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Process Involved in Designing of an Intelligent Additional Track Mechanism Tracked Vehicle for Swamp Peat Terrain

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Abstract

Different types of off road vehicles are widely used in agriculture, oil industry, mining and military operations but none of them can effectively operate over the swamp peat terrain because of its low bearing capacity of 7kN/m^2. Segmented rubber tracked vehicle and intelligent air-cushion system tracked vehicle were developed in Malaysia for swamp peat terrain. 16kN/m^2 of ground pressure was exerted by using the segmented rubber tracked vehicle during field operation therefore could not be operated efficiently. The air-cushion tracked vehicle increased the floatation capacity but at the same time increased the frictional effects therefore the tracks of the vehicle easily slipped out from the traction wheels during operation. Addressing these issues an intelligent additional track mechanism for tracked vehicle has been designed to improve the mobility over swamp peat terrain where the additional track would be increased the ground surface area and reduced the vehicle ground pressure. This paper presents the process involved in designing the intelligent additional track mechanism tracked vehicle for transportation of agricultural and industrial goods on the swamp peat terrain with bearing capacity of 7kN/m^2. The mechanical design comprises of track vehicle frame with track mechanism. Additional track mechanism with Fuzzy expert system. The design parameters are optimized using developed mathematical model based on the dynamics and kinematics behavior of the vehicle. In order to increase the vehicle contact surface area and reduce the surface contact pressure the additional track mechanism is designed in such way that it can be folded and unfolded from its position by using the ball-screw scissor lift mechanism. While, Fuzzy expert system is used to control the movement of the lift mechanism based on 70mm critical sinkage of vehicle detected from a set of sensors. The completed to vehicle system would be used for off-road applications as required.

Keywords: Additional Track, Fuzzy Logic Controller, Off-Road Vehicle, Segmented Rubber Tracked, Swamp Peat Terrain, Tracked Vehicle

1. Introduction

Off-road vehicles are specially designed for mobility on variety earth surfaces in the world. It has been used widely for agriculture, military, mining operation and construction proposed. In Malaysia, most of the off-road vehicle could not be operated smoothly over swamp peat terrain because of its low bearing capacity of about 7 kN/m^2[1]. There were several designs of tracked vehicle had being developed with high crossing ability over the swamp peat terrain such as an intelligent air-cushion system tracked vehicle and segmented rubber tracked vehicle. However,

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those designs were failed to operate effectively over the swamp peat terrain. The implementation of segmented rubber exerted high force on the terrain that made the vehicle ineffective, on the other hand high friction occurred between air-cushion and ground surface caused the slippage of tracks from the driving wheels for intelligent air-cushion system which reduced the effectiveness of the vehicle.

High energy consumption was found due to add-on propeller to make the vehicle move as the air cushion system functioning. Mechanical properties of the terrain are main factors that need to take consideration in developing a swamp peat terrain vehicle to predict the vehicle performance and effectiveness[2]. Along with the development of the swamp peat terrain vehicle, intelligent system for controlling the vehicle also plays an important role in achieving the standard of technology used in most vehicles nowadays. The most common controller being used nowadays is Fuzzy logic controller system. Fuzzy control is a control process which converting natural language into numerical state rather than using direct equations or numbers[3]. It is developed based on the human thinking in solving uncertainty[4]. Compared to conventional PID Controllers, fuzzy controller provides accurate estimation of unknown values from modelled data with quick response[5]. The applications of fuzzy control have increased recently. Most of automatic electrical products such as washing machine, elevator, computer, mobile robot and water quality control are using fuzzy control system[6,7]. Fuzzy controller also has been used as a traffic junction signal controller. It was stated that fuzzy controller can manage more than one input variables, using fewer control rules and each junction can connect with others compared to conventional controller[8].

Hence, for this project, an intelligent additional track mechanism has been developed in subsequence to improve the previous technology of swamp peat terrain vehicle. The intelligent additional track mechanism consists of track, lifting mechanism, a set of distance sensors and fuzzy controller system. It is activated when the vehicle gets sunk in swamps peat terrain and folded back in the middle of vehicle frame on normal ground surface. The movement of the intelligent track is controlled by fuzzy controller based on distance sensor signal. The objective of implementation of the intelligent additional track is to increase ground surface area, floatation on the swamp peat terrain and reduce energy consumption of swamp peat track vehicle.

