battle Field Support – To act as a backup support on a battlefield.
f) Sport – A 4-wheels ground vehicle also being played as a recreation value. There are also a competition of a 4-wheels ground vehicle race.

2.2 HISTORY OF 4-WHEELS GROUND VEHICLE

According to the history, in 1930s, The Union of Soviet Socialist Republics developed Teletanks, a machine gun-armed tank remotely controlled by radio transmission. These were used in the Winter War (circa 1939 to 1940) against Finland and at the start of the Eastern Front after Germany invaded the Union of Soviet Socialist Republics in 1941. Afterwards during World War II, the British developed a control version of their Matilda II infantry tank using radio transmission in 1941. Known as "Black Prince", it would have been used for drawing the fire of concealed anti-tank guns, or for demolition missions. Due to the costs of converting the transmission system of the tank to Wilson type gearboxes, an order for 60 tanks was cancelled. From 1942, the Germans used the Goliath tracked mine for remote demolition work. The Goliath was a small tracked vehicle carrying 60 kg of explosive charge directed through a control cable.

Their inspiration was a miniature French tracked vehicle found after France was defeated in 1940. The combination of cost, low speed, reliance on a cable for control, and poor protection against weapons meant it was not considered a success. The first major mobile robot development effort named Shakey was created during the 1960s as a research study for the Defense Advanced Research Projects Agency for Artificial Intelligence (DARPA-AI) to test its obedience with commands, which is different from advanced robots that are autonomous or semi-autonomous. Shakey was a wheeled

platform that had a TV camera, sensors, and a computer to help guide its navigational tasks of picking up wooden blocks and placing them in certain areas based on commands.

As a fully functioning vehicle capable of military support, there are many subsystems to enhance the capability of a 4-wheels ground vehicle should be considered. These subsystems can be categorized as

a) Propulsion System – Responsible to move the ground vehicle which involves power supply system, moving mechanism and ground navigation system.
b) Sensor System – To observe environment by getting ambient information such as thermal imaging, acoustic imaging, sonar, radar and so on.
c) Information Process and Control System – To extract important information and identify possible danger which will control the vehicle to perform certain operation.
d) Communication System – To communicate with the wireless controller (remote operated ground vehicle) or transfer information with other ground vehicles.

2.3 IMPORTANT COMPONENT OF 4-WHEELS GROUND VEHICLE

There are a lot of important components in order for a 4-wheels ground vehicle to operate perfectly on an uneven road full of obstacles which is suitable for it capability. Each of this components hold their own unique functionality matching with a 4-wheels ground vehicle ability. That means, if one of the component is malfunction or damage, a 4-wheels ground vehicle will not be able to move perfectly according to what has been assigned for it to operate.

As told inside the scope of the project above, the chosen type of 4-wheels ground vehicle for this project is a rock crawler. There are a lot component found inside this type of ground vehicle. But there are only eight important components inside this ground vehicle that need to be maintained with care. The figure 1 below shows all of the eight component on it specified location inside this ground vehicle;

