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Study of Human Driving Skill in Expected and Guided Conditions

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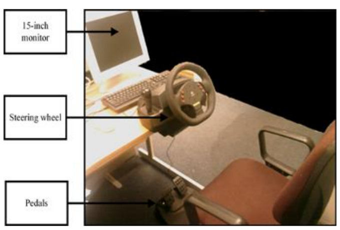
Graphical abstract



Abstract

This day, Human Machine System (HMS) consider being a proven technology, which has gained an important role in various human activities. One of the most recent developments in this area is Human Adaptive Mechatronics (HAM) approach for enhancing human skills. This approach therefore is different compared to an ordinary HMS, in terms of its ability to adapt to changes in its environment and in the human changing level of skills. The crucial issue in HAM is in evaluating the human skills level on machine operation. In this paper, a skill index to quantify the performance of human drivers is studied in expected and guided conditions. The experiments are carried out on human subjects in normal driving. From this experiment, a new skill index formula is proposed based on the logical conditions and the definition of skill in HAM.

Keywords: Human skill index; Human Adaptive Mechatronics (HAM); expected and guided conditions (EGC); driving simulator

■1.0 INTRODUCTION

Research regarding Human Adaptive Mechatronics (HAM) is a continuity of the study of Human Machine System (HMS). The HMS [1] is described as a system that requires only humans to obtain a detailed understanding of the machine operation. Besides that HAM is defined as an intelligent mechanical system that has the ability to adapt to human skills in various situations and to assist a HMS for an increased performance [2, 3]. In addition, the human-robot collaboration is able to reduce human workload, costs and fatigue risk and to increase the productivity and efficiency [4, 5].

This paper describes in detail the approach on the study of human driving skill in Expected and Guided Conditions (EGC) that is used in Human Adaptive Mechatronics (HAM). The term EGC refers to a normal driving situation that requires a driver to maintain direction on a predefined track without the addition of any external disturbance. There are two choices of driving domain exist in experimental work, which are simulated driving and the real driving [6]. In this experiment, the simulated driving is selected in order to decrease the risk of accident or other unexpected problems. An experiment was conducted with the help of computer simulation software as a means of simulating the interaction between human subject and the machine [7-9]; whereby the experiment was conducted on 20 human [10-12] subjects with various years of experience in real-life driving scenarios and also experience in driving simulation games. Subjects were instructed to follow several predefined tracks as precise as possible in the shortest time by using a steering wheel with pedals. Experimental approaches are used in this research to clarify its central questions about the effects of skill track patterns, disturbances and experience in human machine system. These approaches enable exploration of the machine ability to understand the human characteristics and provide the assistance for human to achieve the best performance.

The main aim of this experiment is to understand the human control action in following the expected and guided tracks. 'Expected' means the tracks are in normal condition and shape; while 'guided' means that there are specific lines provided in each track as a driving path reference. In other words, the experiment is designed to differentiate human capabilities and characteristics in a normal human machine system by using a driving simulator. The simulator consists of human interface device and computer simulation software. Driving [13] is considered as a complex task because a human must possess specific skills such as the skill to handle the steering for direction, maintain the pedals for speed, and recognize various driving conditions such as cornering.

In this paper, we focus on driving in expected and guided conditions. The objectives of this experiment are to find the tracking error and elapsed time for three predefined tracks in normal conditions, to measure the skill index of each subject based on the proposed linear equation and to identify the learning skill for each human subject based on five trials. Three types of tracks are used in these experiments. Then, the time taken from each tracks will be used to calculate the value of J. Lastly, the smallest possible error, E_s, average error and average skill index are discussed in the last part of this paper.

2.0 HUMAN SKILL INDEX

In this section, the proposed human skill index, J [14] is introduced in order to measure human driving performance. It is used to measure the human performance in terms of normalized time, T_n and normalized error, E_n.

$$J = 1 - 0.5(T_n + E_n) \tag{1}$$

The normalized time and normalized error are given by

$$T_n = 1 - \frac{T_B}{t} \text{ and } E_n = 1 - \frac{E_S}{e} \tag{2}$$

respectively, where T_B is the ideal best time to complete a track calculated based on maximum speed V_{max} , t is time elapsed by a subject, E_S is smallest error obtained for a track and e is error (dimensionless) achieved by a subject [14].

3.0 SCOPE OF EXPERIMENT

The experiment is designed to measure several main aspects of human-machine interaction [15]. Firstly in this experiment, the input device used is a steering wheel with pedals. Standard input methods for computer based simulation [16] such as keyboard, joystick or mouse were not considered. These standard input devices do not reflect to the actual driving condition experienced in real-life. In order to mimic the actual driving condition, the steering wheel and pedals were chosen. A subject is able to change vehicle direction in the simulation through the steering wheel input and accelerate or decelerate (braking) through the pedals.

