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Fuzzy Logic System for Tractive Performance Prediction of an Intelligent Air-Cushion Track Vehicle

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***Abstract*—**Fuzzy logic system (FLS) is used in this study to predict the tractive performance in terms of traction force, and motion resistance for an intelligent air cushion track vehicle while it operates in the swamp peat. The system is effective to control the intelligent air –cushion system with measuring the vehicle traction force (TF), motion resistance (MR), cushion clearance height (CH) and cushion pressure (CP). Ultrasonic displacement sensor, pull-in solenoid electromagnetic switch, pressure control sensor, micro controller, and battery pH sensor are incorporated with the Fuzzy logic system to investigate experimentally the TF, MR, CH, and CP. In this study, a comparison for tractive performance of an intelligent air cushion track vehicle has been performed with the results obtained from the predicted values of FLS and experimental actual values. The mean relative error of actual and predicted values from the FLS model on traction force, and total motion resistance are found as 5.58 %, and 6.78 % respectively. For all parameters, the relative error of predicted values are found to be less than the acceptable limits. The goodness of fit of the prediction values from the FLS model on TF, and MR are found as 0.90, and 0.98 respectively.

***Keywords*—**Cushion pressure, Fuzzy logic, Motion resistance, Traction force.

I. Introduction

SINCE the transportation operation in agriculture over the swamp peat terrain is considered as the biggest issue of the world, the greater emphasis on tractive performance of track vehicle has stimulated a renewed interest in many parts of the world at present. With increasing demands to the wide application of off-road vehicles over soft terrain and swamp peat such as agriculture, forestry, construction and the military, there is a need to increase the knowledge about intelligent air-cushion system of swamp peat vehicle. The tractive performance of tracked vehicles travelling over moderate bearing capacity terrain (12kN/m^2) is generally well understood. However, the tractive performance prediction is the main requirement for the tracked vehicles, in the situation of vehicles travelling over very low bearing capacity terrain (7 kN/m^2). The Swamp peat terrain (low bearing capacity) is a most critical terrain in Malaysia in where the plantation companies are expanding their plantations. It is reported by Malaysia Agriculture Research Development Institute (MARDI) [1] that the swamp peat terrain surface mat thickness is closed to 70 mm and ground contact pressure is 7 kN/m^2. There is not a single vehicle in Malaysia developed to do the transportation operation on such terrain. Many research works have been carried out and different types of vehicles are introduced to solve the transportation problems on moderate peat terrain [2-5]. But still no one offers any vehicle on low bearing capacity swamp peat terrain in Malaysia. A hybrid vehicle which combines intelligent air-cushion system with a driving mechanism has been proven to be an efficient solution for a heavy duty vehicle on severe working conditions [6]. However, the use of commercial intelligent air-cushion tracked vehicles to test the vehicle parameters is limited due to the difficulties in varying parameters as well as the control of the air-cushion pressure. A small scale hybrid electrical air-cushion tracked vehicle (HEACTV) was therefore developed which offered the possibility to vary vehicle parameters in simple way based on low bearing capacity of peat swamp [7]. In this study the prediction of tractive performance has been taken into account to reduce the dragging motion resistance as well as to minimize the power consumption. Based on the experimental data obtained on the field, a Fuzzy Logic model for predicting the tractive performance of the tracked vehicle under level terrain condition is developed. The air-cushion system is controlled by applying Fuzzy Logic approach more precisely during operation the vehicle over the swamp terrain and is able to reduce the dragging motion resistance significantly. The details of the vehicle are given in the earlier published article [7].

In the transportation era, many expert systems were designed for predicting the tractive performance of the vehicle. Because of its importance, Fuzzy Logic techniques were proposed for power demand prediction [8-9]. To predict the tractive performance on wheeled air-cushion and semi-tracked air-cushion vehicles, Fuzzy Logic has been applied successfully to a large number of expert applications. This work presents the model of FLS, comprising the control rules and term sets of variable with their relates fuzzy sets, in which classical set theory is extended to handle partial memberships, enabling to express vague human concepts using fuzzy sets

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[10]. The aim of this study is to construct of fuzzy knowledge-based models based on the Mamdani approach for the prediction of the tractive performance of the intelligent air-cushion system. A comparative performance analysis of this approach, by sampling data collected from the operation, was used to validate the fuzzy models.

