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ASIAN TRANSPORTATION RESEARCH SOCIETY

Automatic Eco-driving Behavior Guide System in Motorcycle for Reduction of Emissions and Fuel Consumption

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CHAPTER 1 INTRODUCTION

This chapter describes a background, state of problem, objectives of this research.

1.1 Background

This proposing research is the following up step of series of the previous ATRANS researches grant in 2009 (Satiennam, et al., 2009) and 2011 (Satiennam, et al., 2011). As the results of research of 2009, the onboard measurement system for installing on motorcycle to measure and record instantaneously the exhaust emissions and position in according to speed profile of a motorcycle driving on the existing road was developed. As application of collected data, the motorcycle driving cycle and the emissions rate models were developed. For the results of followed up research of 2011, the existing onboard measurement system was further developed by installing fuel consumption sensor to measure the additional fuel consumption in according to speed profile. Consequently, the fuel consumption rate model was also developed. As the current research resources, including the onboard measuring system, development algorithm and knowledge of research team are possible to achieve the following the state of problem

1.2 Statement of Problem

Nowadays, the economic development in Thailand has been highly advanced in various sectors not only communication sector but also industrial and business sectors. As a result of growth, the demands for vehicles are rapidly increasing. The higher numbers of vehicles result in increasing of fuel consumption and exhaust gas emission and cause a huge impact on environment. There are many effective ways to reduce fuel consumption and emissions from transportation sector. The typical implementation ways include the improvement of the traffic signal control system for more appropriate driving cycle (Tong H.Y, 1999) and the improvement of the combustion system and air pollution control of vehicle engine. The proposed advanced technological ways include the dynamic eco-driving system for freeway (Barth and Boriboonsomsin, 2009) and the engine function with a continuously variable transmission (CVT) (R. P. Fiffner and el., 2003). However, almost of previous searches and developments focused on the large vehicle, main mode in developed countries, but lack of concern for the motorcycle, main mode in the other developing countries.

This research plans to design the eco-driving-cycle engine for motorcycle and to design a prototype of automatic eco-driving behavior guide system for motorcycle achieving the reduction of fuel consumptions and emissions.

1.3 Objectives

The objectives of this study are following.

- To develop the eco-driving cycle for motorcycle
- To design a prototype of automatic eco-driving behavior guide system in motorcycle

CHAPTER 2 RESEARCH METHODOLOGY

This chapter describes the research methodology of this study. The research methodology of this research is displayed Figure 2-1.

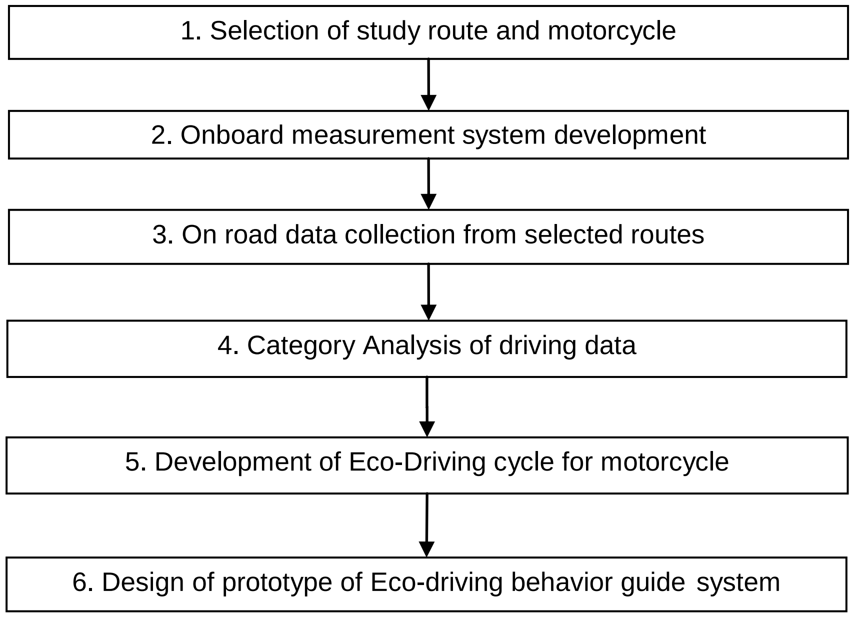


Figure 2-1 Research Procedure

2.1 Selection of study route and motorcycle

This research selects the Khon Kaen City and their road network as a study area and onboard data collecting routes as following previous ATRANS researches (Satiennam at el., 2009 and Satiennam et al., 2011). The previous collected data and collecting data of this study would be compared and accumulated for application in development of Eco-driving cycle.