2. Methodology

In order to design the tracked vehicle in this study, previous research on segmented rubber tracked vehicle[9] and hybrid electrical air-cushion tracked vehicle[10] have been used as a reference model. Creo Parametric 2.0 design software is used in this design process to produce the 2D and 3D model for each component. This design is a custom-build small size of intelligent additional track mechanism with ratio of 4 and still in developing process. Even though in small scale, the design has satisfied the requirement of the design criteria so that the vehicle can run over low bearing capacity of 7kN/m^2. Mathematical models of the vehicle have been developed by considering ground contact pressure and vehicle sinkage. All calculations in this research work are based on force acting on tracked vehicle in Figure 1 by considering total vehicle weight W, track size with length L, width B, height of centre gravity h_{cg}, radius of rear sprocket R_{rs}, wheel radius R_r, and grouser height H.

2.1 Mathematical Model of Additional Track Tracked Vehicle

To keep moving in swamp peat terrain, ground contact pressure of tracked vehicle needs to be less than the terrain nominal pressure otherwise vehicle will be stacked due to critical sinkage of 70mm. The ground contact pressure with and without additional track is formulated in Equations 1, 2 and 3 as below:

2.1.1 Terrain Nominal Pressure (TNP)

$$p = k_p z + \frac{4}{D_{ht}} m_m z^2 \quad (1)$$

$$\text{With } D_{ht} = \frac{4LB}{2(L+B)}$$

Where, p is nominal pressure of terrain in kN/m^2, z is vehicle sinkage in m, k_p is underlying peat stiffness in kN/m^3, m_m is surface mat stiffness in kN/m^{3}and D_{ht} is hydraulic diameter of track in m. now the Vehicle Ground Contact Pressure (VGCP) without additional track is expressed as:

$$p_g = \frac{W}{A_t} \quad (2)$$

Where, W is vehicle total load in kN and At is ground contact area of the track in m^2.

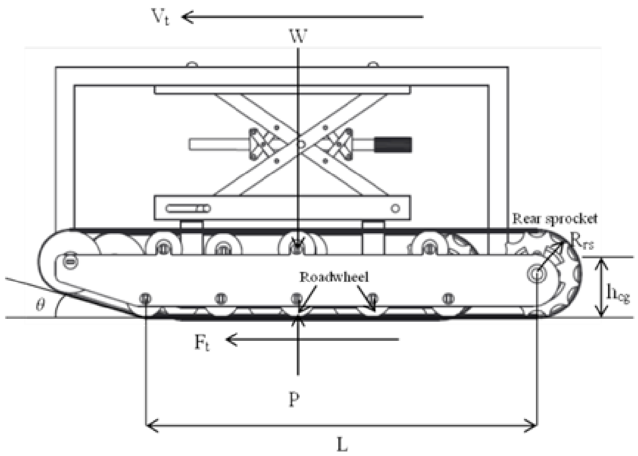

Figure 1. Force acting on track vehicle.

Vehicle ground contact pressure with additional track is expressed as:

$$p_g = \frac{W + W_a}{A_t + A_a} \quad (3)$$

Where, A_a is effective area of additional track in m² and W_a is weight of additional track.

It is noted that VGCP without additional track is higher than TNP, which means the vehicle cannot move over the swamp peat terrain as the vehicle ground contact area is small which cannot provide enough support to the vehicle from its sinking. While, with the presence of an additional track, the vehicle ground contact area is increased. This can provide enough support to the vehicle on terrain with bearing capacity of approximately 7kN/m². Sinkage of vehicle track system without additional track is expressed as:

$$z_1 = \frac{-\left(\frac{k_p D_{ht}}{4m_m}\right) \pm \sqrt{\left[\left(\frac{k_p D_{ht}}{4m_m}\right)^2 + \frac{D_{ht}}{m_m} p_g\right]}}{2} \quad (4)$$

Where $D_{ht} = \frac{4LB}{2(L+B)}$, $L = L_{YZ}$, $p_g = \frac{W}{A_t}$, where, $A_t = 2(L \times B)$. Sinkage of vehicle track system with additional track is expressed as:

$$z_2 = \frac{-\left(\frac{k_p D_{hta}}{4m_m}\right) \pm \sqrt{\left[\left(\frac{k_p D_{hta}}{4m_m}\right)^2 + \frac{D_{hta}}{m_m} p_g\right]}}{2} \quad (5)$$

Where $D_{hta} = \frac{4BL_{ta}}{2(L_{ta}+B)}$, $L_{ta} = (L_{XY}\cos\theta + L_{YZ} + R_{rs}\sin\theta)$,

