INTELLIGENT TRACTION CONTROL SYSTEM OF AN ELECTRIC GOLF CAR: Nonlinear Dynamics Investigation

Ataur Rahman* and AKM Mohiuddin

Department of Mechanical Engineering, Faculty of Engineering,
International Islamic University Malaysia, 50728 KL, Malaysia
*Corresponding Author: E-mail. arat@iiu.edu.my, Telephone.+6-03-61964544, Fax.+6-03-61964455

Abstract

Intelligent traction control system of an electric golf car has been developed by using the experience of the traction in order to maintain the golf car traction as required with utilizing optimum power. Compared with conventional control approach, fuzzy logic approach is more efficient for nonlinear dynamic systems and embedding existing structured human knowledge into workable mathematics. The purpose of this study is to investigate the relationship between vehicle's input parameters of power supply (PI) and moisture content (MC) and output parameter of traction force (TF) and Power Consumption (P). Experiment has been conducted in the field to investigate the vehicle traction and the result has been compared with the developed fuzzy logic system (FLS) based on Mamdani approach. Results show that the mean relative error of actual and predicted values from the FLS model on TF is found as 7.68 %, which is less than the acceptable limit of 10%. The goodness of fit of the prediction value from FLS is found close to 1.0 as expected and hence shows the good performance of the developed system.

Keywords: Golf car; Nonlinear intelligent traction system; Fuzzy logic system; power strategy

1. Introduction

Traction controllers improve a driver's ability to control a vehicle under adverse conditions, such as a wet or icy road. The fast and stable acceleration and deceleration can be maintained by controlling the traction force between the vehicle's tires and the road (Rahman et.al.2011, Tan 1988, Tan 1989, Leiber 1983, Layne 1993, Kachroo 1994). The effective control of a vehicle's traction is essential for lateral and longitudinal guidance systems. The intelligent traction control system becomes an important option for controlling the vehicle. Traction controllers regulate wheel slip with normalizing the difference between wheel and vehicle speed. Wheel slip strongly influences the tire-road adhesion coefficient. The traction control system is complicated to establish especially for off-road vehicle as it is highly non-linear due to the changing of road conditions significantly with time. Moreover, the tire-road interaction is difficult to measure and to estimate (Tan 1989, Leiber 1983, Layne 1993, Kachroo 1994). The uncertainty and non-linearity associated with traction control make a fuzzy-logic control approach appealing (Hossain et al. 2011, Layne 1993, Tong 1977, Lee 1990, Wang 1992). Fuzzy-logic-based traction control could substantially improve longitudinal performance and offer significant potential for optimal control of driven wheels (Khatun, 2003). This paper presents fuzzy knowledge based model for prediction the traction force and justify the traction controller development for investigate the vehicle longitudinal traction performance. A fuzzy logic approach is appealing for traction control because of the nonlinearity and time-varying uncertainty involved in traction control systems. The controller is attractive because of its ability to maximize acceleration and deceleration regardless of road conditions. However, it is found through simulations the controller's performance to regulate vehicle dynamic traction at any desired value of wheel slip.

1.1 ELECTRIC GOLF CAR CONFIGURATION

The electric golf car has been given by Jabson and Janshon for the establishment of optimum power management system. The specification of the golf cart is stated in Table 1. The car is operated with a DC motor of 48 volt DC, series wound, 3.1@2400RPM powered by a battery pack of Six 8 volts, 117 min @ 56 amp.