II. Methodology

The developed small-scale hybrid electrical air-cushion tracked vehicle made for the transportation operation of agricultural and industrial goods on swamp peat in Malaysia is shown in Fig. 1 [7]. The steering of the developed vehicle was achieved by means of an individual switch of the DC motor with a power of 1.50 kW @ 2.94 Nm. The dry weight of the vehicle was considered as 2.43 kN and it was designed mainly for operating a maximum load of 3.43 kN including

Fig. 1 Photo of the developed HETAV [7]

a 1.00 kN payload over the swamp peat terrain. The total ground contact area of the vehicle was 1.052 m^2 including 0.544 m^2 of the air-cushion system. The vehicle was powered by a battery pack comprising eight (8) lead acid batteries. Total power stored in the pack was 10.08 kWh. Battery arrangement was made in such a way that the pack could deliver the power to the DC motors for three hours. The vehicle could travel 36 km powered of the single charging battery pack. A small IC Engine power of 2.5 kW @ 4000 rpm was installed on the vehicle to recharge the battery pack with the help of an alternator.

The field experiment was carried out on the terrain of length 50 m which was made similar to swamp peat just on the river side of the International Islamic University Malaysia with loading conditions of 2.43 kN and 3.43 kN and travelling speed of 10 km/h and 15 km/h. The vehicle was found to have much potential to travel over the field without the air-cushion. However, it was stuck once the air-cushion contacts with the terrain. By using the propeller additional thrust, it was operated without getting stuck. But, it was sliding on the terrain without adjusting much on the terrain. Therefore, much more power had required to develop the additional thrust. An intelligent air-cushion system is developed in this study with incorporating the Fuzzy Logic technique in order to optimize the load distribution ratio [11].

III. Theoretical Models

A. Traction Force

The traction force equation for the bottom of the vehicle's track ground contact part on peat terrain is calculated by using the mechanics of Refs. [6, 12]:

$$F_b = (A_t c + W_t \tan\varphi)\left[\frac{K_w}{iL}e^1 - \left(1+\frac{K_w}{iL}\right)\exp\left(1-\frac{iL}{K_w}\right)\right] + R_{drag} \quad (1)$$

where, $A_t = (L_{XY}\cos\theta + L_{YZ} + R_{rs}\sin\theta)(2B)$,

$L = (L_{XY}\cos\theta + L_{YZ} + R_{rs}\sin\theta)$ and $L_{XY} = \dfrac{z}{\sin\theta}$

In Eq. (1), F_b is the traction that develops at the bottom part of the track in kN, L is the ground contact length of the track in m, B is the width of the track in m, A_t is the area of the track ground contact part in m^2, W_t is the vehicle load supported by the track system in kN, c is the cohesiveness in kN/m^2, φ is the terrain internal friction angle in degrees, K_w is the shear deformation modulus of the terrain in m, i is the slippage of the vehicle in percentage, θ is the angle between the track of the 1st road-wheel to tensioned wheel and to the ground in degrees, and R_{drag} is the drag motion resistance which is developed due to the sliding of the air-cushion system over the terrain in kN.

The traction mechanics of the track at the side of the grouser is highly significant on the development of vehicle traction if the vehicle sinkage is more than the grouser height [12, 13] and is calculated as

$$F_s = 4HL(c + W_t \tan\varphi)\cos\alpha\left[\frac{K_w}{iL}e^1 - \left(1+\frac{K}{iL}\right)\exp\left(1-\frac{iL}{K_w}\right)\right] \quad (2)$$

where, $L = (L_{XY}\cos\theta + L_{YZ} + R_{rs}\sin\theta)$

In Eq. (2), F_s is the tractive effort developed at the side of the front idler grouser in kN, H is the height of the grouser in m, and α is the slip angle in degree. The total tractive effort of the vehicle can be defined as,

$$F_{tt} = F_b + F_s \quad (3)$$

B. Motion Resistance

In this study, the intelligent air-cushion system for swamp peat vehicle is designed mainly for supporting the vehicle's partial load and making the vehicle mobile to do the basic operation over the terrain. As the vehicle is designed to travel over the terrain at 10-15 km/h, so the aerodynamic motion resistance is ignored. Hence, the total motion resistance R_t will be only the sum up of motion resistance due to terrain compaction R_c, inner resistance R_{in}, and the dragging motion resistance R_{drag}. For peat terrain, the compaction resistance R_c is given by [12, 13].

