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HUMAN DRIVING SKILL FOR HUMAN ADAPTIVE MECHATRONICS APPLICATIONS BY USING NEURAL NETWORK SYSTEM

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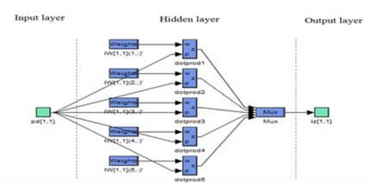
Graphical abstract



Abstract

The existence of the new improvement system for Human Machine System (HMS) is called as Human Adaptive Mechatronic (HAM) system. The main difference between these two systems is the relationship between human and machine in the system. HMS is one way relationship between human and machine while HAM is a two way relationship between human and machine. In HAM, not only human need to adapt the characteristics of machine but the machine also has to learn on human characteristics. As a part of mechatronics system, HAM has an ability to adapt with human skill to improve the performance of machine. Driving a car is one of the examples of application where HAM can be applied. One of the important elements in HAM is the quantification of human skill. Therefore, this project proposed a method to quantify the driving skill by using Artificial Neural Network (ANN) system. Feedforward neural network is used to create a multilayer neural network and five models of network were designed and tested using MATLAB Simulink software. Then, the best model from five models is chosen and compared with other method of quantification skill for verification. Based on results, the critical stage in designing the network of the system is to set the number of neurons in the hidden layer that affects an accuracy of the outputs.

Keywords: Human machine system (HMS), human adaptive mechatronics (HAM), artificial neural network (ANN), driving skill.

1.0 INTRODUCTION

Nowadays, machine is needed by human to help us in daily lives. But most of the machine cannot operate independently without guided and controlled by the human. Therefore, human factor is the main consideration in order to design the motion control system [1]. Unfortunately, the main limitation of HMS is the adaptation of machine as respect to human reaction which the communication between human and machine is not in balance condition. Most of existing machine only required human to understand and learn on machine characteristics which is refer to one way relationship [1, 2]. HAM will be defined as an intelligent mechanical system to adapt the human skills in various kind of environment, help a system to improve human skill and to support HMS to achieve the best performance [3]. In other words, HAM will be described as the recognition of human characteristics based on the skill levels of human to enable suitable response [4]. One of the research [5] explains a system is supposed to be adaptive if the system has a capacity of adaptation to respond to a new situation successfully. In HAM, the system is not directly focus to replace the human as a main controller, but more to support the human in handling a machine. It will determined by driving a car which can be considered as the manual complicated process in our real life [6]. In other words, driving is refers to the highly complex task which contains a multiple critical task execution and dynamic interleaving process [7]. In other side of view, it describes that the ability to achieve a very possible smallest error within a short period of time when driving a car, which the error is inversely proportional to the time performance. The important element in HAM is the quantification of human skill. But the concept of skill is too ambiguous [2].

This paper proposes a method to quantify the index driving skill by using Artificial Neural Network (ANN) system [2, 8, 9]. In literature, there are other researchers who have proposed method for driving skill classification [8, 10]. In [8], Sasaki provides the index driving skill based on time and error. Unfortunately, it proven that the formula only proven by considered the distance between certain points as a method to quantify the index skill. Based on [10], M. Hafis Izran has carried out the experiment through a Graphical User Interface (GUI) of the driving simulator [10, 11]. 20 participants were selected from different background and the experiment was done through two conditions which are Expected and Guided Condition (EGC) and Sudden Transitory Conditions (STC). Thus, in this paper, all formula development and data collection are based on [10] as the main reference.

2.0 FORMULA DEVELOPMENT

As mentioned in [10], M. Hafis Izran's synthetic data has been created by using the logical conditions and the definition of skill in HAM as depicted in Table 1. The table is based on the principle of a 'Truth Table' as applied in Digital Electronics. For example, if the human subject performed a task in a fast time (F = Fast) with a small error (S = Small), therefore the index skill, J of human subject is rated as Very Highly Skilled (VHS). Based on Table 1 and Table 2, the new synthetic data has been created to validate the simulation results. In M. Hafis Izran's synthetic data, there are only two types of En which are S (Small) and M (Medium), with two types of Tn which are F (Fast) and Sl (Slow). Therefore, for the new synthetic data, there are 5 types of En are produced which are VS (Very Small), S (Small), M (Medium), L (Large), and VL (Very Large). Another 5 types of Tn such as VF (Very Fast), F (Fast), MD (Medium), SL (Slow), and VSL (Very Slow) has developed to validate the network object.