Table 1: Specification of golf car

Drive Motor	48 volt DC, series wound
Horsepower	10.0@ 1125RPM (intermittent)
Drive Unit	12.3 to 1 direct drive axle,double reduction helical gear
Electrical system	48 volts
Batteries	Six 8 volts, 117 min @ 56 amp.
Key or pedal start	Pedal
Steering	Self adjusting rack & pinion
Front Suspension	Independent leaf spring
Rear Suspension	Leaf Springs
Brakes	Self adjusting drum
Frame/ chassis	Aluminum I-Beam
Front and rear tires	24 x 14.4 wide
Overall length	91.5in (232cm)
Overall width	47.25in (120cm)
Wheelbase Differential	65.5in (166.4cm)
Overall Height	68.5 in (174cm)
Ground Clearance	4.5in (11.4cm)

This study is conducted on the effectiveness of fuzzy knowledge based model for prediction the traction force and justify the traction controller development for investigate the vehicle longitudinal traction performance and power optimization. It is reported that the vehicle is powered by the power pack which is claimed to operate for two hours. But it is operated only for one and half hours instead of two hours due to the unnecessary lost of the power. The establishment of optimum power management system is considered as the main purpose of this study for the operation cost effectiveness of the golf cart.

2. **Theory associated to the study**

Traction controls intervene to maintain stability, reduction of yawing moment reactions, provide optimum propulsion at all speed, and reduce driver workload. We consider two forces acting on the vehicle body: driving (longitudinal) and side (lateral) forces. As the tracton force developed by a tire is proportional to the applied wheel torque under steady state conditions, slip is a function of traction force.. The slip is defined as the ratio of the linear velocity at the tire centre to the spin velocity of straight free-rolling tire expressed as a percentage. The slip of the wheel could determine by using the cycloid principle. A cycloid is the curve defined by a fixed point on a rim of the wheel as it rolls, or, more precisely, the locus of a point on the rim of a circle rolling along a straight line.

Points of rolling rim describe a cycloid. Consider a wheel of radius R_0 which is free to roll along the x-axis as shown in Figure 1.1.

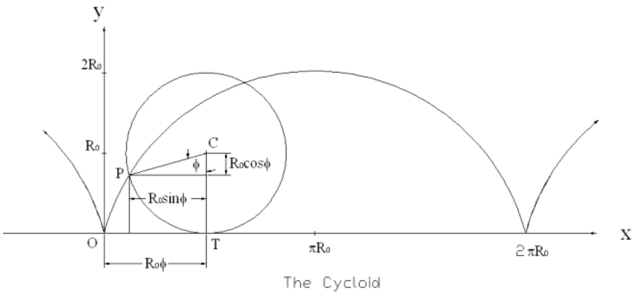


Figure 1: Typical cycloid for the wheeled vehicle rolling on peat terrain

$$x = R_0\phi - R_0\sin\phi = R_0(\phi - \sin\phi)$$

(1)

$$y = R_0 - R_0\cos\phi = R_0(1 - \cos\phi)$$

(2)

It is assumed that the driving wheels operate with exerting a longitudinal force (traction force) due to the applied driving torque at the wheel, and its elastic deformation and the accompanying soil deformations create a condition as if the wheels roll with slip radius R_z. The radius R_z can be measured by using the following equation:

$$R_z = R_0(1 - i_{rd}) \qquad (3)$$

In Equation (3), i_{rd} is the slippage of wheel relative to the terrain in percentage which is induced due to the friction at the interface between driving wheel and terrain, V is the linear speed at the wheel in m/s, and ω is the angular speed of the tire in rad/s. The resulting slip radius R_i can be calculated by using the following equation:

$$R_i = R_z(1 - i) = R_0(1 - i_r)$$

(4)

In Equation (4), i_r is the resultant slippage,

$$i_r = i + i_{rd} \quad \text{and} \quad i_r = \left(1 - \frac{V}{R_i\omega}\right)$$

The vehicle ground contact pressure (P_c) is higher than the normal ground pressure (P_g) when the tires of the car are inflated by 100%. In this case the vehicle would have higher sinkage and leads the higher motion resistance. The inflation pressure of the tire is reduced by 5%, 10%, 15%, 20% and 25% for the moisture content of 40%, 50%, 60%, 70% and 80% respectively. The tire deflection and contact length increase significantly with decreasing the inflation pressure of the tires. The contact length of the tire H can be computed by considering the vertical equilibrium of the tire. The length of the contact surface is definitely the function of the tire deflection. Therefore, H is computed by considering the tire deflection δ.