The study route was a section of Sri Chan Rd., the main road passing through the CBD of Khon Kaen City as displayed Figure 2-2. The selected study section was a section of 3.6 km length as displayed in Figure 2-3.

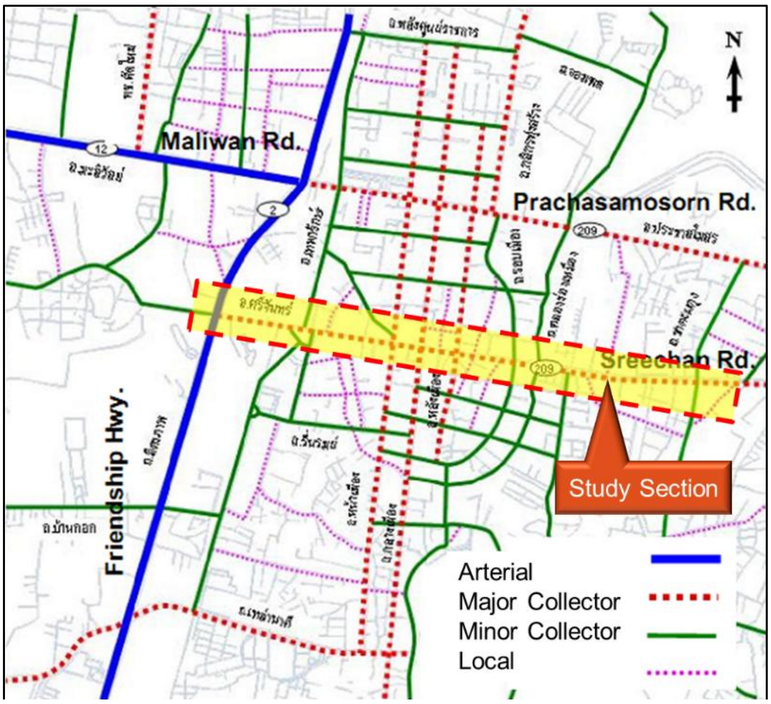


Figure 2-2 Sri Chan Rd. in Khon Kaen City road network

Figure 2-3 Selected study section located with 8 closing signalized intersections

The vehicle used in this study is engine gasoline which is a 4-stroke motorcycle with engine capacity of 108 cc. It was selected because of its highest number of register in Thailand. Its picture and specification was presented in Figure 2-4 and Table 2-1.

Figure 2-4 Selected motorcycle

Table 2-1 Specification of selected motorcycle

List	Specification
Fuel system	PGM-FI fuel injection
Engine	4 Stroke (Single overhead camshaft)
Bore x Stroke	50 mm. x 55 mm.
Total displacement	108 cc.
Max. torque	1.22 kg/m at 2,800 rpm/min
Compression ratio	11:01
Cooling system	Liquid cooling
Ignition system	Digital transistorized
Transfer ratio	2.53-0.85

2.2 Onboard measurement system development

This study further developed the onboard measurement system previously developed from previous studies (Satiennam et al., 2009 and 2011) to instantaneously measure and continuously measure speed-time profile, fuel consumption, and exhaust emissions of motorcycle driving on the road. A fuel injection sensor was installed at the fuel injection point in order to measure time injection. This data would be further applied to calculate the fuel consumption of the motorcycle (Schmid, 1995; Desantes, 2003; Payri, 2004). A mobile exhaust gas analyser was installed on the rear side of the motorcycle to measure the amount of CO and CO_2 emissions. The suction tube of the equipment can be connected to the motorcycle's exhaust pipe. Accordingly, the suction tube sucks the exhaust gas into the equipment to analyse the amount of emissions. The analysed data is then displayed on the equipment monitor and recorded in the memory storage per second.

Consequently, the developed onboard measurement system consists of several units, including the data logger for processing and recording the collected data, rear wheel speed sensor for measuring speed, fuel injection sensor for calculating fuel consumption, and an exhaust gas analyser for measuring the amount of exhaust emissions. Its data flow diagram is displayed in Figure 2-4.