$L_{XY} = \frac{z}{\sin\theta}$, $p_g = \frac{W_t}{A_{ta}}$, where $A_{ta} = 2(L_{ta} \times B) + L_a(B_a)$

and $W_t = (W + W_a) - W_{v(at)} = (1-\delta)(W + W_a)$

where, p_g is ground contact pressure of the vehicle in kN/m², z is the sinkage in m, m_m is surface mat stiffness in kN/m³, k_p is underlying peat stiffness in kN/m³, D_{hta} is hydraulic diameter of the track in m when additional track touches the ground, L_{ta} is ground contact length of the track in m when additional track touches the ground, A_{ta} is ground contact area of the track in m² when additional track touches the ground, W_t is total vehicle load in kN, $W_{v(at)}$ is vehicle partial load supported by the additional track system in kN, δ is load distribution ratio, R_{rs} is rear sprocket radius in m, θ is angle between the track of the 1st road-wheel to tensioned wheel and to the ground in degrees.

The computed values of z_1 and z_2 are 0.170 m and 0.020 m, for the vehicle without and with additional track. From the value, it is clearly showed the benefit of applying an additional track mechanism as the tracked vehicle movement support in swamp peat terrain. Hence, based on the developed mathematical model, an intelligent additional track mechanism is designed with ground contact area of 0.184 m² with total weight of 2.2563 kN.

3. Mechanical Design of an Additional Track Tracked Vehicle

Figure 2 shows the whole assembled structure of the tracked vehicle with an intelligent additional track mechanism.

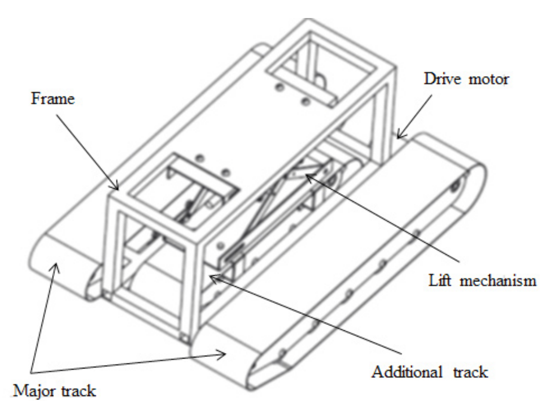

Figure 2. Assembled structure of intelligent additional track tracked vehicle.

3.1 Track Vehicle Frame with Track Mechanism

The size of an intelligent additional track frame is smaller than the major track frame. It is designed in such a way so that the intelligent track mechanism can be fitted in the middle portion of track vehicle major frame. The major frame of track vehicle can support two sets of major tracks, one set of additional track, lift mechanism, motor and controlling system as shown in Figure 3.

The track mechanism as shown in Figure 4 consists of wheels, two sprockets, front idler and rubber track. The wheels are used to support the track shoes when moving on the ground. While, the sprockets of the two major tracks are used to drive the track mechanism. It is equipped with two motors for flexible movement[11,12].

3.2 Intelligent Additional Track Mechanism with Fuzzy Expert System

Intelligent additional track mechanism is equipped with ball-screw scissor lift mechanism. It is used to support swamp peat tracked vehicle from being sunk in swamp peat terrain and move smoothly across on it. The additional track mechanism is functioned as the distance sensors detect the changes of the vehicle position from the ground surface. Then the signal from the sensor is transferred to the fuzzy controller system for interpretation. Fuzzy system gives direction to the lift mechanism to move downward or upward according to the distance of the vehicle's CG and the ground surface. Figure 5 shows the lift mechanism of the additional track.

3.3 Fuzzy Expert System

There are four main principle components used in Fuzzy Logic Expert System (FLES) which are fuzzification: take input and convert to fuzzy form, rule base: consists if-then rule based on human thinking in solving problem, inference: creates action based on the received information and defuzzification: calculate the actual output[5]. Fuzzy expert system can hold various inputs and produce one accurate output. Fuzzy tool in MATLAB Simulink is used in this project to develop fuzzy expert system model for intelligent part of the additional track mechanism. Figure 6 shows the fuzzy structure in MATLAB Simulink window.