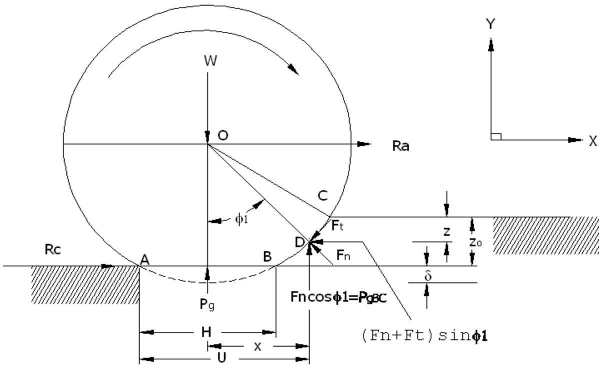


Figure 2: Tyre-terrain interaction model

From the wheel-terrain interaction model as shown in Figure 2, the traction force of the vehicle could be determined by applying the Newton's motion law:

$$(F_t + F_n)\sin\varphi_1 - R_c - R_a = \frac{W}{g}\frac{d}{dt}(v)$$

$$(F_t + F_n)\sin\varphi = R_c + R_a + \frac{W}{g}\frac{d}{dt}(v) \quad (5)$$

where, $(F_t + F_n)\sin\varphi = 2B\int_0^L \tau dx$,

$\tau = \tau_{\max}\left(1 - e^{-j/K_w}\right)$ and $F_t + F_n = F$

In equation (9), F_t is the tangential force in kN, F_n is the normal force that exert from the terrain in kN, W is the total of the vehicle weight in kN, R_c is the motion resistance due to terrain compaction in kN,

3. Membership Function and Fuzzification

For implementation of fuzzy values into the system by using fuzzy logic system (FLS), moisture content (MC), sinkage (SL) and power deliver (PD) are used as input parameters and traction force (TF) is used as output parameter. For fuzzification of these factors the linguistic variables low (L), medium (M), and high (H) are used for the input parameters and very low (VL), low (L), medium (M), high (H), and very high (VH) are used as output parameters. The logical AND is implemented with the minimum operator, the aggregation method is maximum, and the center of gravity defuzzification method is used

The units of the used factors are: MC (%), SL (%) PD (kW) and TF (kN). For the three inputs and one output, a fuzzy associated memory or decision is formed as regulation rules.

Control Surface of the Fuzzy Inferring System

The control surfaces display the range of possible defuzzified values for all possible inputs of *MC*, *SL* and *PD*. Both figures depict the impacts of terrain and vehicle parameters on the traction force. The surface plot shown in Fig. 12 depicts the impacts of *MC* and *PD* parameters on *TF*. It shows that as the power delivering and moisture content increase, there is concomitant increase in traction force as expected. The traction force reaches the apex when the power delivering and moisture content both reach their respective maximum level. Fig. 13 demonstrates as the power delivering increases up to a certain amount, especially at lower level of vehicle slippage, traction force is lower. However, traction force increases with the further increase of power delivering even at lower level of slippage. Hence, lower level of slippage does not contribute much towards traction force. But it could be noted that the effect is highly significant at the higher level of slippage. Traction force increases with the increase of vehicle slippage, although the effect is less prominent at the level of power delivering.

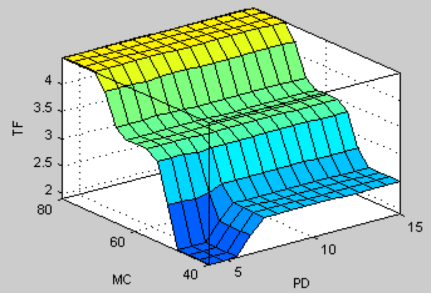


Figure 3. Control surface of the fuzzy inferring system.