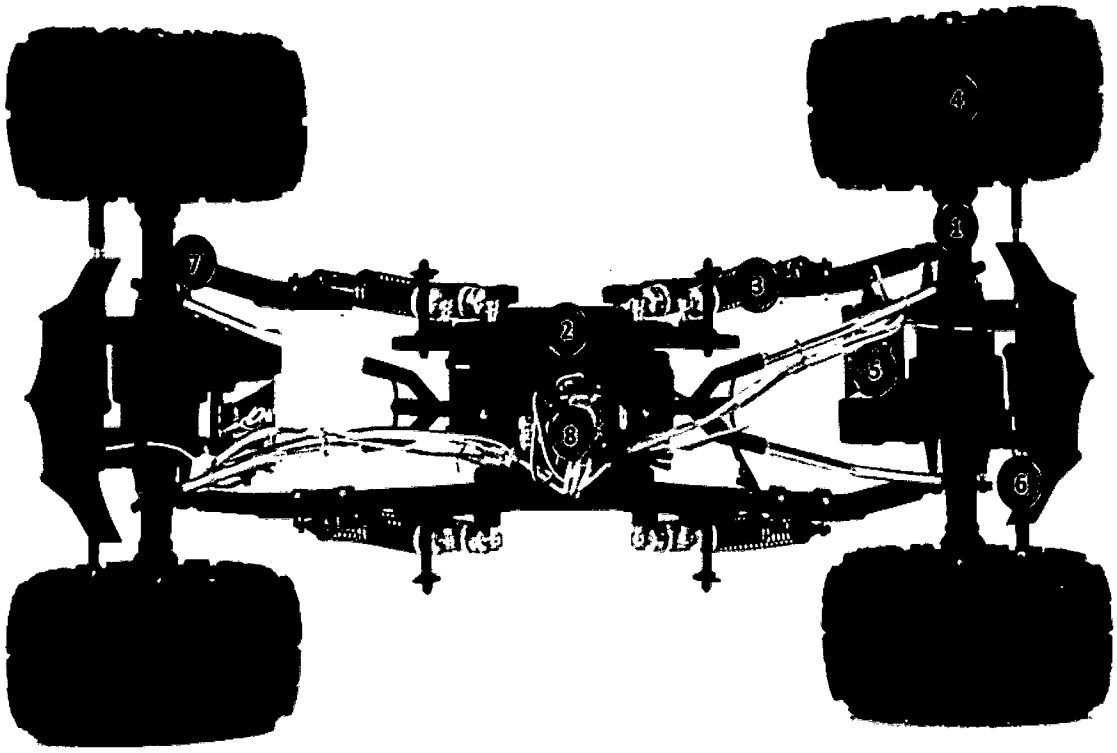

Figure 2.1: A rock crawler type 4-wheels ground vehicle

Source: Team Losi Racing (2010)

From the figure 1 above, all of the eight important component inside a rock crawler type 4-wheels ground vehicle with their own specified location are shown. The name of each of the eight components is:

1) Axle
2) Chassis
3) Shock
4) Wheel and tire
5) Motor
6) Steering system
7) Suspension links
8) Control system

2.3.1 Axle

The front and rear axles are one of the most important parts inside a ground vehicle. Usually an axle are designed with a set of gear drive inside it such as worm gear. It is also designed to have the motor installed directly to them, that means it require one motor per axle to complete a ground vehicle. The most effective upgrades for an axle is by combining it with a set of bearings to smoother the rotation of the wheel.

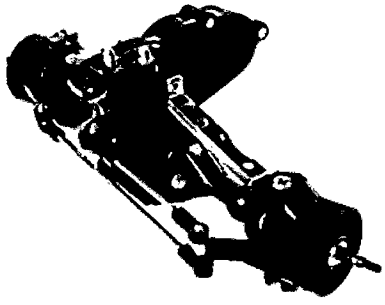

Figure 2.2: Standard axle for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.2 Chassis

The chassis component is like a heart of a ground vehicle which is a critical part of an overall ground vehicle. It is in the middle of a ground vehicle and it act as a house or a holder for all of electronics components used as a control system involves inside a ground vehicle. Usually it's come in all shapes and sizes, allowing the user to choose according to their desired capability as the design of a chassis will affect the performance of a ground vehicle. The design of a chassis takes into accounts things like 4-link suspension design, as well as allowing easy installation and access to electronics components.

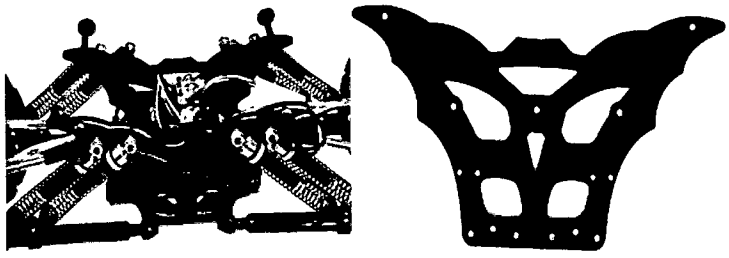

Figure 2.3: Standard chassis part for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.3 Shock

There are multiple style of shocks used inside a ground vehicle such as eight friction style shocks. A shock can help absorbing an impact from an external forces avoiding them damaging a ground vehicle ground vehicle. Difference style of shock give difference performance of a ground vehicle as the user can choose according to their desires performance for their ground vehicle. Most aftermarket chassis kits are designed to use four shocks. Oil-filled shocks are a huge performance improvement and the numerous shock oil and spring combinations allow the user to tune their ground vehicle to suit their desired requirement.

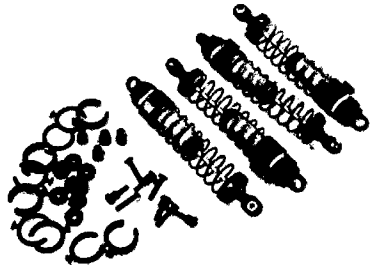

Figure 2.4: Standard shock for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.4 Wheel and Tire

The wheels of a ground vehicle usually designed with bead lock. The functioning bead lock allows for the tires to maintain more contact and traction. The tread design of a tire will affect the performance of a ground vehicle. The best tread design tire can give the ability to aggressively attack uneven road and rocky terrain. The creative multi-edged tread design enhances traction by simultaneously gripping in multiple planes on uneven surface. The large lug design also helps in cleaning itself from mud and dirt giving enhanced traction.

