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System Modelling of Rocker-Bogie Mechanism for Disaster Relief.

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Abstract

In December 2014, the east coast of Malaysia faced a massive flood from heavy downpour, leading to huge flood damage and caused irreparable loss to life and property. The flood carries the debris, soil and trees along their path, damaging the road and building structure, leaving the road become uneven. This situation gives difficulty to task force bearing aids during the post disaster management. This paper proposed an intelligent inclined motion control of an amphibious vehicle while moving on uneven terrain surface.

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Keywords:flood; damage;inclined motion;amphibious.

1. Introduction

Malaysia is a modern and developing country located in Southeast Asia. In every year, it receives a tropical storm, raging river, massive flood and landslide. In December 2014, East Coast of Peninsula Malaysia facing a heavy rain leads to a massive flood that leads to property losses. Local news reported that 10 house at Gua Musang's district had been drifted by the heavy flood [1]. The flood carries the debris, soil and trees along their path damaging the road, building structure living the road become uneven. This situation gives a difficulty to task force while bringing the aid during the post-disaster management. The vehicle is proposed to meet the post-disaster occurrence is an amphibious vehicle. The amphibious vehicle is combining the land and water vehicle. The vehicle should be able to transverse on

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an uneven road surface and at the same time be able to manoeuvre smoothly on a water surface. The ground vehicles are suitable in collecting the environment data compare to the aerial vehicle [8].

In this paper, we focus on the development and design of mechanical system on land that took consideration the features of water vehicle. The wheel should be retracted to enhance the stability of vehicle while it in water mode. Retractable wheels are designed to reduce the loss of the bow wave wheel. It increases vehicle speed when manoeuvring on the water's surface. If the wheels deployed, the water flow under the surface of the vehicle will be blocked and distracted by the wheel. The wheel will disturb the water flow path causing a high pressure before the wheel and low pressure after it. This produces a negative pressure that will affect the speed and stability of the vehicle. A low-pressure hole will also reduce the speed of water flow, encouraging the whirlpool flow and increase the loss of the bow wave [2]. On the land mode, the vehicle should able transverse smoothly on the uneven surface and overpasses the obstacle. The wheel-track type vehicle are most suitable to use in uneven surface because the construction are simplest and not required complicated algorithm control compare to the leg type vehicle that equipped with lot of sensor and actuator [6] [8]. Rocker-bogie mechanism is an example of passive linkage that been used in Mars Rover Exploration [5] [6] due to it stability and adaptive ability on terrain surface (uneven surface). In a post- disaster relief, the road surfaces become uneven and rough. It will disrupt the mobile stability and movement. The intelligently designed wheel suspension allows the vehicle to traverse over very uneven or rough terrain and even climb over obstacles. The rocker-bogie allows the chassis of the rover to average its pitch overall wheel deflections while still maintaining load equalization on all wheels and avoiding a low oscillation frequency. The rocker-bogie mechanism consists of rocker that attached to a frame and a bogie that connects to rocker link with pivot joint as shown in figure 1. The main advantage of this mechanism is no suspension required, and total loads are distributed equally over all wheels. These ensure even working condition all wheels and prevents from excessive sinkage of a wheel in a soft terrain (muddy) [3]. However, the uneven surface is not predictable; the different configuration is needed for different terrain surface. The commons problem facing while using this mechanism are wheel slip, slow in speed and power consumption.

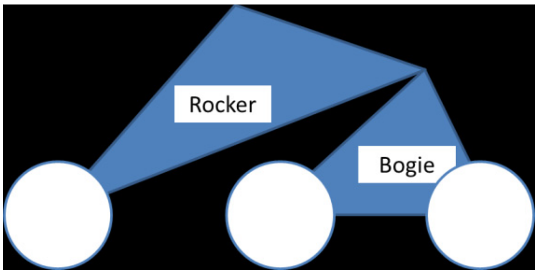


Fig. 1 Kinematic diagram of Rocker Bogie Mechanism

2. Experimental Setup

The vehicle controls manually by a user using a joystick to manually override the system in case of failure. The main body will attach the IMU to locate it initial state and pitch angle of a vehicle. The pitch angle of the main body is related to terrain condition and normal gravity. Each bogie and rocker are been attached the angular sensor to determine the incline angle of a vehicle. Then the servo motor will move the rocker and boogie based on angular value and IMU data to avoid the vehicle from flip. Each motor must have an encoder to determine it speed and torque. The data are used to control the slip's problem. The bogie and rocker can move and varies to maximum cross-hill and downhill. On land, it intelligently controls to maximize the angle of cross-hill and down-hill grade ability. While on water, retracted bogie and rocker are necessary to enhance the vehicle movement. The robot has six tires that move independently, it consume a lot of power for a motor to manoeuvre and the difference motor's speed made it difficult to move. Synchronising all tire using an algorithm have been discussed in a motorised vehicle that have more tire to reduce the power consumption and enhancing the robot's stability [4]. Therefore, in this paper, we proposed an approach to move the tire position toward body centre and distribute the angles caused by the inclined surfaces via distribution among the robot joints [12]. Since the vehicle has a retractable wheel, the mechanism is used to distribute the angle and made it stable when traverse on the uneven road surface. Figure 2 show the vehicle in deployed mode while figure 3, the vehicle in retracting mode.