The simulation is then conducted on three predefined tracks. The tracks are defined based on the route shape/direction. Each track is capable of measuring a different set of human dexterity. The tracks are (1) a straight track, (2) a circular track and (3) an elliptical track. These tracks have been designed by using MapMaker [17]. This program is created to simplify the track design process. However, this program is only used as pre-experimental tool and is not intended for human subjects. The program lets the users design a desired track by using ‘click and drag’ function embedded in a computer mouse.

This experiment only involves visual ability from the human subject as a feedback mechanism, without any assistance from the machine. Any movement or action made by the human subject will directly affect the driving path and is important in determining the tracking error. The driving simulator is implemented with an automatic transmission, which has a linear speed increment with a top speed of six hundred (600) units per second. In this experiment, automatic transmission driving simulator is used since it is suitable for all human subjects, and is not limited to experienced drivers. Top speed is achieved if the accelerator pedal is pressed gradually for a certain period of time. Similarly, if the accelerator is released, the simulation vehicle will gradually decelerate until it comes to a complete stop. The simulation vehicle will come to a complete stop if the accelerator is released continuously for 2 seconds without braking. This situation will help the subjects to make a decision whether to stop or continue the driving. This also allows the program to record the last movement before resetting the time.

Finally, in terms of gender, the experiment assumed that the human-machine interaction dexterity is gender neutral. Although in the experiment, the human subjects consisted of both male and female [18], it is assumed that the experiment outcome reflects human skill in general and is not biased towards any gender.

4.0 EXPERIMENTAL SETUP

The block diagram of all experiments is shown in Figure 1. According to the Figure 1, it appears that the control system used is a closed loop system with feedback, by considering that the human as part of system. The input is a track coordinate and the output is a car position. Therefore, in order to make the task achievable, a track and a car are shown in three dimensions (3D) simulation, so that the human subjects have a perspective preview of the road ahead, as shown in Figure 2. It gives the user a perspective preview of the road ahead and the green line as guidance. The user has independent control of the steering, brake and accelerator.

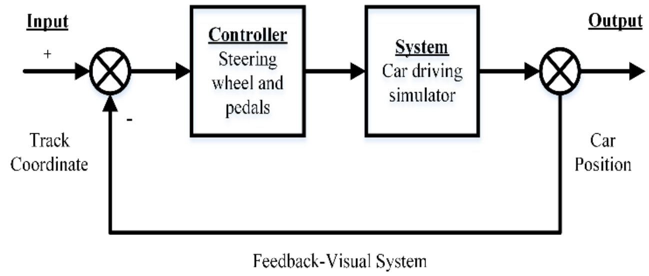


Figure 1 Block diagram of the experimental work

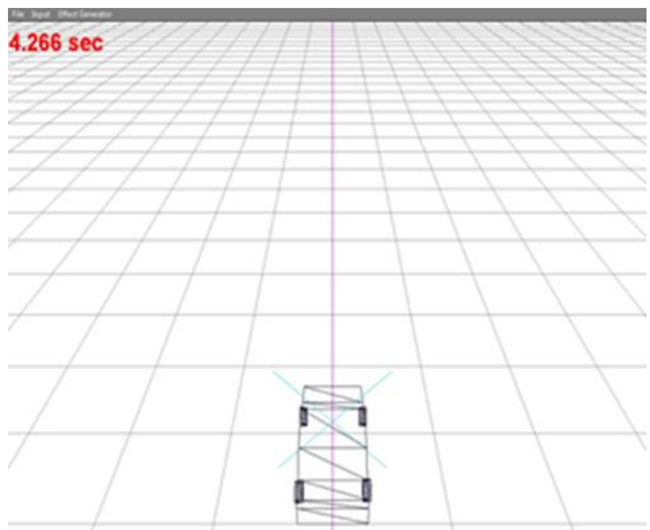


Figure 2 The designed driving simulator program

Moreover, the system for experiments is a car driving simulator and the controller is a keyboard or a steering wheel with pedals. The feedback is a visual system from the human subject itself, which has an important role in reacting and correcting the position of the car through the specific tracks. In other words, it totally depends on human visual system in order to make sure the simulated car is following the track accurately.

The hardware setup in this study is shown in Figure 3. The steering wheel is attached to a desk using its triple clamping system in order to avoid rocking or slipping. The pedals are located in a way that the system imitates the real car driving environment. In addition, these pedals have their own carpet grip system to avoid slipping during the experiment.