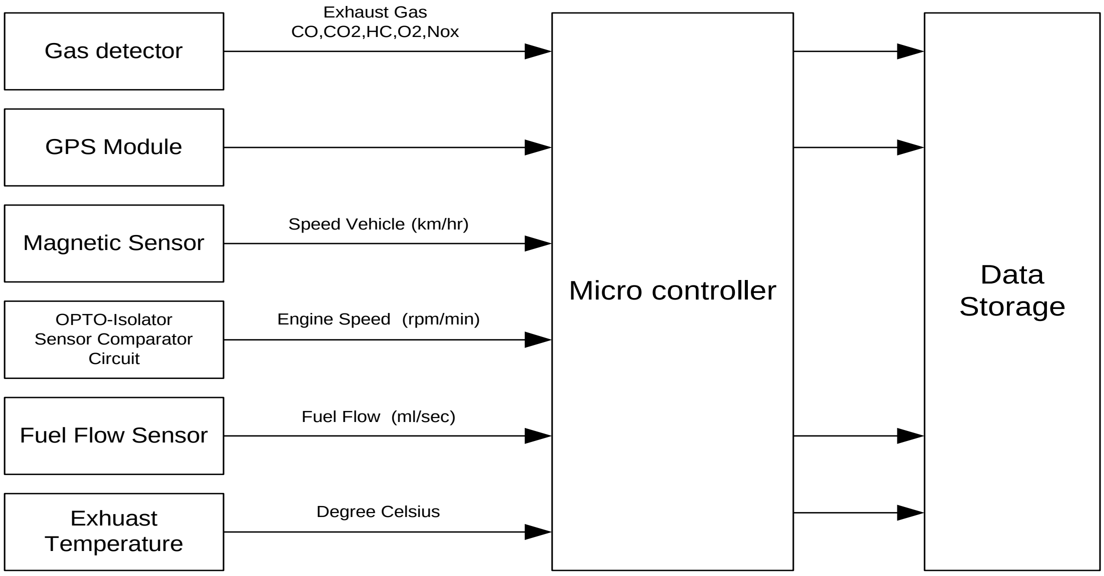


Figure 2-4 Functional block diagram of driving behavior data logger

The installing positions of onboard system units are displayed in Figure 2-5. The test motorcycle was driven on a specific route to measure and record speed-time profile as well as exhaust emissions in order to test the accuracy of the developed motorcycle onboard measurement system. All test results implied that the developed onboard measurement system could accurately measure and record the on-road driving data of the motorcycle.