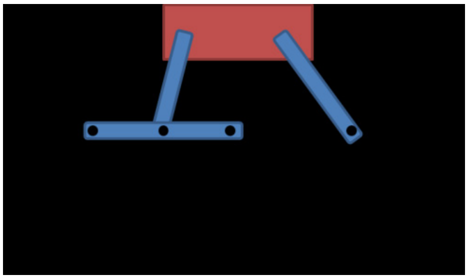


Fig. 2 Normal Mode (Deployed Wheel Condition)

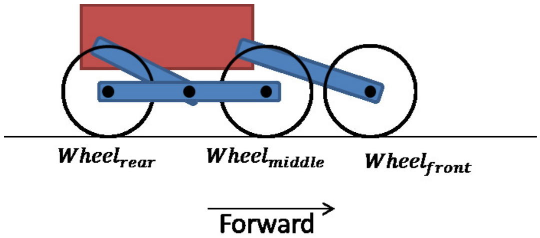


Fig. 3 Water Mode (Retract Wheel Condition)

2.1. Downhill and Front grade ability.

Down-Hill Grade ability is to measure maximum incline angles that stabilize the vehicle from slip and flip over. Wheel slip can damage the vehicle and jeopardize the whole rescue mission during the post-disaster occurrence. The Down-Hill Grade ability can be analysis statically as refer in figure 4 and equation 1. The vehicle must have trainability aspects to overcome the unpredicted terrain and overpassed the obstacle. Downhill grade ability can be enhancing by minimizing the wheel's slip or maximizing the rover traction [6]. Intelligently control the slip will affect the power consumption. The slip made the vehicle use a lot of power to overcome it.

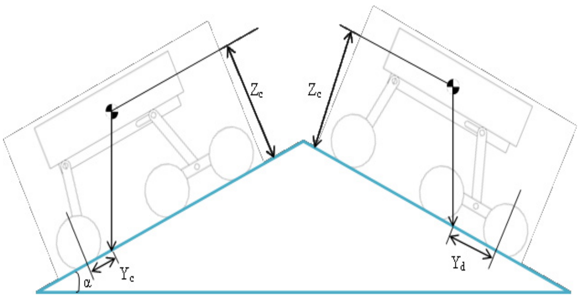


Fig. 4 Downhill and Front grade ability

$$\alpha_{max} = min\left\{tan^{-1}\frac{Y_d}{Z_c}, tan^{-1}\frac{Y_c}{Z_c}\right\} \quad (1)$$

$where,$

$$Y = Z_c \tan^{-1}\alpha \quad (2)$$

$$Y_c = L_{cc} - Y \quad (3)$$

2.2. Cross-hill grade ability.

The speed movement of rocker bogie mechanism is very slow to avoid it flipping while turning. It consumed a time that are crucial during disaster occurrence. Furthermore, a normal vehicle will avoid the terrain that made it flip. Cross-hill grade ability is to measure the maximum angle that suitable for a vehicle to cross. Flip can be overcome by increasing the tire radius or increasing the width of a vehicle [3]. However, it will change the vehicle specification and need another analysis. Thus, the controlling distance of tire towards the centre on a body is proposed [10].

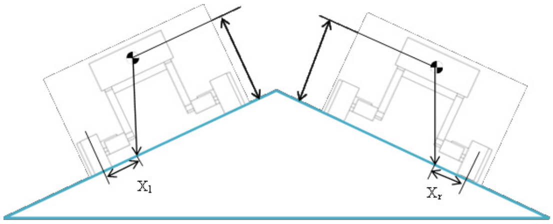


Fig. 5 Cross hill grade ability

$$\alpha_{max} = min\left\{tan^{-1}\frac{X_l}{Z_c}, tan^{-1}\frac{X_r}{Z_c}\right\} \quad (4)$$

2.3. Tractive Force of wheels.

The wheel is an important component of the vehicle to manoeuvre in both land and water surface. The tire radius supports the vehicle in climbing an obstacle, and a width prevents it from sinking in muddy place. Using an off-road tire will reduce the slip and provide a mechanical grip since a thread will dig the ground and increase a contact ratio. The table shows the vehicle specifications. The advantage of a rocker-bogie mechanism is the load equally distributed on all wheels.