$$R_c = 2B\left(\frac{k_p z^2}{2} + \frac{4}{3D_{htc}} m_m z^3\right) \quad (4)$$

where $z = \dfrac{-\left(\dfrac{k_p D_{htc}}{4m_m}\right) \pm \sqrt{\left[\left(\dfrac{k_p D_{htc}}{4m_m}\right)^2 + \dfrac{D_{htc}}{m_m} p'\right]}}{2}$, $D_{htc} = \dfrac{4BL}{2(L+B)}$

and $P' = \dfrac{W_t}{(L)(2B)} = \dfrac{W - p_c A_C}{2BL}$

where, p' is the normal pressure of the vehicle in N/m^2 and z is the sinkage in m, m_m is the surface mat stiffness in N/m^3, k_p is the underlying peat stiffness in N/m^3, D_{htc} is the track hydraulic diameter in m when air cushion touches the ground, A_C is the air-cushion effective area, W is the total weight of the vehicle in N, W_t is the weight supported by the two tracks (weight of driving system or weight supported by propulsion system) in N, and p_c is the cushion pressure in N/m^2. The total motion resistance of the vehicle can be defined as,

$$R_t = R_c + R_{in} + R_{drag}$$
$$= 2B\left(\frac{k_p z^2}{2} + \frac{4}{3D_{htc}} m_m z^3\right) + \left(\frac{W - p_c A_c}{1000\, g}\right)[222 + 3v]$$
$$+ p_c A_C \tan\varphi \quad (5)$$

where, v is the vehicle theoretical speed in km/h, g is the gravitational acceleration in m/s^2, W is the total weight of the vehicle in N, φ is the terrain internal friction angle in degrees, and $W_{v(ac)}$ is the weight supported by the air-cushion in N and can be expressed as

$$W_{v(ac)} = p_c A_c \quad (6)$$

IV. Fuzzy Logic System

Fuzzy Logic system is introduced in this study for the prediction of tractive performance of the vehicle with controlling the intelligent air-cushion system. The main advantage of Fuzzy Logic is that it can be tuned and adapted if necessary, thus enhancing the degree of freedom of the system [14].The general configuration of the fuzzy logic system, which is divided into four main parts [9] as shown in Fig. 2 are: (1) Fuzzification- which converts controller inputs into information that the inference mechanism can easily use to activate and apply rules, (2) Knowledge base- which contains a fuzzy logic quantification of the expert's linguistic description of how to obtain satisfactory control for a particular application, (3) Inference-which creates the control actions according to the information provided by the fuzzification module by applying knowledge about how best to control the plant, and (4) Defuzzification-which calculates the actual output, i.e. converts fuzzy output into a precise numerical value and then sends them to the physical system, so as to execute the control of the system.

For implementation of fuzzy values into the intelligent air-cushion system by using FLS, CH and CP were used as input parameters and TF and MR were used as output parameters. For fuzzification of these factors the linguistic variables very low (VL), low (L), medium (M), high (H), and very high (VH) were used for the inputs and outputs. In this study, the center of gravity (Centroid) method for defuzzification was used because these operators assure a linear interpolation of the output between the rules [15].

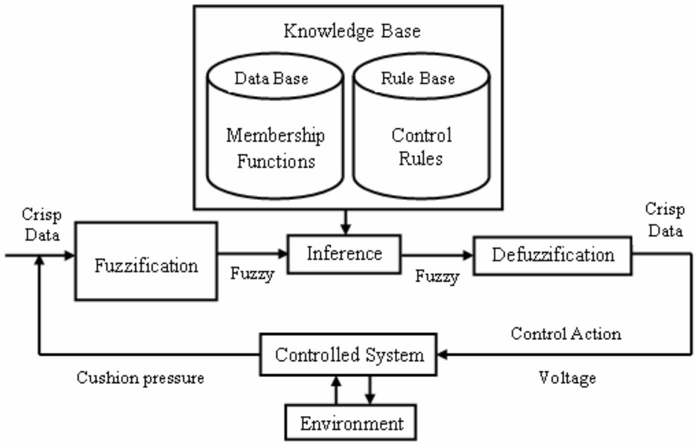


Fig. 2. Basic structure of the fuzzy logic system

For the two inputs and three outputs, a fuzzy associated memory or decision (also called decision rule) is shown in Table I. Total of 25 rules were formed.

The first block inside the fuzzy logic system (FLS) is fuzzification, which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. There is a degree of membership for each linguistic term that applies to that input variable.

TABLE I
RULE BASE OF FUZZY LOGIC SYSTEM

Rules	Input Variables		Output Variables	
	CH	CP	TF	MR
1	VL	VL	VL	VL
…….	……..	……..	……..	……..
10	L	VH	VH	M
…….	……..	……..	……..	……..
15	M	VH	H	L
…….	……..	……..	……..	……..
20	H	VH	M	L
…….	……..	……..	……..	……..
25	VH	VH	M	L