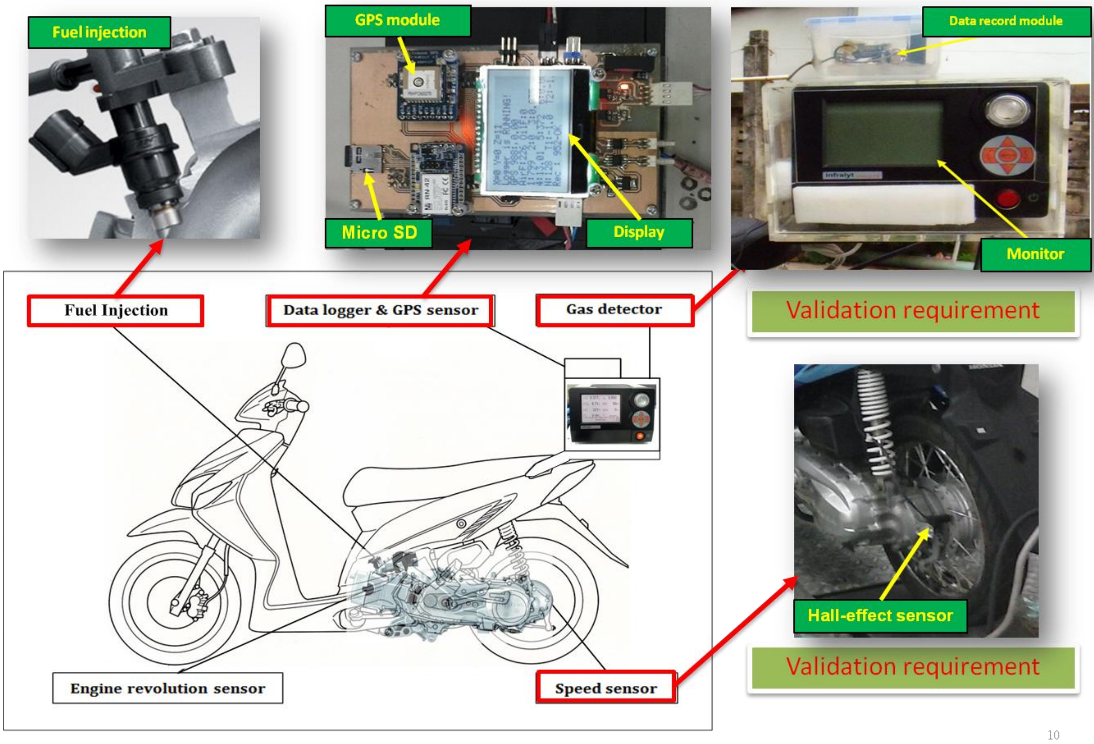


Figure 2-5 Component units of developed onboard measurement system

2.3 On road data collection

The onboard measurement system was installed on the selected motorcycles to measure on-road driving patterns and exhaust emissions. The 30 sample drivers were selected to ride on this corridor during the morning peak hours of between 7:00 a.m. to 9:00 a.m. to collect on-road driving data for a total of 112 hours. All driving tests started with a full fuel in the tank. The study chose to collect data during the peak morning period as the most critical congestion period occurs during this time of the day. Thusly, each driver would randomly encounter different in-traffic conditions and day-time signal timing.

2.4 Category Analysis of driving data

Cluster analysis was applied to uncover driving parameters influencing fuel consumption and emissions. The collected data sets of 30 drivers were categorized by level of fuel consumption and driving behavior. The study categorized the drivers by fuel consumption to determine which driving parameter influencing fuel consumption and emissions.

2.5 Development of Eco-driving cycle for motorcycle

The on-road collected data of non-aggressive drivers, resulted by a category analysis, was applied to develop the Eco-driving cycle for motorcycle. The algorithm for driving cycle development, proposed by a previous study (Satiennam, et al., 2009), was applied to develop the Eco-driving cycle for motorcycle. As a first step of the algorithm, the collected on-road driving data would be separated by a successive stop (more than 3 sec) as a sequence of speed-time data to develop a high number of micro trips. Then, the micro trips were classified into five speed ranges. The time fraction of speed range, resulting from the classification of micro trip, would also be the reference target to develop the driving cycle, rather than the target parameters. Then, the micro trips would be randomly selected and arranged from slower to higher speed ranges to develop a combination of micro trips with its time duration not exceeding the pre-defined duration of the driving cycle. The target parameters and the time fraction of each combination of micro trips were calculated and compared with the target parameters and the time fraction of the entire collected data. The average error (%) could be calculated from Equation 1.

$$\text{Average Error(\%)} = \frac{\sum_{i=1}^{n} \left(\frac{p_i - P_i}{P_i} \times 100 \right)}{n} \qquad (1)$$

Where

P_i = Target parameter i of entire collected data

p_i = Target parameter i of a combination of micro trips

n = Number of target parameters

The average error would be used as the criteria to determine the driving cycle. The algorithm would be repeated to generate a combination of micro trips once its average error exceeded the defined threshold, 4%. Vice versa, the algorithm would be stopped to generate a combination of micro trips once its average error (%) was not over the threshold. The combination of micro trips, having an average error less than 4%, was selected as the driving cycle. Finally, the Eco-driving cycle for motorcycle was developed.

2.6 Design of automatic Eco-driving behavior guide system

As the previous study, Barth and Boriboonsomsin (2009), a passenger car was drove under a guide line of Eco-driving cycle with using CVT power train could reduce emission and fuel consumption. A sophisticated engine speed and gear ratio control method can control an engine to operate corresponding to driving cycle precisely. This fact can be used for a conceptual design of an automatic Eco-driving behavior guide system in Figure 2-6 which illustrated only engine control system.