This experiment is conducted by using steering wheel and pedals. The steering wheel and pedals used in the experiment is shown in Figure 4, which is the MOMO Racing Force Feedback

Wheel. This hardware is commercialized by Logitech Company.

4.1 Hypotheses

Before conducting the experiment, the following hypotheses were outlined:

H1 Tracking error is inversely proportional to elapsed time.
H2 Elapsed time is expected to decrease after several trials.
H3 Tracking error is also expected to decrease after several trials.
H4 A higher tracking error is expected on a track with more bends and corners.
H5 Human skill is expected to improve gradually after several trials.
H6 It is expected that the human performance decreases gradually from very high (straight track), high (circular and elliptical tracks).
H7 Experienced drivers or experienced gamers are expected to have high skill.

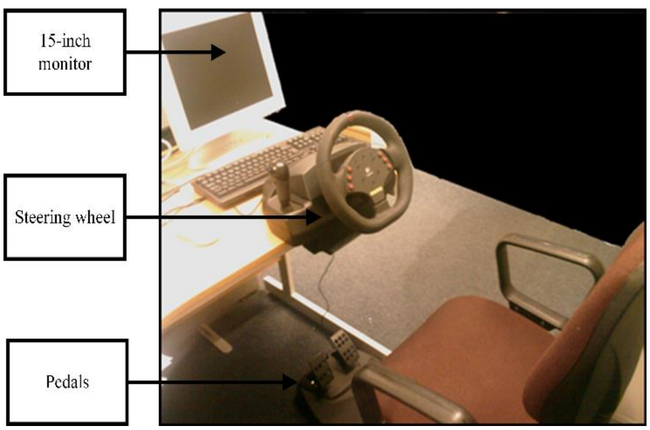


Figure 3 Experimental setup and hardware used

(a)

(b)

Figure 4 Steering and foot pedals used in the experiment (a) Logitech MOMO Steering wheel. (b) Foot pedals

4.2 Experimental Features

Table 1 shows the features of each track used and the types of skill measured during the experiment. T_B is the best time. The tracks without any corners are expected to give at least high skilled (HS) to any subject. Tracks with corners are expected to give at least medium skilled (MS) to any subject, as the experiment is conducted in EGC mode. The best time, T_B is the ideal elapsed time to complete any track based on maximum speed used and is obtained by using the following formula:

$$T_B = \frac{L}{V_{\max}} \tag{3}$$

Based on (3) L is defined as length of track in the driving simulator (units) while V_{max} is a maximum speed in the driving simulator, which is 600 units per second.

Table 1 Summary of Tracks used in EGC

Track	T_B(s)	Skills to negotiate	Expected skill (at least)
Straight	8.3	Skill to follow linear and continuous line.	HS
Circular	15.8	Skill to follow nonlinear line and continuous turning.	HS
Elliptical	18.3	Skill to follow other type of nonlinear line and continuous turning.	HS

4.3 Experiment Procedure

Figure 5 shows the flowchart of the experimental procedure for each human subject. Before conducting the experiment, the subjects are briefed on the experimental procedures. The subjects are given 30 seconds to test and get familiarized with the steering wheel and the pedals before starting the real trial. After the initial familiarization period, the experiment is conducted in the following sequence:

i. Straight track
ii. Circular track
iii. Elliptical track

The human subjects are requested to accurately follow the track as fast as possible without stopping until the end point. There are five trials for each track. For each trial, the elapsed time and the coordinates of the simulation car in x and z axes are recorded. By using these coordinates, the path of human subject is obtained and the tracking error is measured in a separate program.