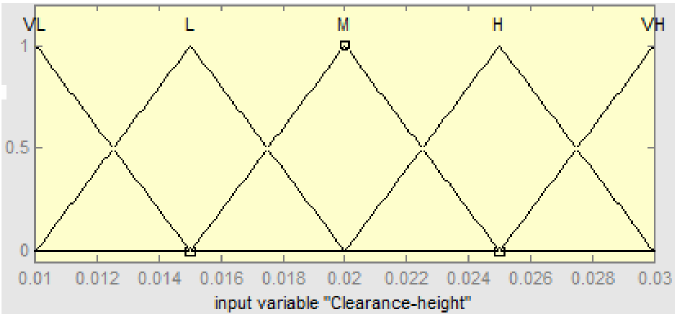
Fuzzifications of the used factors are made by aid follows functions and are determined by using measurement values.

$$CH(i_1) = \begin{Bmatrix} i_1; 0.01 \le i_1 \le 0.03 \\ 0; otherwise \end{Bmatrix} \quad (7)$$

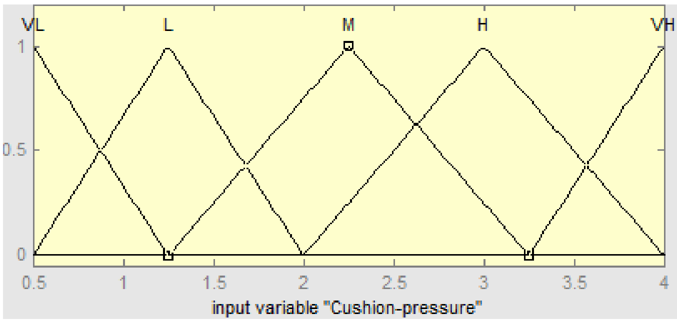
$$CP(i_2) = \begin{Bmatrix} i_2; 0.5 \le i_2 \le 4 \\ 0; otherwise \end{Bmatrix} \quad (8)$$

$$TF(o_1) = \begin{Bmatrix} o_1; 2 \le o_1 \le 4 \\ 0; otherwise \end{Bmatrix} \quad (9)$$

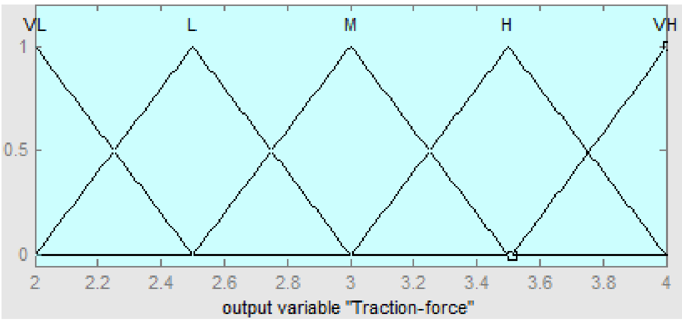
$$MR(o_2) = \begin{Bmatrix} o_2; 0.4 \le o_2 \le 2 \\ 0; otherwise \end{Bmatrix} \quad (10)$$



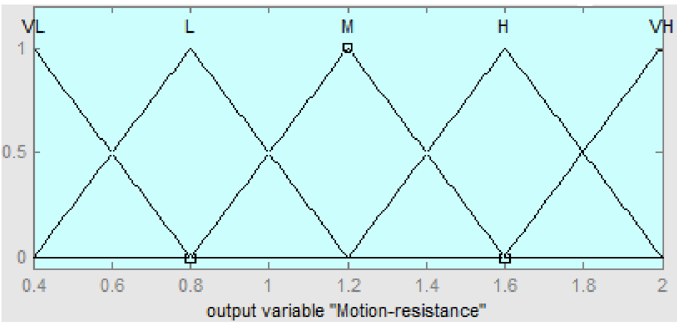
(a) clearance height



(b) cushion pressure



(c) traction force



(d) motion resistance

Fig. 3. Membership functions for CH, CP, TF and MR

Using MATLAB FUZZY Toolbox, prototype triangular fuzzy sets for the fuzzy variables, namely, clearance height (CH), cushion pressure (CP), traction force (TF) and motion resistance (MR) are set up. The membership values used for the FLS are obtained from the above formulas and are shown in the Fig. 3 (a)-(d).