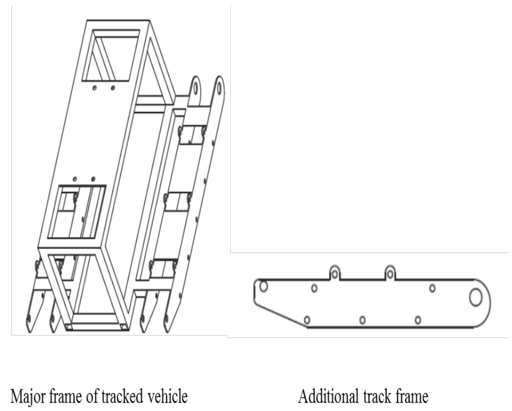

Figure 3. Major frame and additional track frame of tracked vehicle.

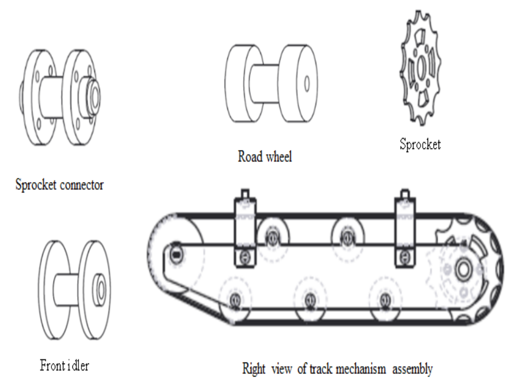

Figure 4. Track mechanism.

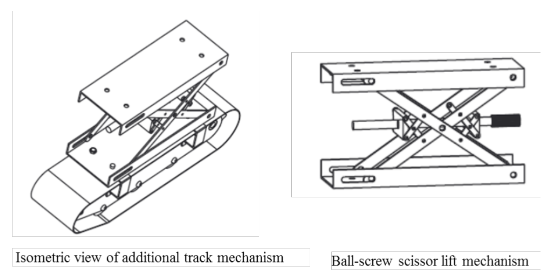

Figure 5. Lift mechanism of addition track of the tracked vehicle.

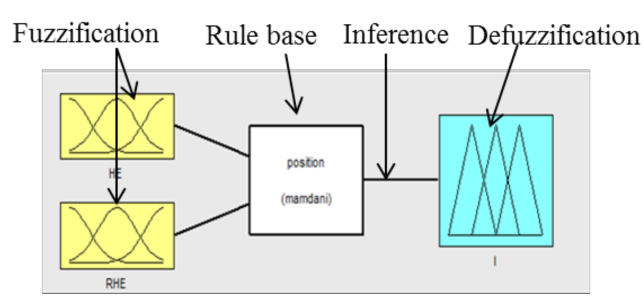

Figure 6. Fuzzy structure in MATLAB Simulink window.

Intelligent part or fuzzy control system in this project is constructed with two linguistic variables inputs of High Error (HE) and Rate of High Error (RHE) in unit of meter, 25 sets of IF-THEN rules and one linguistic variable output of current (I) needed to rotate the ball-screw lift mechanism in percentage (%). Each of input and output parameters consist of 5 linguistic values where, for HE input, there are Large Negative Error (LNE), Small Negative Error (SNE), Zero Error (ZE), Small High Error (SHE), and Large High Error (LHE). As for RHE input variables, there are Large Negative Rate of Error (LNRE), Small Negative Rate of Error (SNRE), Zero Rate of Error (ZRE), small rate of high error (SRHE), and Large Rate of High Error (LRHE). For output I, the variables are Large Negative Supply (LNS), Small Negative Supply (SNS), Leave Alone (LA), Small Positive Supply (SPS), and Large Positive Supply (LPS). In this paper, the ranges of linguistic values showed is estimated referrence value[5] as the tracked vehicle is still in the development process.

In fuzzy system, a Mamdani Fuzzy Inference System (FIS) is used to mapping a given input to an output based on fuzzy sets. It is involved with four basic steps: fuzzification of the input variables, rule evaluation, aggregation of the rule outputs and defuzzification[13]. Table 1 shows the inference rules of controller parameters in Mamdani rule base.

Triangular shaped membership function is mostly used in this study to represent the fuzzy sets of linguistic variables input and output. This is for more accuracy and simplifies the computation process[13]. After completing the fabrication of the tracked vehicle, the fuzzy controller will be implemented and some analysis will be done to get the exact range value of the input parameters. Therefore the concept of fuzzy controller used in this paper would be the same as in real condition. Figures 7–9 shows the prototype of membership functions for input variable of HE, RHE and the output current, I.