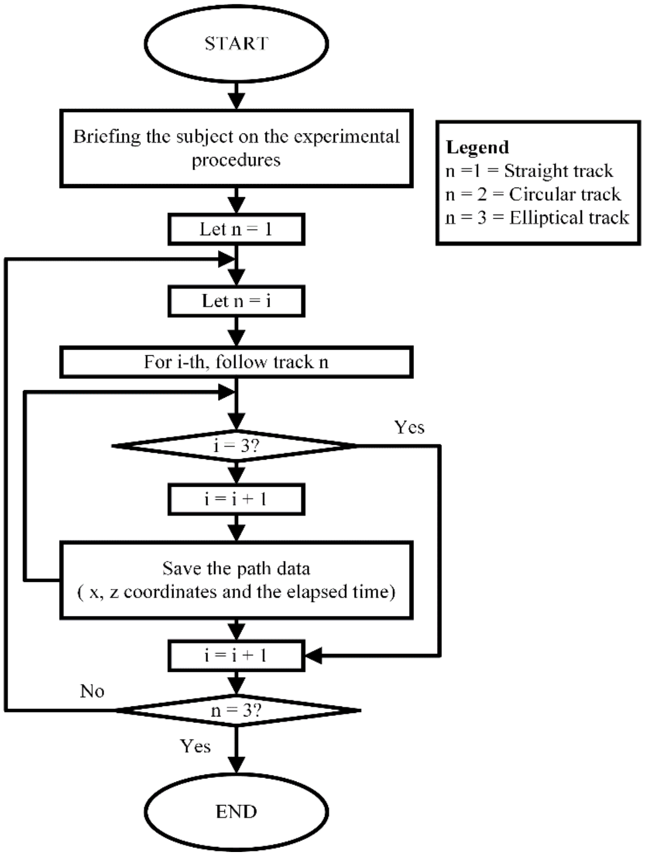


Figure 5 Flowchart of the experimental procedure

5.0 RESULT BY TRACK

The experimental results have been taken from 20 human subjects (Subject A to Subject T). Every human subject generated 50 data sets of elapsed time and tracking error obtained from five tracks. Therefore, for this experiment, a total of 600 data sets were generated.

Note that the column graphs as in Figure 6 until Figure 11 are for elapsed time and tracking error. Also, E1 is the tracking error in trial 1, E2 is the tracking error in trial 2, T1 is elapsed time for trial 1 and T2 is elapsed time in trial 2 and so on.

5.1 Straight Track

For straight track, Figure 6 and 7 show the results of tracking error and elapsed time for each subject in every trial. For trial 1 (Figure 6 and 7), Subject F is the slowest and Subject I is the fastest. However, the smallest error obtained by Subject G and the largest error obtained by Subject H. Thus, trial 1 does not support hypothesis H1.

For trial 2 (Figure 6 and 7), Subject C is the fastest and obtained the largest error. Thus, this result in trial 2 supports H1. However, the slowest (Subject F again) and the smallest error (Subject A) do not support H1.

Figure 6 and 7 shows the results of every subject in trial 3. It can be shown that, Subject F is the slowest for third consecutive time. However, for this trial, the slowest yields the smallest error. Thus, H1 is supported. Other results show that Subject E is the fastest and Subject I is obtained the largest error.

For trial 4 (Figure 6 and 7), results show that the slowest is Subject J, the fastest (Subject E), the largest error (Subject D) and the smallest error (Subject A and Subject H). Thus, H1 does not supported in trial 4.

For trial 5 (Figure 6 and 7), results show that Subject C is the fastest and obtained the largest error. Therefore, these results support hypothesis H1. Other results demonstrate that Subject J is the slowest for second consecutive time and the smallest error (Subject F and Subject P).

For overall, H1 is supported in trial 2, trial 3 and trial 5. Trial 2 and trial 5 show that the fastest time yields the largest error. However, trial 3 demonstrates that the slowest time yields the smallest error.

5.2 Circular Track

Figure 8 and 9 show the results from circular track for every subject in each trial. It can be prove that in trial 1 (Figure 8 and 9), Subject I and Subject E are the slowest and the fastest, respectively. On the other hand, the smallest and the largest errors are obtained by Subject H and Subject A, respectively. Therefore, hypothesis H1 does not supported in trial 1.

For trial 2 (Figure 8 and 9), the same condition occurred, where H1 does not supported. Results show that Subject F is the lowest, Subject E (the fastest), Subject A (the smallest error) and Subject B (the largest error).

For trial 3 (Figure 8 and 9), Subject F and Subject B are the slowest and the largest error, respectively for second consecutive time. Furthermore, Subject E obtained the fastest time for third consecutive time. Other result shows that Subject G obtained the smallest error. Therefore, hypothesis H1 is still unsupported.