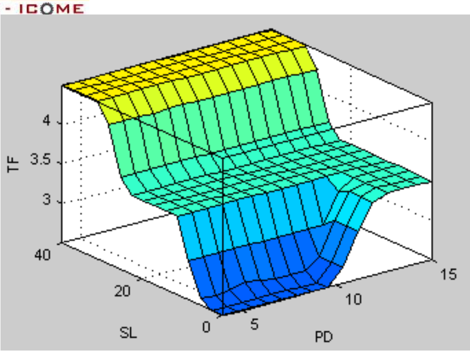


Figure 4. Control surface of the fuzzy inferring system.

The prediction accuracy of the developed fuzzy logic system has been investigated according to mathematical and statistical methods (Carman, 2008). In order to establish the relative error (ε) of structure, the subsequent equation is used:

$$\varepsilon = \sum_{i=1}^{n} \left| \frac{y - y^{\wedge}}{y} \right| \frac{100\%}{n} \qquad (6)$$

The goodness of fit (η) of the predicted system is calculated by the following equation:

$$\eta = \sqrt{1 - \frac{\sum_{i=1}^{n} (y - y^{\wedge})^2}{\sum_{i=1}^{n} (y - y_{mean})^2}} \qquad (7)$$

Where, n is the number of interpretations, y is the measured value, $y^{\wedge}$ is the predicted value, and y_{mean} is the mean of measured value.

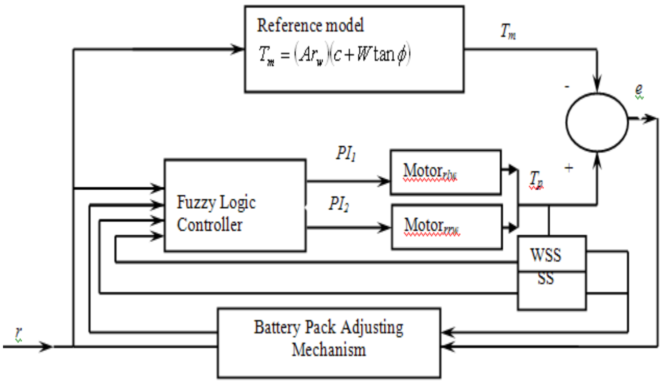


Figure 5: Fuzzy Logic Controller Model

Power management of an off-road vehicle is established in order to minimize fuel consumption, while enhancing or maintaining the vehicle tractive performance. In this case, fuzzy logic controller is used which can effectively control the motor output torque. A schematic of this control strategy is shown in Fig. 17. At any particular points, the power supply from the battery to the DC motor is determined based on the demand torque of the vehicle. The optimal power supply from the battery to the DC motor optimal torque is adjusted initially with the battery

pack adjusting mechanism which is mainly based on the moisture content (MC) of the terrain. The

maximum power supply is made to the DC motor for the maximum car dynamic torque development with the help of the FLC. The battery packs adjusting mechanism to control the variable power input (*PI*) for the plant (motor) to develop the traction torque (T_p) with FLC. It is noted that the sensing inputs of the wheel speed sensor (WSS) and slope sensor (SS) are effective for the car at high speed and climbing on slope, respectively.

Consider a system with the plant model (Motor) of the form,

$$\dot{y}_p = -a_p y_p + b_p u \qquad (9)$$

where u is the control variable, and y_p is the measured state output torque in Nm, a_p and b_p are unknown coefficient. Assuming that it is desired to obtain a closed – loop system described by

$$\dot{y}_m = -a_m y_m + b_m r \qquad (10)$$

where r is the control variable, and y_m (T_m) is the reference torque in Nm, a_m and b_m are known coefficient. After knowing the parameters of the plan, the following control law gives the model as follows:

(i) For the motor of rear left wheel (Motor$_{rlw}$),

$$u_1(t) = br(t) - ay_{p1}(t) \qquad (11)$$

(ii) For the rear right wheel (Motor$_{rrw}$),

$$u_2(t) = br(t) - ay_{p2}(t) \qquad (12)$$

with

$$b = \frac{b_m}{b_p}\ ; \quad a = \frac{a_m - a_p}{b_p} \quad and \quad y_p = y_{p_1} + y_{p2}$$