The linguistic expressions and membership functions of CH obtained from the developed rules and formula (7) is given as following.

$$\mu_{VL}(i_1) = \begin{Bmatrix} 1; i_1 \langle 0.01 \\ \dfrac{0.015 - i_1}{0.005}; 0.01 \le i_1 \le 0.015 \\ 0; i_1 \rangle 0.015 \end{Bmatrix} \tag{11}$$

$$\mu_{L}(i_1) = \begin{Bmatrix} \dfrac{i_1 - 0.01}{0.005}; 0.01 \le i_1 \le 0.015 \\ \dfrac{0.02 - i_1}{0.005}; 0.015 \le i_1 \le 0.02 \\ 0; i_1 \rangle 0.02 \end{Bmatrix} \tag{12}$$

$$\mu_{M}(i_1) = \begin{Bmatrix} \dfrac{i_1 - 0.015}{0.005}; 0.015 \le i_1 \le 0.02 \\ \dfrac{0.025 - i_1}{0.005}; 0.02 \le i_1 \le 0.025 \\ 0; i_1 \rangle 0.025 \end{Bmatrix} \tag{13}$$

$$\mu_{H}(i_1) = \begin{Bmatrix} \dfrac{i_1 - 0.02}{0.005}; 0.02 \le i_1 \le 0.025 \\ \dfrac{0.03 - i_1}{0.005}; 0.025 \le i_1 \le 0.03 \\ 0; i_1 \rangle 0.03 \end{Bmatrix} \tag{14}$$

$$\mu_{VH}(i_1) = \begin{Bmatrix} 0; i_1 \langle 0.025 \\ \dfrac{i_1 - 0.025}{0.005}; 0.025 \le i_1 \le 0.03 \\ 1; i_1 \rangle 0.03 \end{Bmatrix} \tag{15}$$

Similarly, the linguistic expressions and membership functions of CP, MR, and TF could be calculated.

In defuzzification stage, truth degrees (μ) of the rules were determined for the each rule by aid of the min and max between working rules. For example, for CH = 0.022 m and CP = 2.25 kPa, using Fig. 3 (a) and (b) and using Table 1, it is observed that the rules 13, 14, 18 and 19 are on (i.e., their values are non zero) and all other rules have membership functions that are off (i.e., their values are zero). To get the fuzzy inputs the values for CH and CP are obtained as

$\mu_M(CH) = 0.6$, $\mu_H(CH) = 0.4$,

$\mu_M(CP) = 1$, $\mu_H(CP) = 0.25$

and the strength (truth values) of the four rules are obtained as

$\alpha_{13} = \min\{\mu_M(CH), \mu_M(CP)\} = \min(0.6,1) = 0.6$,

$\alpha_{14} = \min\{\mu_M(CH), \mu_H(CP)\} = \min(0.6,0.25) = 0.25$

$\alpha_{18} = \min\{\mu_H(CH), \mu_M(CP)\} = \min(0.4,1) = 0.4$,
$\alpha_{19} = \min\{\mu_H(CH), \mu_H(CP)\} = \min(0.4,0.25) = 0.25$

The output denoted by "TF^{crisp}" and "MR^{crisp}" can be calculated which represents the conclusions of the fuzzy controller. Due to its popularity, the "center of gravity" (COG) defuzzification method [16] is used for combing the recommendations represented by the implied fuzzy sets from all the rules.

$$TF^{crisp} = \frac{\sum b_i \mu_i}{\sum \mu_i} \tag{16}$$

$$MR^{crisp} = \frac{\sum b_i \mu_i}{\sum \mu_i} \tag{17}$$

In addition, the predictive ability of the developed system was investigated according to mathematical and statistical methods. In order to determine the relative error (ε) of system, the following equation was used [11]:

$$\varepsilon = \sum_{i=1}^{n} \left| \frac{y - \hat{y}}{y} \right| \frac{100\%}{n} \tag{18}$$

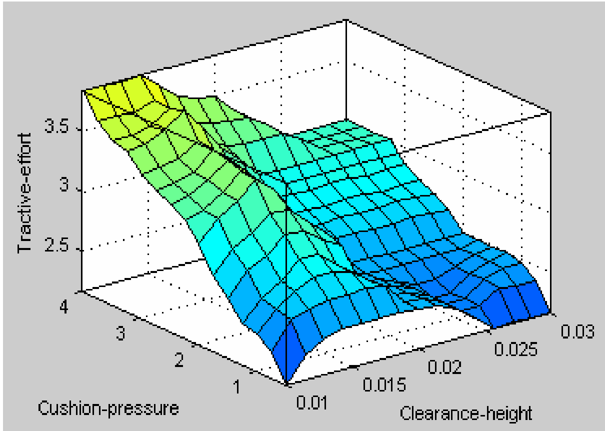
where, n is the number of observations, y is the actual value, and $\hat{y}$ is the predicted value. The relative error gives the deviation between the predicted and experimental values and it is required to reach zero.