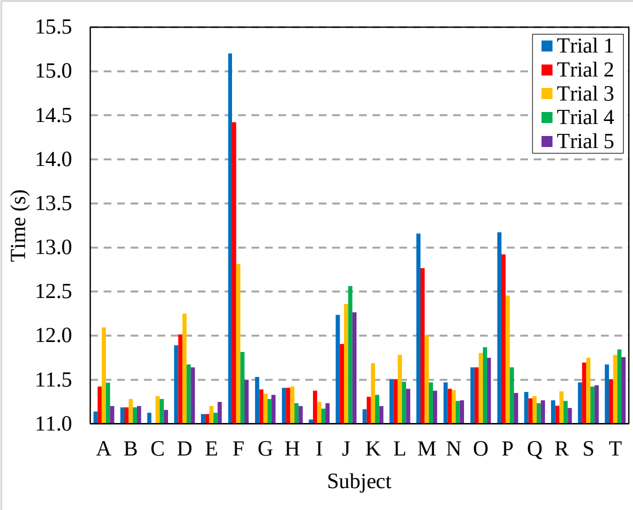


Figure 6 Results for time in straight track for trial 1-5

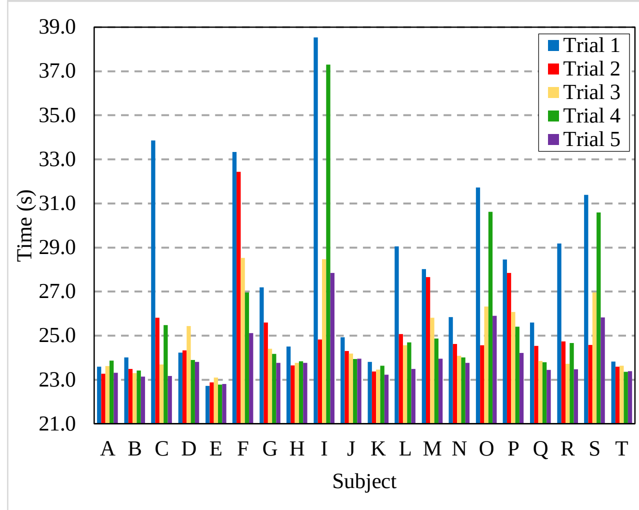


Figure 8 Results for time in circular track for trial 1-5

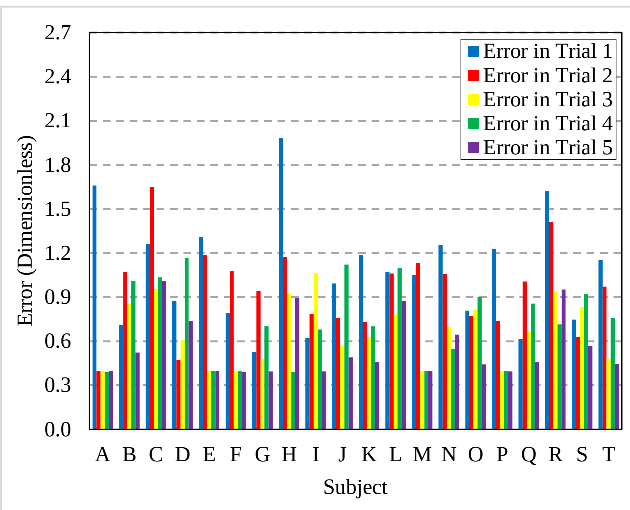


Figure 7 Results for error in straight track for trial 1-5

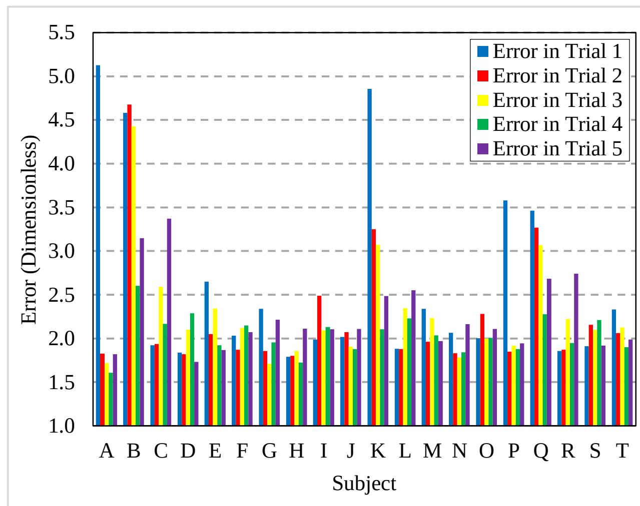


Figure 9 Results for error in circular track for trial 1-5

For trial 4 (Figure 8 and 9), the largest error is obtained by Subject B for third consecutive time. Again, Subject E obtained the fastest time for fourth consecutive time. Other results show that Subject A obtained the smallest error and Subject I is the slowest. Therefore, results in trial 4 still do not support hypothesis H1.

Lastly, for trial 5 (Figure 8 and 9), Subject C obtained the largest error, Subject D (the smallest error), and Subject I (the slowest). For fifth consecutive time, the fastest time is obtained by Subject E. Thus, trial 5 does not support hypothesis H1.

For the overall results from circular track, hypothesis H1 does not supported in any trial. No sign shows that the tracking error is inversely proportional to elapsed time in circular track. However, the fastest time is obtainable by the same subject in all five trials, which is Subject E.

5.3 Elliptical Track

Figure 10 and 11 show the elapsed time and tracking error for all subjects from elliptical track in every trial. For trial 1 (Figure 10 and 11), Subject E is the fastest. However, Subject E obtained the smallest error. Thus, these results are contradicted with hypothesis H1. Other results show that Subject B and Subject F obtained the largest error and the slowest time, respectively. Therefore, trial 1 does not support H1.