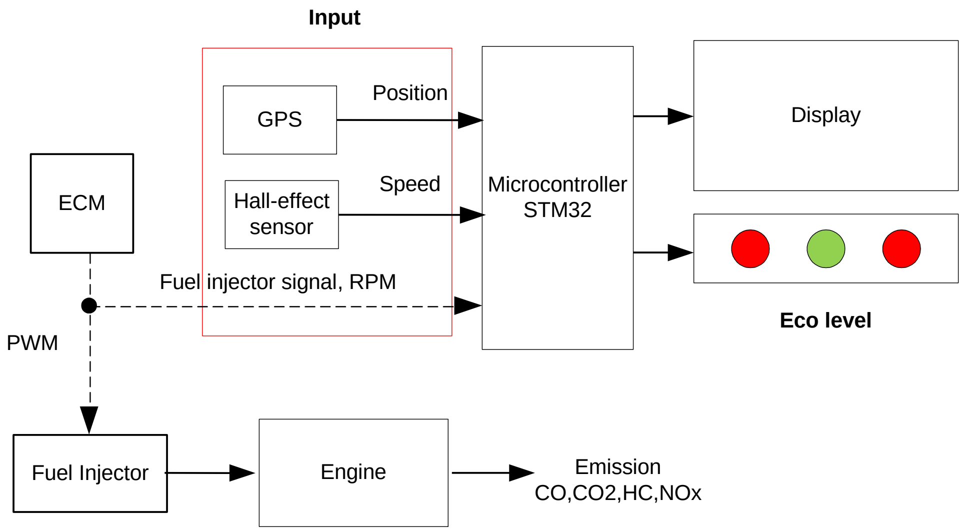


Figure 2-6 Functional block diagram of an automatic Eco-driving behavior guide system

In conventional control, the fuel injector, which is controlled by an electronic control module (ECM) with a pre-defined engine efficiency map, supply fuel corresponding to engine speed and air intake pressure in an intake manifold. Throttle valve is operated directly from a handed accelerator. In this research, the throttle valve will be modified to be an electronic throttle driving by a Eco-drive control unit. This unit will use information from the Eco-driving cycle, manifold absolute pressure (MAP), temperature of exhaust (TP), and intake air temperature (IAT) to control the throttle angle. Therefore, the original ECM control algorithm from manufacturer will not be disturbed and this unit can be applied to any type of motorcycle that has a throttle valve. In the display of the guide system, the display area is divided into four sections: the driving speed, fuel consumption, eco-driving behavior level and driving behavior as displayed in Figure 2-7.

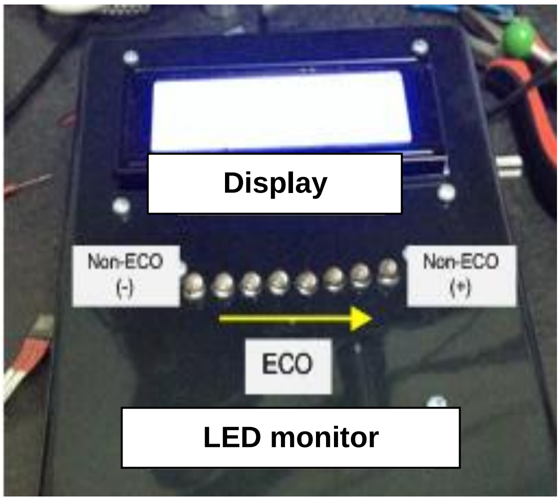


Figure 2-7 Display of the automatic eco-driving behavior guide system

The display monitor may be assembled with an LED display while driving data records to the SD card in order to monitor driving behavior on a daily basis.

Each section of the display is explained as follows.

1) The driving speed; it displays the travelling speed of the vehicle.

2) The rate of fuel consumption; it displays the fuel consumption rate at such driving speed.

3) The eco-driving level; it displays the percentage of eco-driving level to let the driver know the eco-driving status therefore the driver can adjust his/her driving behavior to get the eco mode. The LED is to shown the eco-driving which status on a green light of the eco-driving but the non-eco-driving is a red light.

The driving behavior data can also record to a data storage device.

CHAPTER 3 RESULTS AND DISCUSSIONS

This chapter presents the results and discussions of this study.