Goodness of fit (η) of predicted system was calculated by following equation [11]:

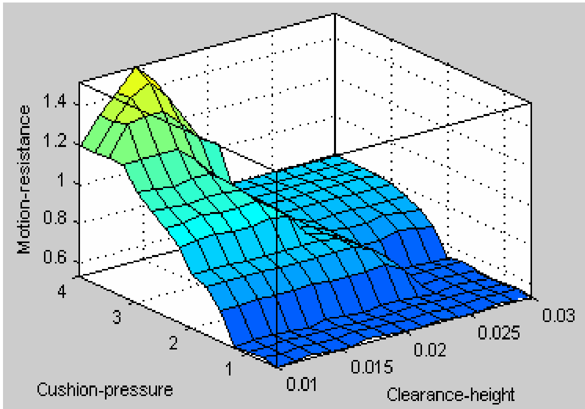
$$\eta = \sqrt{1 - \frac{\sum_{i=1}^{n} \left(y - \hat{y} \right)^2}{\sum_{i=1}^{n} \left(y - \bar{y} \right)^2}} \tag{19}$$

where, $\bar{y}$ is the mean of actual values. The goodness of fit also gives the ability of the developed system and its highest value is 1.

Using MATLAB, the fuzzy control surfaces are developed as shown in Fig. 4 (a), and (b). The relationships between clearance height and cushion pressure are on the input side, and controller outputs traction force and motion resistance are on the output side. The control surface is the output plotted against the two inputs, and displays the range of possible defuzzified values for all possible inputs. The plot results from the interpolation of rule base with twenty five rules as shown in Table I. The plot is used to check the rules and the membership functions on determining the effect of input parameters on the output parameters such as traction force, and motion resistance. Figures show that the output of the controller such as traction force, and motion resistance are within the range of the vehicle performance according to the results reported elsewhere [17-18].



(a) Traction force



(b) Motion resistance

Fig. 4. Control surfaces of the fuzzy inferring system

V. RESULTS AND DISCUSSIONS

The power consumption of the vehicle is optimized based on the total motion resistance which is mainly for compaction motion resistance and dragging motion resistance. From the experimental result, it is found that compaction and dragging motion resistance are mainly incurred due to the load distribution from the track system to the air-cushion system. The present study is focusing on load distribution (defined as the load transferred from the driving system to the air cushion system) for minimizing total power consumption. The effect of load distribution on the TF and MR for the HETAV are investigated. Figs. 5 and 6 show the relationship between load distribution ratio and traction force, and motion resistance respectively. Traction force of the vehicle almost gradually decreases with the increase of load distribution from the vehicle to the air-cushion system. The variation of traction force as a depending on load distribution is given in Fig. 5. Figure shows that the traction force is varied from 1.87 to 3.9 kN. The greatest changes in traction force occurred at a load distribution of 0.6. Based on previous researches [7, 19], the traction force is observed as about 2.5 kN for the load distribution ratio of 0.2 [20, 21].

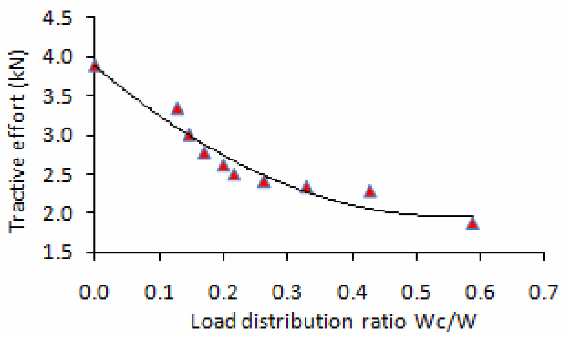


Fig.5. Effects of load distribution ratio on traction force.

Fig. 6 shows the variation of total motion resistance of the vehicle which is in the range of 0.45 to 1.32 kN. Lower value of motion resistance and greater value of traction force are found due to the additional traction force developed by the propeller. Furthermore, air-cushion system is a crucial part for the vehicle which reduces the vehicle motion resistance with reducing the vehicle sinkage. It is observed that the greater load distribution shows higher values of motion resistance due to the dragging motion resistance. Based on established theoretical model and the designed prototype, corresponding simulation and experimental results were carried out and an optimal load distribution ratio of 0.2 was obtained which could result in prediction of optimum tractive efficiency of 56%. The conclusion is supported by the author in the previous article [7] for the vehicle loading condition of 3.43 kN.

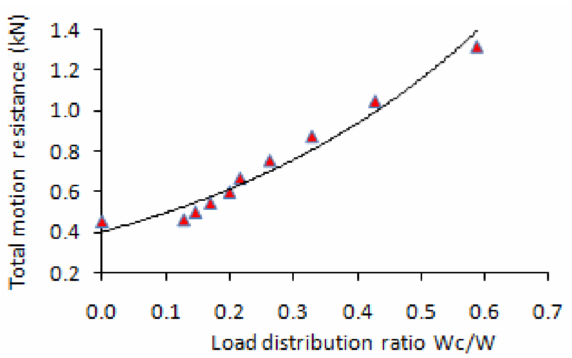


Fig.6. Effects of load distribution ratio on total motion resistance.