In trial 2 (Figure 10 and 11), results demonstrate that Subject A and Subject B obtained the smallest and the largest error, respectively. On the other hand, Subject E and Subject F obtained the fastest and the slowest time, respectively. Thus, trial 2 also does not support H1.

In trial 3 (Figure 10 and 11), Subject A obtained the smallest error for second consecutive time. Other result in trial 3 shows that Subject H, Subject C and Subject D obtained the largest error, the fastest and the slowest time, respectively. Thus, trial 3 also does not support H1.

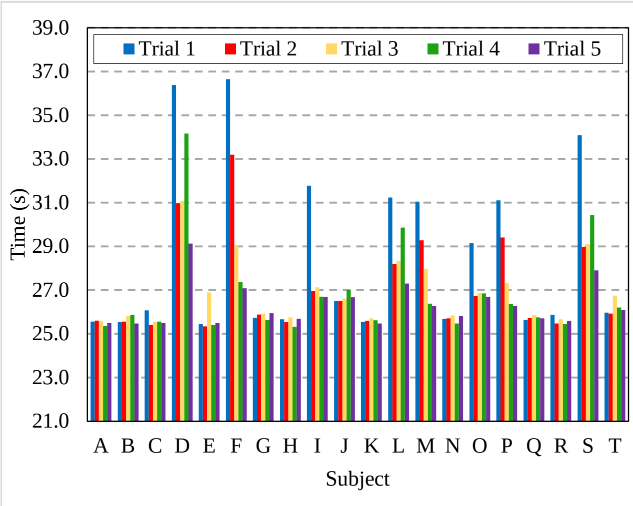


Figure 10 Results for time in elliptical track for trial 1-5

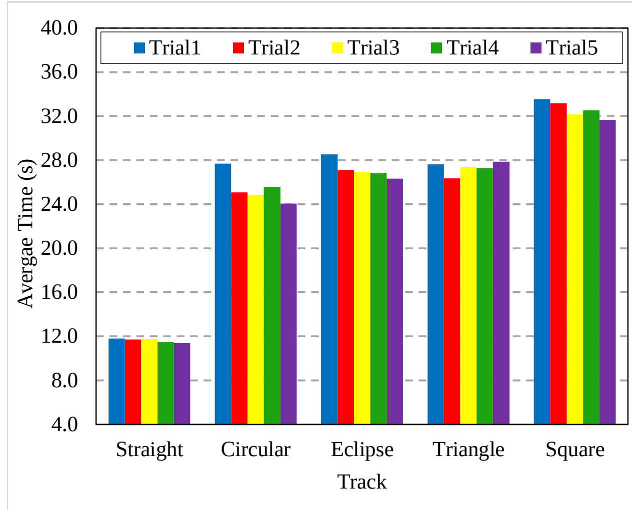


Figure 12 Results for average time in all tracks

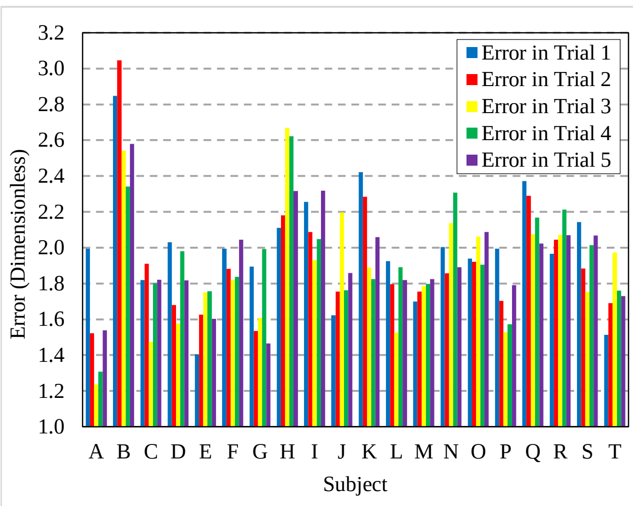


Figure 11 Results for error in elliptical track for trial 1-5

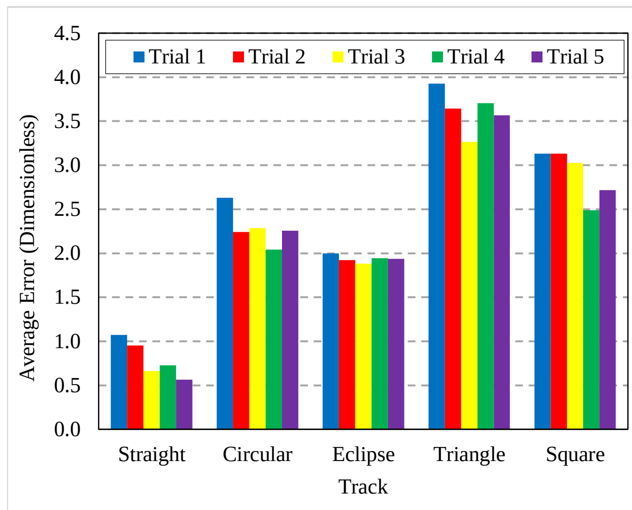


Figure 13 Results for average error in all tracks

In trial 4 (Figure 10 and 11), the results are corresponded to hypothesis H1 because Subject H obtained the fastest time with the largest error. Other results in trial 4 show that Subject A and Subject D obtained the smallest error and the slowest time, respectively.

Lastly, results in trial 5 (Figure 10 and 11) are agreed to hypothesis H1, since Subject B obtained the largest error with the fastest time. Other results in trial 5 demonstrate that Subject G obtained the smallest error and Subject D is the slowest.

Overall results for elliptical track demonstrate that hypothesis H1 is supported in trial 4 and trial 5, when the fastest subject is obtained the largest error. However, there is no sign that the slowest subject obtained the smallest error.

5.4 Average Result for All Tracks

The average time and error for each trial for all tracks shown in Figure 12 and 13. For straight track, it can be shown that there is a downward trend in both average results after several trials. Therefore, these results support hypotheses, H2 and H3.

For circular track, it seems that both average results show a downward trend within five trials. Thus, these results support hypotheses H2 and H3.

While for elliptical track, it can be proved that average elapsed time is decreased within five trials. Thus, the results are supported the hypothesis H2. There is also a downward trend in average error, thus the results are also correspond to hypothesis H3.

6.0 DISCUSSION

6.1 Smallest Possible Error, *Es*

Based on the experiments done, the smallest possible error for each track in EGC is obtained and shown in Table 2. It seems that Subject F obtained the smallest error for straight tracks from trial 5.