Table1 M. Hafis Izran's Synthetic Data

E_n	T_n	*J*
S	F	VHS
S	M	HS
S	Sl	MS
M	F	HS
M	M	MS
M	Sl	LS
L	F	MS
L	M	LS
L	Sl	VLS

Legend: S- Small, M- Medium, L- Large, F- Fast, Sl- Slow, VHS- Very Highly Skilled, HS- High Skilled, MS- Medium Skilled, LS- Low Skilled, VLS- Very Low Skilled.

For proposed skill index formula [10], only some of the details will be mentioned here since it has been discussed in other research. The experiment has been done by using a driving simulator [11]. The skill index, J is used to measure the human performance in terms of normalized time and error. Formulas to normalize time and error are also presented with a few assumptions made. The classification of J into five levels is also shown.

Table 2 M. Hafis Izran's Synthetic Data with Equivalent Value of T_N, E_N and J

E_n	T_n	J
0.00	0.00	1.00
0.00	0.50	0.75
0.00	1.00	0.50
0.50	0.00	0.75
0.50	0.50	0.50
0.50	1.00	0.25
1.00	0.00	0.50
1.00	0.50	0.25
1.00	1.00	0.00

2.1 Normalization – In General

The formula for normalizing the raw data is shown in Eq. 1.

$$X_n = \frac{X - X_n}{x} = 1 - \frac{X_{\min}}{x} \qquad \text{(Eq. 1)}$$

where,

X = a real value or score,

$X_{\min}$ = a minimum score and $X \geq X_{\min}$

If $X \to X_{\min}$, then $X_n \to 0$

If $X_n \to \infty$, then $X_n \to 1$

2.2 Normalized Time, T_n

The formula to normalize time is shown in Eq. 2. In reality, the value can never reach one.

$$T_n = 1 - \frac{T_B}{t} \qquad \text{(Eq. 2)}$$

where,

T_B = the best theoretical time by assuming the track is a straight line; ignoring the corners and braking; and using the maximum speed during operation.

t = time elapsed by each subject.

Based on (2), a human subject can obtain zero in normalized time if $t = T_B$, which is the fastest time. In other words, if he/she is very fast to complete any track, then $T_n \to 0$. Similarly, he/she can obtain one in T_n when the time is the slowest $T \to \infty$.

2.3 The Best Time, T_B

As explained above, the best time is the ideal elapsed time to complete any track based on maximum speed used and is obtained by using the following formula in Eq. 3:

$$T_B = \frac{L}{V_{\max}}, \qquad \text{(Eq. 3)}$$

where,

L = length of track in driving simulator (units).

$V_{\max}$ = maximum speed in driving simulator, which is 600 unit/second.

3.0 PROPOSED INDEX DRIVING SKILL FORMULA

3.1 Data Collection

The first step in the network design process is to collect and to prepare the data. Two variables are assigned as the input neurons which are normalized time, Tn and normalized error, En. Skill index, J acts as the output product. M. Hafis Izran's experimental data are used to train and validate the network where 400 data are used for simulation and 500 data for validation. Data collections are produced by two types of experiments which are Expected and Guided Conditions (EGC) and Sudden Transitory Conditions (STC).

3.2 Create, Configure and Initialize the Network

After the data for simulation has been collected, the next procedure is to create the network object. In this research, 'feedforwardnet" is used to create a multilayer feedforward network. Feedforwardnet automatically assign processing functions to the network inputs and outputs. These functions transform the input and target values into the values that are better suited for network training.

3.3 Train the Network

Once the network weights and biases are initialized, the network is ready for training. Multilayer feedforward network will be used for function approximation or nonlinear regression. It requires a set of proper network behavior which is the network inputs and the target output. In this case, the network input consists of two types of variables which are normalized time, Tn and normalized error, En. The target output is driving index skill, J. The performance function for feedforward networks is Mean Square Error (MSE) which used to calculate the average squared error between the network outputs, J. The process of training a neural network involves tuning the values of the weights and biases of the network to optimize the network performance.