Effectiveness of the developed system has emphasized to the tractive performance of an intelligent air-cushion tracked vehicle (IACTV) [22]. Figure 7 and 8 show the correlation between traction force and motion resistance for the actual and predicted FLS values. The mean of actual and predicted values are 2.70 and 2.89 kN for traction force, and 0.75 and 0.73 kN for motion resistance. Furthermore, the correlation between actual and predicted values (from FLS model) of traction force and motion resistance for different load distribution conditions is also examined. The relationships are significant for all the parameters in different operating conditions. The correlation coefficients of traction force and motion resistance are found as 0.97 and 0.98 respectively.

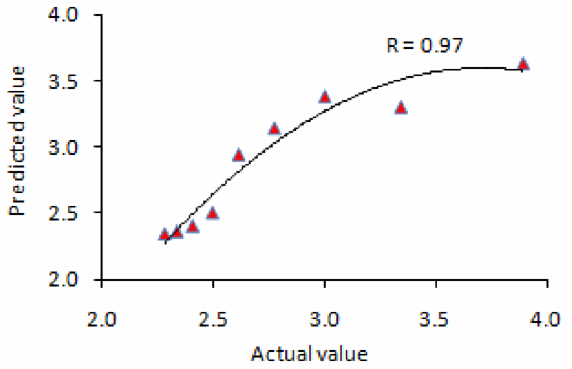


Fig.7. Correlation between actual and predicted values of traction force.

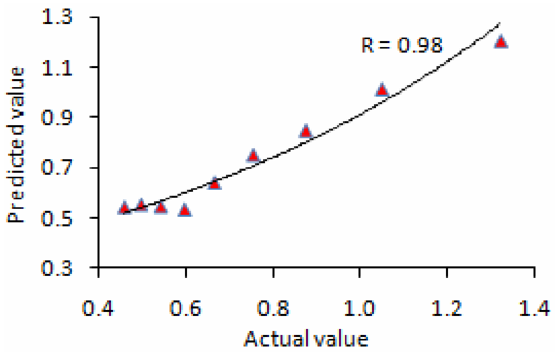


Fig.8. Correlation between actual and predicted values of total motion resistance.

The mean relative error of actual and predicted values from the FLS model on traction force and motion resistance are found as 5.58 % and 6.78 % respectively. For all parameters, the relative error of predicted values are found to be less than the acceptable limits. The goodness of fit of the prediction values from the FLS model on traction force and motion resistance are found as 0.90 and 0.98 respectively. All values are found to be close to 1.0 as expected.

VI. Conclusion

This paper presents an adaptive approach based on the use of fuzzy logic for the prediction of tractive performance for the hybrid electrical air-cushion track vehicle in transportation efficiency and fuel efficiency. In comparison to other predictive modeling techniques, fuzzy models have the advantage of being simple (rule base and membership functions) and robust. In this study, according to evaluation criteria of predicted performances of developed fuzzy knowledge-based model was found to be valid from the display result of the control surfaces. However, the conclusions drawn from this investigation are as follows:

(a) The mean relative error of actual and predicted values from the FLS model on traction force, and total motion resistance are found as 5.58 %, and 6.78 % respectively. For all parameters, the relative error of predicted values are found to be less than the acceptable limits.

(b) The goodness of fit of the prediction values from the FLS model on TF, and MR are found as 0.90, and 0.98 respectively. All values are found to be close to 1.0 as expected.

(c) The developed model can be used as a reference for the full scale prototype which is being carried out as the model will be developed with incorporating the output of the ultrasonic sensor, pressure control sensor, micro controller, and battery pH sensor.

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REFERENCES

[1] B. J. Jamaluddin, Sarawak: Peat agricultural use. Malaysian Agriculture Research and Development Institute (MARDI), pp. 1-12, 2002.

[2] R. Ataur, Y. Azmi, M. Zohadie, D. Ahmad, W. Ishak, Design and development of a segmented rubber tracked vehicle for Sepang peat terrain in Malaysia, Int. J. Heavy Vehicle Systems, 12 (3) (2005) 239-267.

[3] A. Bodin, Development of a tracked vehicle to study the influence of vehicle parameters on tractive performance in soft terrain, Journal of Terramechanics, 36 (1999) 167-181.

[4] H.S. Ooi, Design and development of peat prototype track type tractor. MARDI, Report No. 184, 1996.