For other tracks, the smallest error is obtained by Subject A. However, there is no rationale to explain that only these two subjects (Subject A and Subject F) obtained the smallest error in this experiment. It might happen because of coincident. These values of E_s are then used in the entire calculation of normalized error for all subjects in both main experiments.

6.2 Average Error

From Table 3, it clearly shows that a higher tracking error is obtained from circular and elliptical tracks. These tracks have more bends and corners, thus the experimental results totally support hypothesis H4.

Table 2 E_S for each track

Track	Smallest error obtained by subject	Smallest possible error, E_S	Subject	Trial
Straight	0.39	0.35	F	5
Circular	1.61	1.60	A	4
Elliptical	1.24	1.20	A	3

Table 3 Average error for each track

Track	Length, L (units)	Best time, T_B (seconds)	Expected skill level
Straight	5000	8.3	HS
Circular	9500	15.8	HS
Elliptical	11000	18.3	HS

6.3 Average Skill Index

According to Table 4, it can be summarized that only five subjects obtained HS in all tracks, which are Subject A, E, G, M and Subject P. Three subjects obtained HS in any one tracks (Subject D, H and Subject S). However, only Subject B is MS in all tracks.

From Table 4 also, it can be concluded that the easiest track is circular track because the number of HS is the highest, which is 17 subjects. On the other hand, the hardest track is straight-shaped track because only nine HS subjects in this track. Thus, in general, H6 is not supported from this experiment.

Table 4 Average skill index for each subject in every track

Subject	Straight		Circular		Elliptical	
	J	***C***	***J***	***C***	***J***	***C***
A	0.74	**H**	0.74	**H**	0.76	**H**
B	0.60	M	0.55	M	0.58	M
C	0.53	M	0.65	**H**	0.70	**H**
D	0.60	M	0.74	**H**	0.62	M
E	0.69	**H**	0.72	**H**	0.73	**H**
F	0.66	**H**	0.66	**H**	0.62	M
G	0.68	**H**	0.72	**H**	0.71	**H**
H	0.58	M	0.76	**H**	0.61	M
I	0.64	**H**	0.63	**H**	0.61	M
J	0.58	M	0.73	**H**	0.67	**H**
K	0.63	**H**	0.61	M	0.65	**H**
L	0.54	M	0.69	**H**	0.65	**H**
M	0.67	**H**	0.69	**H**	0.66	**H**
N	0.59	M	0.74	**H**	0.65	**H**
O	0.60	M	0.67	**H**	0.64	**H**
P	0.68	**H**	0.68	**H**	0.68	**H**
Q	0.63	**H**	0.60	M	0.63	**H**
R	0.54	M	0.70	**H**	0.65	**H**
S	0.60	M	0.68	**H**	0.61	M
T	0.62	M	0.72	**H**	0.70	**H**
Average	0.62	M	0.68	**H**	0.66	**H**

J : Skill Index
C : Class
H : High skilled
M : Medium skilled
L : Low skilled

7.0 CONCLUSIONS

The experiments to obtain the elapsed time and the tracking error from 20 human subjects in EGC are described in detail. There is a downward trend in the elapsed time and tracking error after several trials. The skill index is also improved gradually after several trials. It shows that human skill can be quantified and differentiated based on the tracks.