This research use 'trainlm' as the training function for 'feedforwardnet'. Trainlm is a network training function that updates weight and bias values according to Levenberg-Marquardt optimization. Trainlm is the fastest function but it tends to be less effective for large networks since it need more memory and more computation time. Besides, trainlm also perform better function fitting or nonlinear regression problem rather than on pattern recognition. In ANN design, selecting the number of hidden layers is a critical part of designing a network and it is not straightforward as input and output layers. There is no mathematical approach to get the optimum number of hidden layers [12]. Nevertheless, the number of hidden layers can be chosen based on the training of the networks by using various configurations, and the selection of the configuration with the fewest number of layers and neurons, which still yields the minimum Root Mean Square (RMS) error quickly and efficiently. Therefore, the number of neurons in the hidden layer has set into 5 (Model 1) as depicted in Fig. 1 and it will be increased to 10 (Model 2), 15 (Model 3), 20 (Model 4), and 50 (Model 5) for validation process.

4.0 RESULTS

The accuracy will be determined by calculating the percentage of accuracy of average value of J in simulation data. Based on Table 4, Model 2 is the highest percentage of accuracy followed by Model 1. However, there is not much differentiation between both models since the total FALSE for Model 1 and Model 2 are 10 and 9 respectively. Therefore, Model 1 and Model 2 are acceptable. Based on Table 3 and Table 4, Model 1 is selected as the best model of Artificial Neural Network (ANN) to quantify the index of human driving skill for HAM applications due to highest accuracy of index skill, J in three different tracks; ellipse track, square track, and triangular track.

5.0 SUMMARY

As a summary, a function of "feedforwardnet" has been used as a tool to create the network object. These functions create a multilayer feedforward network which consists of the number of neurons in the hidden layer. The critical stage in designing of the ANN system is to set the number of neurons in the hidden layer. Too few numbers of neurons generates small number of parameters and provides fast training, but it can lead to under fitting. However, too many numbers of neurons can produces over fitting and it requires more computation time.

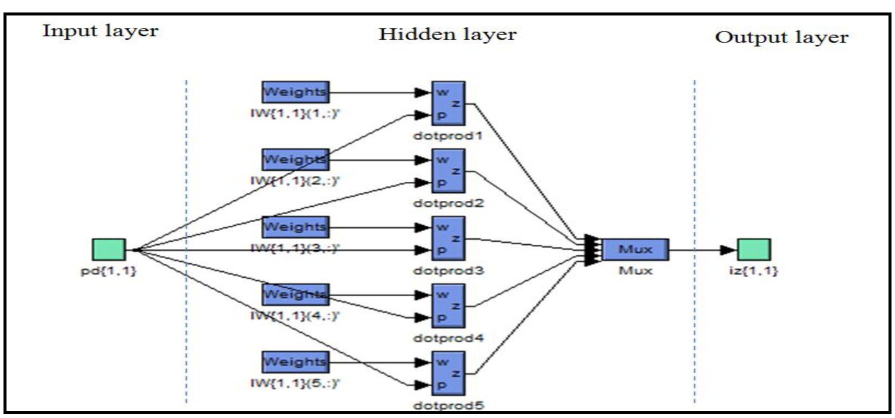


Figure 1 Description of Model 1 with 5 neurons in the hidden layer

Table 3 Percentage of Accuracy of J within 5 Different Tracks

Model	Straight	Circular	Ellipse	Square	Triangle
1	99.811%	99.863%	99.999%	99.949%	99.978%
2	99.646%	99.917%	99.905%	99.947%	99.914%
3	99.923%	97.882%	99.981%	99.415%	99.616%
4	99.544%	98.300%	99.876%	99.344%	99.315%
5	99.627%	98.326%	99.511%	99.906%	99.571%

Table 4 Percentage of Accuracy of J by Each Model Through Synthetic Data

Analysis	Total FALSE result	Total TRUE result	Error	% Error	% Accuracy
1	10	15	0.40	40.00%	60.00%
2	9	16	0.36	36.00%	64.00%
3	12	13	0.48	48.00%	52.00%
4	16	9	0.64	64.00%	36.00%
5	15	10	0.60	60.00%	40.00%

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