[5] A. Rahman, A.K.M Mohiuddin, A. Hossain, Noraini, Irwan, Mobility of the Lpg-30 Wheeled Vehicle on Peat Terrain in Malaysia, 7th International Conference on Mechanical Engineering, ICME 2007, 28-30 December, 2007, Dhaka, Bangladesh.

[6] L. Zhe, Y. Fan, C.C. Bing, Design of a novel semi-tracked air-cushion vehicle for soft terrain, In. J. of Vehicle, Design, 31 (1) (2003) 112-123.

[7] R. Ataur, A. K. M. Mohiuddin, A.I. Faris, Y. Azmi, A. Hossain, Development of hybrid electrical air-cushion tracked vehicle for swamp peat, Journal of Terramechanics, 47 (2010) 45-54.

[8] A. Hossain, R. Ataur, M. Rahman, SK. Hasan, and H. Jakir, Prediction of Power Generation of Small Scale Vertical Axis Wind Turbine Using Fuzzy Logic, *Journal of Urban and Environmental Engineering (JUEE*), Vol. 3, No.2, pp. 43-51, 2009.

[9] A. Al-Anbuky, S. Bataineh, and S. Al-Aqtash, Power demand prediction using fuzzy logic, *Control Engineering Practice*, Vol. 3, No. 9, pp. 1291-1298, 1995.

[10] K. Carman, Prediction of soil compaction under pneumatic tires a using fuzzy logic approach, *Journal of Terramechanics*, Vol.45, pp.103-108, 2008.

[11] A. Hossain, R. Ataur, and A.K.M Mohiuddin, Intelligent Air-Cushion System of Swamp Peat Vehicle Control: Fuzzy Logic Technique, 8th International Conference on Mechanical Engineering, ICME 2009, 26-28 December, 2009, Bangladesh.

[12] A. Rahman, A.K.M. Mohiuddin, A. Hossain, A. F. Ismail, A. Yahya, Integrated mechanics of hybrid electrical air-cushion tracked vehicle for swamp peat, Int. J. Heavy Vehicle Systems, x (x) (2009) xxx-xxx, Inderscience (In Press).

[13] A. Hossain, R. Ataur, A.K.M. Mohiuddin, A.K.M.P. Iqbal, and M. Arifin, Modeling of the Developed Flexible Skirt Air-Cushion Track Vehicle Model, 4th BSME-ASME International Conference on Thermal Engineering, 27-29 December, 2008, Dhaka, Bangladesh.

[14] A. Rajagopalan, G. Washington, G. Rizzani, and Y. Guezennec, Development of Fuzzy Logic and Neural Network Control and Advanced Emissions Modeling for Parallel Hybrid Vehicles, *Center for Automotive Research, Intelligent Structures and Systems Laboratory,* Ohio State University, USA, December 2003.

[15] A. Hossan, R. Ataur, A.K.M. Mohiuddin, and Y. Aminanda, Power Consumption Prediction for an Intelligent Air-Cushion Track Vehicle: Fuzzy Logic Technique, Journal of Energy and Power Engineering (JEPE), x (x) (2010) xxx-xxx (In Press).

[16] K.M. Passino, and S. Yurkovich, Fuzzy control, Addison Wesley Longman, Inc. Menlo park, CA, USA, 1998.

[17] J. Y. Wong, Theory of Ground Vehicles, 4th Ed., New York, John Willey & Sons, Inc., 2008.

[18] J.Y. Wong, Performance of the air-cushion-surface-contacting hybrid vehicle for overland operation, Proceedings of the IMech E, 186 (50/72) (1972) 613-624.

[19] L. Zhe, Y. Fan, Load distribution control system design for a semi-track air-cushion vehicle, Journal of Terramechanics, 44 (4) (2007) 319-325.

[20] A. Hossain, R. Ataur, A.K.M. Mohiuddin, and Y. Aminanda, Modeling and Simulation on Load Distribution of Air-Cushion Track Vehicle, 6th International Conference and 13th Annual Paper Meet of Mechanical Engineering Division, The Institution of Engineers, Bangladesh (IEB), 30-31 December, 2009, Bangladesh.

[21] A. Hossain, R. Ataur, A.K.M. Mohiuddin, A.K.M.P. Iqbal, and M. Arifin, Modeling of the Developed Flexible Skirt Air-Cushion Track Vehicle Model, 4th BSME-ASME International Conference on Thermal Engineering, 27-29 December, 2008, Dhaka, Bangladesh.

[22] R. Ataur, A.K.M. Mohiuudin, and A. Hossain, Effectiveness of the Developed Instrumentation System on the Vehicle Tractive Performance Measurement, International Journal of Mechanical and Materials Engineering (IJMME), 2 (2) (2007) 118-124.