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References

[1] S. Suzuki. 2010. Human Adaptive Mechatronics-Skill Acquisition in Machine Manipulation. *Industrial Electronics Magazine, IEEE*. 4: 28–35.
[2] H. Yu. 2008. Overview of Human Adaptive Mechatronics. Presented at the 9th WSEAS International Conference on Mathematics & Computers in Business and Economics (MCBE '08).
[3] S. Suzuki. 2010. Human Adaptive Mechatronics. *Industrial Electronics Magazine, IEEE*. 4: 28–35.
[4] K. Kyoungchul, B. Joonbum, and M. Tomizuka. 2012. A Compact Rotary Series Elastic Actuator for Human Assistive Systems. *Mechatronics, IEEE/ASME Transactions on*. 17: 288–297.
[5] R. Parasuraman, T. B. Sheridan, and C. D. Wickens. 2000. A Model for Types and Levels of Human Interaction with Automation. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*. 30: 286–297.
[6] Y. Xu, J. Song, M. C. Nechyba, and Y. Yam. 2002. Performance Evaluation and Optimization of Human Control Strategy. *Robotics and Autonomous Systems*. 39: 19–36.
[7] F. Harashima and S. Suzuki. 2006. Human Adaptive Mechatronics - Interaction and Intelligence. In *Advanced Motion Control, 2006. 9th IEEE International Workshop on*. 1–8.
[8] K. Kurihara, S. Suzuki, and K. Furuta. 2006. Elucidation of Skilled Human Controller on Stabilization with Voluntary Motion. In *Computer Aided*

Control System Design, 2006 IEEE International Conference on Control Applications, 2006 IEEE International Symposium on Intelligent Control, 2006 IEEE. 573–578.

[9] J. Y. C. Chen and M. J. Barnes. 2014. Human-Agent Teaming for Multirobot Control: A Review of Human Factors Issues. *Human-Machine Systems, IEEE Transactions on*. 44: 13–29.

[10] T. Lajunen, D. Parker, and S. G. Stradling. 1998.Dimensions of Driver Anger, Aggressive and Highway Code Violations and Their Mediation by Safety Orientation in UK Drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*. 1: 107–121.

[11] T. Lajunen and H. Summala. 1995. Driving Experience, Personality and Skill and Safety-Motive Dimensions in Drivers' Self-Assessments. *Personality and Individual Differences.* 19: 307–318.

[12] R. A. Marottoli and E. D. Richardson. 1998. Confidence in, and Self-rating of, Driving Ability Among Older Drivers. *Accident Analysis & Prevention*. 30: 331–336.

[13] I. I. Delice and S. Ertugrul. 2007. Intelligent Modeling of Human Driver: A Survey. In *Intelligent Vehicles Symposium, 2007 IEEE*. 648–651.

[14] M. H. I. Ishak, U. U. Sheikh, Z. Mohamed, and A. B. Aujih. 2013. Skill Index of Human Driver for Human Adaptive Mechatronics. *Latest Trends in Circuits, Control and Signal Processing.* 110–116.

[15] Z. Wang, W. P. He, D. H. Zhang, H. M. Cai, and S. H. Yu. Creative Design Research of Product Appearance Based on Human–Machine Interaction and Interface. *Journal of Materials Processing Technology*, 129: 545-550.

[16] K. Furuta, Y. Kado, and S. Shiratori. 2007. Identification of Dynamic Characteristics in Human Operation. In *Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on*. 2977–2982.

[17] M. H. I. Ishak, M. F. A. M. Kasai, A. A. B. Hisham, and N. H. I. Idris. 2013. Driving Simulator Development for Human Adaptive Mechatronics Application. In *2013 IEEE Student Conference on Research & Development (SCOReD)*. Palm Garden Hotel, Putrajaya, Malaysia,

[18] S. Oltedal and T. Rundmo. 2006. The Effects of Personality and Gender on Risky Driving Behaviour and Accident Involvement. *Safety Science*. 44: 621–628.