The output of the plant y_{p1} (Tp_1) and y_{p2} (Tp_2)are not equal all the ways. It equality depends on the track conditions. The error variable of the control model,

$$e(t) = y_p(t) - y_m(t) \qquad (13)$$

The rate of change of the error can be defined as,

$$\begin{aligned}\frac{de(t)}{dt} &= \left[-a_p y_p(t)+b_p u(t)\right]-\left[-a_m y_m(t)+b_m r(t)\right]\\ &= -a_m e(t)+\left[a_m-a_p-b_p a(t)\right]y_p(t)+\left[b_p b(t)-b_m\right]r(t)\end{aligned} \tag{14}$$

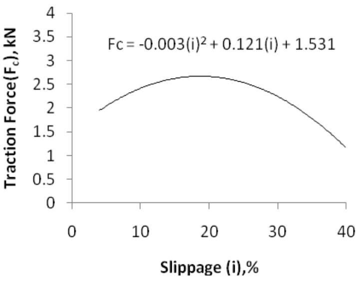
The equation 14 indicates that the error of the control model will be zero if a(t) and b(t) are zero. The emphasis is given to construct a battery pack adjustment mechanism in MRATCS that will drive the parameters a(t) and b(t) to appropriate values, such as the resulting control law for the motor forces the motor output yp(t) to follow the model output ym(t). In order to achieve this target, the Lyapunov function is introduced,

$$V(e,a,b)=\frac{1}{2}\left[e^2(t)+\frac{1}{b_p\gamma}\left(b_p a(t)+a_p-a_m\right)^2+\frac{1}{b_p\gamma}\left(b_p b(t)-b_m\right)^2\right] \tag{15}$$

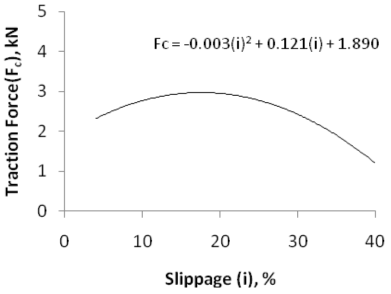
where $\gamma > 0$. This function will be zero when *e (t)* is zero and the controller parameters *a(t)* and *b(t)* are equal to the optimal values.

4. Result and Discussion

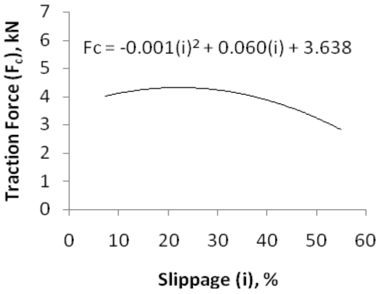
Figure 6 shows the typical performance of a golf car over the field. Vehicle performance test was conducted without using controller for the different moisture contents at constant speed with two passengers after installing the important instrumentation system on the vehicle. The traction force increased with increasing vehicle slippage up to a certain limit and then decreased with further increase of slippage. It is observed that the traction force varies from 0.688 kN to 5.541 kN. The degree of traction force was usually larger for higher moisture content. Hence, moisture content was the major contributory factor on traction force as compared to vehicle slippage. As expected, the greatest value in traction force was observed at a slippage of 23 % and moisture content of 70 %. Figure 7 shows the correlation between actual and predicted values (from FLS model) of vehicle traction force for different vehicle slippage. The correlation coefficient is found as 0.93 which is significant in operation. Therefore, it can be inferred that the developed fuzzy logic system can explain up to 86.5 % (R^2 = 0.865) of the total variability of traction force.