Figure 10 shows the surface developed from inputs and output parameters. Based on the Figure 10, as the surface is increased positively, the HE and RHE are achieved the maximum positive values with the supplied current (I) of 100%. Hence, the result shows the satisfaction of the controller systems with the expected result. Then, the fuzzy system would be converted into code language such as Matlab programming code and downloaded in microprocessor. Finally, the microprocessor would run the machine based on the developed fuzzy controller system.

Table 1. Inference rules of controller parameters

Rules	Input Variables		Output Variables
	HE	RHE	I
1	LNE	LNRE	LNS
-----	-----	-----	-----
6	SNE	LNRE	SNS
-----	-----	-----	-----
10	SNE	LHRE	SNS
-----	-----	-----	-----
14	ZE	SHRE	LA
-----	-----	-----	-----
25	LHE	LHRE	LPS

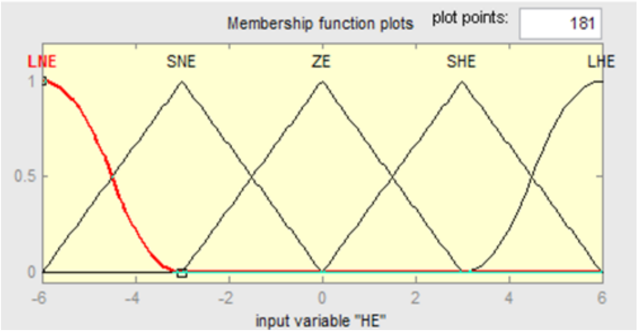

Figure 7. Prototype membership functions of input HE.

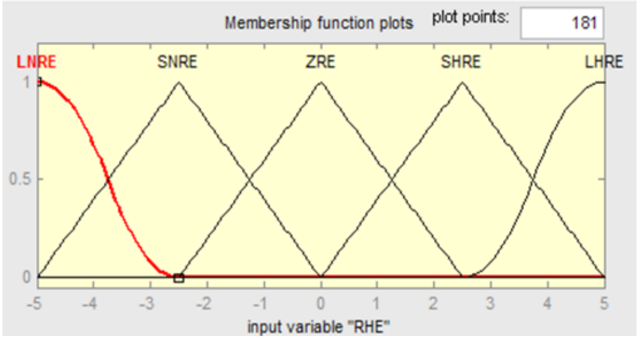

Figure 8. Prototype membership functions of input RHE.

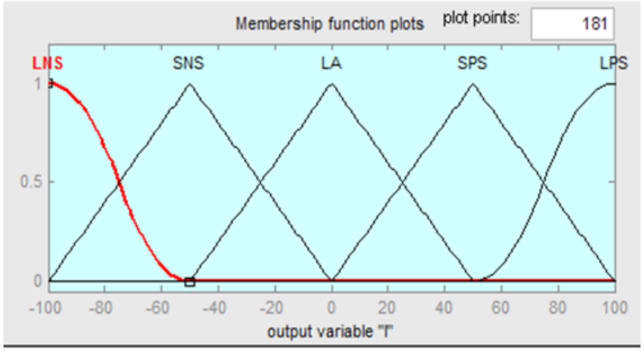

Figure 9. Prototype membership functions of output I.

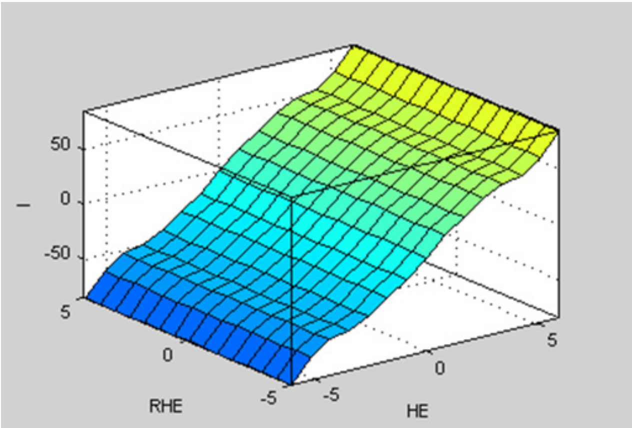

Figure 10. Surface of fuzzy controller.

4. Conclusion

Low bearing capacity of swamp peat terrain gives a big influence in designing of the whole body for tracked vehicle with intelligent additional track mechanism. In order to overcome the problem, the suitable mathematical model is required to produce satisfied design parameters such as vehicle ground pressure and vehicle sinkage so that the vehicle satisfied the swamp peat terrain conditions. The usage of fuzzy controller system for intelligent part of tracked vehicle produced better results and satisfied the expected outcome of the project.

5. Acknowledgement

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