3.1 Results of On-road Data Collection

The on-road driving data from 29 drivers (except driver no. 27) was able to be completely collected. In total 112 hours of driving data were collected. The parameters of driving behavior, determined according to many previous studies (Chen et al., 2003; Tsai et al., 2005; Tong et al., 2011; Tamsanya et al., 2009), as well as fuel consumption and emissions from each driver/motorcycle were calculated. Driving behavior parameters included average running speed (excluding idling period) (km/h), average acceleration or a rate of change of speed above 0.27 (m/s^2), average deceleration or rate of change of speed below -0.27 (m/s^2), time spent at idle or portion of time at zero speed (%), time spent accelerating or portion of time accelerating for ≥ 0.27 m/s^2 (%), time spent decelerating or portion of time decelerating for ≤ -0.27 m/s^2 (%). The weight of the driver might have an effect on fuel consumption and the emissions of the motorcycle, fuel consumption (ml/kg-km), CO_2 and CO Emissions (g/kg-km) were therefore calculated per travel distance and total weight (the sum of the weights of the motorcycle, fuel and driver). Average momentum of a moving motorcycle (kg-m/s) was also calculated by multiplying total weight with running speed. The results of on-road driving data collection and calculation is presented in Table 3-1. The descriptive statistics analysis on-road driving data is presented in Table 3-2.

Table 3-1 Results of on-road driving data collection and calculation

No.	T	D	W	V	ACC	DEC	Pi	Pa	Pd	M	FC	CO_2	CO
1	1,423	7.13	161.4	23.2	0.53	-0.56	22.42	27.83	25.44	1,042.0	0.1731	0.2296	0.0047
2	1,422	7.12	151.4	23.7	0.51	-0.55	23.98	28.27	25.46	998.1	0.1855	0.2476	0.0050
3	1,006	7.11	166.4	28.8	0.77	-0.78	11.03	37.38	35.79	1,331.8	0.1336	0.1568	0.0065
4	1,568	7.22	169.4	23.4	0.54	-0.67	28.13	32.14	25.26	1,098.9	0.1734	0.2756	0.0066
5	1,203	7.21	155.4	25.9	0.60	-0.63	15.79	33.50	31.09	1,116.0	0.1558	0.2438	0.0082
6	1,117	7.10	164.4	26.3	0.61	-0.64	12.62	34.83	32.05	1,201.2	0.1433	0.1749	0.0054
7	1,030	7.12	169.4	27.1	0.61	-0.69	7.38	38.45	33.01	1,273.0	0.1309	0.1667	0.0047
8	1,255	7.11	153.4	28.9	0.82	-0.85	29.24	29.56	27.81	1,233.3	0.1641	0.2101	0.0075
9	987	7.19	166.4	29.2	0.65	-0.80	9.73	41.44	32.93	1,351.7	0.1291	0.1935	0.0069
10	1,468	7.17	168.4	22.3	0.60	-0.58	20.84	31.61	31.34	1,043.3	0.1694	0.2625	0.0082
11	1,187	7.13	171.4	26.5	0.58	-0.56	18.11	30.50	30.41	1,260.9	0.1403	0.2112	0.0074
12	1,403	7.10	165.4	24.5	0.61	-0.64	25.30	31.50	29.44	1,126.2	0.1659	0.1855	0.0083
13	1,328	7.13	164.4	28.2	0.82	-0.79	31.17	28.01	28.24	1,287.0	0.1538	0.2432	0.0089
14	954	7.12	161.4	24.1	0.53	-0.53	16.25	31.34	29.98	1,079.7	0.1537	0.2129	0.0053
15	1,112	7.19	168.4	27.3	0.54	-0.60	14.48	35.16	30.22	1,278.6	0.1361	0.2083	0.0063
16	1,096	7.18	163.4	28.1	0.65	-0.59	15.88	32.21	34.95	1,273.8	0.1390	0.1964	0.0066
17	1,540	7.05	161.4	21.9	0.54	-0.56	24.09	27.86	26.23	982.9	0.1840	0.2920	0.0078
18	1,281	7.22	168.4	27.8	0.55	-0.67	26.78	31.46	24.67	1,299.6	0.1474	0.2128	0.0062
19	1,383	7.16	170.4	24.1	0.52	-0.52	22.27	27.77	26.54	1,141.3	0.1576	0.2488	0.0068
20	1,385	7.23	155.4	24.4	0.50	-0.63	22.74	32.71	25.20	1,054.7	0.1718	0.2917	0.0075
21	1,482	7.15	169.4	22.8	0.50	-0.57	23.68	29.76	25.44	1,073.0	0.1668	0.2787	0.0075
22	1,203	7.21	161.4	25.9	0.60	-0.63	15.79	33.50	31.09	1,159.0	0.1499	0.2348	0.0079
23	1,149	7.21	153.4	26.1	0.64	-0.73	13.14	39.43	33.59	1,112.7	0.1528	0.2374	0.0078
24	1,136	7.17	158.4	28.0	0.60	-0.61	18.93	31.78	30.81	1,232.6	0.1450	0.2354	0.0064
25	1,368	7.14	156.4	22.6	0.59	-0.66	16.52	34.94	30.26	982.4	0.1733	0.2753	0.0081
26	1,356	7.16	153.4	24.8	0.50	-0.52	22.79	28.24	26.11	1,054.7	0.1711	0.2851	0.0081
28	1,371	6.90	149.4	25.1	0.55	-0.61	27.72	30.12	26.19	1,040.1	0.1806	0.2792	0.0081
29	1,525	7.03	158.4	20.6	0.52	-0.49	19.28	30.95	31.54	908.3	0.1869	0.3073	0.0083
30	1,335	7.19	155.4	23.6	0.63	-0.60	18.13	33.33	34.16	1,020.1	0.1474	0.2256	0.0069