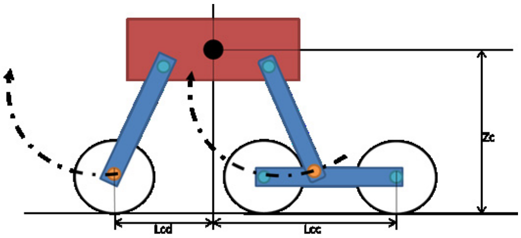
Table 1: Vehicle Specification

Vehicle's Load	8 kg (78.4 N)
Tire Specification - Width, *w* - Radius, *r* - Circumference, *c*	 0.06 m 0.06 m 0.377 m
Motor Torque, M_T	0.7848 Nm

The tractive force is the amount of the total traction that is parallel to the direction of motion can be calculated using an equation below. The calculation is based on a single wheel.

$$F_z = \frac{2\pi M_T \eta}{c} = \frac{2\pi(0.7848)(0.95)}{0.377} = 12.426\ N \quad (5)$$

Where,
F_z = Tractive Force on single wheel in N
M_T = Motor Torque
η = Overall efficiency in the drive train (0.95 for One Driven axles)
c = circumference



2.4. Gradeability of vehicle.

Gradeability is defined as the highest grade a vehicle can ascend while maintaining a particular speed. It commonly used in slope analysis, where the vehicle weight act against the direction of motion which is proportional to the angle of inclination of the road surface [5]. It can be obtained using the equation 6.

$$p = 100\left[\frac{F_z}{9.81G_z} - f_r\right] = 100\left[\frac{12.426(6)}{(9.81)(8)} - 0.032\right] = 91.8\ \% \qquad (6)$$

Where,
p = Gradeability, in %
F_z = Tractive Force in N
Gz = Overall combined mass, in kg
fr = Coefficient of rolling resistance (0.032 – Poor Road)

The angle of front hill and downhill Gradeability can be calculated using the equation 7.

$$\alpha = \tan^{-1} p/100 = 42.55\,° \qquad (7)$$

where;
α = Angle of gradient, in °
p = Gradeability, in %

3. Result And Discussion

In this paper, we will focus the relation the distance between centres of a body towards the terrain surface. The vehicle will have two configurations which are the rocker-bogie mechanism is retracted and deployed. We were using an equation 1 to equation 4 to calculate the vehicle's angle. The L_{cd} is a distance of front wheel towards the vehicle's centre and L_{cc} is a distance between the rear wheel and vehicle's centre. The z_c is a distance of vehicle's centre towards the ground surface while b_c is a distance of wheel to the centre at the front view. The L_{cd} and z_c values changes will affect the angle of front-hill Gradeability while L_{cc} and z_c contributing changes for downhill Gradeability. The cross-hill Gradeability affected by the changes of z_c only since the b_c is a distance of wheel toward vehicle's centre remain unchanged. The values of z_c give major effect since lowering the centre of a vehicle is increasing the vehicle stability [6]. Figure 6 shown the variables link of vehicles.

Figure 6 Vehicle variables

There are 4 input variables respecting for roll and pitch angle output. The table 2 is summarizing input of vehicle under two conditions which are retracted and deployed. The variable z_c and b_c will affect the roll angle while z_c, L_{cc} and L_{cd} give contribution change angle for pitch. This variable is a distance from wheel toward the centre of the vehicle. Thus, the angle of the vehicle as stated in Table 3.

Table 2: Tyre distance form vehicle's centre

Condition	Retract (cm)	Unretract (cm)
z_c	265	120
b_c	195	195
L_{cc}	200	315
L_{cd}	200	73

Table 3: Angle of vehicle for two difference condition

Grade ability	Retract (°)	Unretract (°)
Front Hill (Pitch)	37	69
Rear Downhill (Pitch)	37	31
Left-Right Cross hill (Roll)	36	59

The vehicle front-hill grade ability while it retracts is 37º, rear down-hill grade ability is 37º and cross-hill grade ability is 58º. In the deployed configuration, the angle is same for all grade ability which is 69º. In the whole system, the front hill grade ability can vary from 37º to 69º while rear downhill is from 31º to 37º. The vehicle cross-hill grade ability is from 36º to 59º.

Incline angle calculation based on equation 1 to equation 4 is actually having a continuous changing distance of wheel toward centre mass. However, using a minimum input of torque that based on the vehicle's mass which is 0.7848 N on each wheel, the vehicle is able to transverse smoothly on incline road with an angle of 42.55°. Poor rood is chosen for a coefficient of rolling resistance since, during the post-disaster occurrence, most of the road surface are damaged by debris and covered mud. The motor torque can be increased to optimize the incline angle achieved from a retractable wheel.

4. Conclusions

The trainability is an important characteristic should be embedded in an amphibious vehicle during the post-disaster occurrence. This ability helps the vehicle reducing a flipping back and slippage while it on a mission since the terrain surface after a disaster is unpredictable. Thus, applying the controller algorithm will optimizing the vehicle ability to manoeuvre in any surface condition with minimum risk.

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