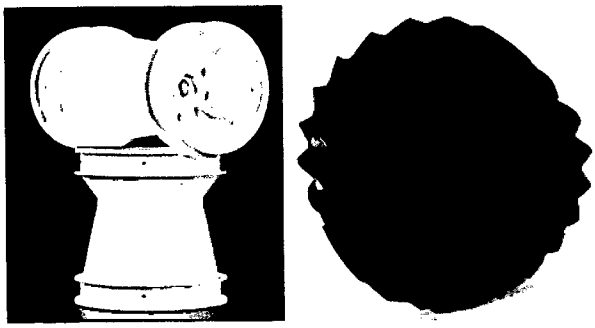

Figure 2.5: Standard wheel and tire for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.5 Motor

There are two basic motor options for a ground vehicle which is brushed and brushless motors. A brushed motor has a rotating set of wound wire coils called an armature which acts as an electromagnet with two poles. The advantages of using a brushed motor is the electronics is simple and inexpensive control. No controller is required for fixed speed of a motor. The disadvantages of using brushed motor is it require more maintenance as the higher current draw wears brushes faster. The speed range will also become lower due to mechanical limitations on the brushes.

A brushless motor uses a permanent magnet external rotor, three phases of driving coils, one or more Hall Effect devices to sense the position of the rotor, and the associated drive electronics. The advantages of using a brushless motor is it required less maintenance due to absence of brushes unlike brushed motor. The efficiency of brushless motor is high considering there is no voltage drop due to brushes usage. The disadvantages of using a brushless motor is the cost of a brushless motor is quite expensive compared to a brushed motor and the control of a brushless motor is complex and expensive which an electric controller is required to keep the motor running.

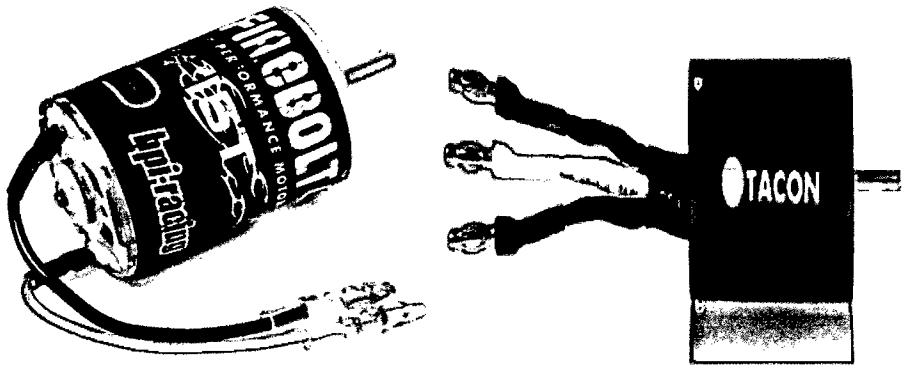

Figure 2.6: Standard motor for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.6 Steering System

The steering system is importance to steer the direction of a ground vehicle. The steering geometry is required to raise the main steering link closer to the axle housing in front of a ground vehicle, giving it an additional clearance when approaching difficult obstacles. The steering system that provides precise control as well as 45^0 degrees of steering throw is the best steering system with a maximum performance. With precise control, the direction of a ground vehicle can be easily steer with precise angle as it will not deviated from a designated road.

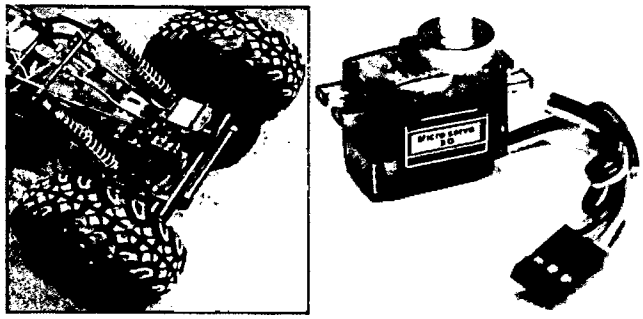

Figure 2.7: Standard steering system for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)

2.3.7 Suspension link

A suspension link is important as it connecting the front and rear axles to the middle chassis of a ground vehicle. The standard suspension link design is a 4-link suspension setup which is used in combination with the twin vertical plate chassis. It will reduce axle swing and eliminating side-to-side movement for increased steering and maneuvering precision. 7mm diameter aluminium lower links are hard anodized and triangulated to the center of the chassis for better balance front to rear when the suspension starts to twist.

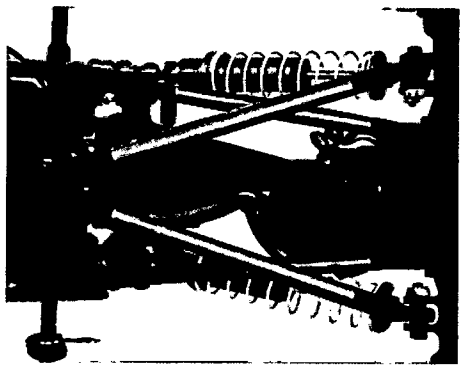

Figure 2.8: Standard suspension link for a rock crawler type 4-wheels ground vehicle

Source: Crawford Performance Engineering (2008)