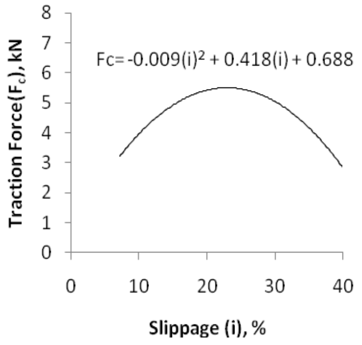
(a) MC =40%



(b) MC =50%



(c) MC=60%



(d) MC =70%

Figure 6: Vehicle traction

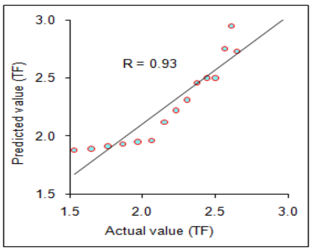


Figure 7: Correlation between actual and predicted values of traction force

5. CONCLUSION

Prediction of vehicle performance characteristics is necessary for agricultural applications. In this paper, the fuzzy logic system is presented and described its implementation on traction force prediction for an electric golf car. The developed fuzzy rules give a very good understanding about the interaction between important soil parameters and their influence on vehicle traction. The results indicate that the prediction accuracy of the developed fuzzy knowledge-based model is reasonably good. However, the main conclusions drawn from this study are as follows:

1. The mean relative error of actual and predicted values from the FLS model on traction force is 5.74 % which is less thanthe acceptable limit.
2. The correlation coefficent is found as 0.93 which is significant in operation and the goodness of fit value is found to be close to 1.0 as expected.
3. The system is quite easy to develop and it could be modified easily if the soil parameters are changed in agricultural application.

ACKNOWLEDGEMENT– The authors are grateful for the financial support provided by International Islamic University Malaysia (IIUM) for this project.

REFERENCES

[1] Bekker, G. 1969. *Introduction to Terrain-Vehicle Systems,*University of Michigan Press, MI.

[2] Hossain, A., Rahman, A. and Mohiuddin, AKM. 2011. Nonlinear control of an Intelligent Air-cushion system of Swamp Vehicle. Proc. IMech E, part D, Journal of Automobile Engineering, Vol.225, No.6, pp:721-734.

[3] Rahman, A., Mohiuddin, AKM and Sany, I.I. 2011. A study on the development of traction control system of a golf car. Int. J. of Electrical and Hybrid Vehicle. Vol.3, No.1, pp: 47-61.

[4] Gopal, M. *Digital control and state variable methods: conventional and intelligent control systems*. 3rd edition, Tata McGraw-Hill Education Pvt. Ltd. 2009.

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

[6] Ivanov, V., Shyrokau, B., Augsburg, K., and Algin, V. Fuzzy evaluation of tyre-Surface interaction parameters. *Journal of Terramechanics*, 2010, 47, 113-1130.

[7] Marakoglu, T. and Carman, K. Fuzzy knowledge-based model for prediction of soil loosening and draft efficiency in tillage. *Journal of Terramechanics*, 2010, 47, 173-178.

[8] Rajasekaran, S. and Vijayalakshmi Pai, G. A. *Neural networks, fuzzy logic, and genetic algorithms: synthesis and applications*. Prentice-Hall of India Private Limited, New Delhi, 2007.

[9] P. Khatun, C. M. Bingham*, Member, IEEE*, N. Schofield, and P. H. Mellor.2003. Application of Fuzzy Control Algorithms for Electric Vehicle Antilock Braking/Traction Control Systems. IEEE Transaction on vehicular technology, Vol.52, No.5, 2003.

[10] Kachroo, P.. and M. Tomizuka. 1994. Vehicle Traction Control and Its Application. California PATH Research Paper, UCB-ITS-PRR-94-08.

[11] Layne, J., K. Passino and S. Yurkovich. 1993. Fuzzy Learning Control for Anti-skid Braking Systems. *IEEE Trans. on Control Systems Technology*, Vol. 1, No. 2.

[12] Lee, C. C. 1990. Fuzzy Logic in Control Systems: Fuzzy Logic Controller, part I and II. *IEEE Trans. on Syst., Man. and Cybern.*, Vol. SMC-20, No. 2, pp. 404-435.

[13] Tong, R. M. 1977. A Control Engineering Review of Fuzzy Systems. *Automatica*, Vol. 13, pp.559-569.

[14] Wang, L. W. 1992. Stable Adaptive Fuzzy Control of Nonlinear Systems. *Proceedings of the31st Conf. on Decision and Control*.