Remark: T: Driving time (s), D: Driving distance (km), W: Total weight or sum of weight of the motorcycle, fuel and driver (kg), V: Average running speed, excluding idle period (km/h), ACC: Average acceleration or Rate of change of speed above 0.27 (m/s^2), DEC: Average deceleration or Rate of change of speed below -0.27 (m/s^2), Pi: Time spent at Idle or Portion of time at zero speed (%), Pa: Time spent in acceleration or Portion of time accelerating for ≥ 0.27 m/s^2 (%), Pd: Time spent in deceleration or Portion of time decelerating for ≤ -0.27 m/s^2 (%), M: Average Momentum (kg·m/s), FC: Fuel consumption (ml/kg·km), CO_2: CO_2 Emission (g/kg·km), CO: CO Emission (g/kg·km).

It found that average driving distance (D) of all drivers was 7.14 km. Average driving time (T) was 1,279 sec. Average total weight (W), a summation of motorcycle weight, full fuel weight and driver weight, was 161.7 kg. Average running speed (V) was 25.4 km/h. Average acceleration (ACC) was 0.59 m/s^2. Average deceleration (DEC) was -0.62 m/s^2. Average of time spent at idle (Pi) was 19.8%. Average of time spent in acceleration (Pa) was 32.2%. Average time spent in deceleration (Pd) was 29.5%. Average Momentum (M) was 1,139.9 kg·m/s. Average fuel consumption (FC) was 0.1580 ml/kg·km. Average CO2 Emission (CO2) was 0.2352 g/kg·km and average CO Emission (CO) was 0.0070 g/kg·km. These driving parameters, V, ACC, DEC, Pi, Pa and Pd, were consistent with those driving parameters found in the previous study of motorcycle driving cycle development in the same city (Satiennam et al., 2009).

Table 3-2 Results of descriptive statistics analysis on on-road driving data

No.	Driving parameters	Mean	S.D.
1	T: Driving time (s)	1,279	176
2	D: Driving distance (km)	7.14	0.07
3	W: Total weight (kg) (Motorcycle weight = 98.8 kg, Fuel weight = 2.6 kg, and Mean weight of drivers = 60.4 kg)	161.7	6.5
4	V: Average running speed (km/h)	25.4	2.4
5	ACC: Average acceleration (m/s^2)	0.59	0.09
6	DEC: Average deceleration (m/s^2)	-0.62	0.09
7	Pi: Time spent at Idle (%)	19.8	6.1
8	Pa: Time spent in acceleration (%)	32.2	3.6
9	Pd: Time spent in deceleration (%)	29.5	3.3
10	M: Average Momentum (kg·m/s)	1,140	121
11	FC: Fuel consumption (ml/kg·km)	0.1580	0.0171
12	CO_2: CO_2 Emission (g/kg·km)	0.2352	0.0403
13	CO: CO Emission (g/kg·km)	0.0070	0.0012

3.2 Results of Cluster Analysis

The results of cluster analysis, categorized drivers by fuel consumption into three groups of low, medium and high fuel consumption, are presented in Table 3-3. The results revealed that the group of drivers consumed low fuel consumption emitted the lowest emissions of CO_2 and CO, yet their speed, acceleration, deceleration and momentum were higher than the other groups. Obviously, their proportion of idle time was lowest.

Table 3-3 Results of driver category by fuel consumption

Group	**Driver no.**	**FC**	**CO_2**	**CO**	**V**	**ACC**	**DEC**	**Pi**	**Pa**	**Pd**	**M**
Low FC	3, 7, 9, 11, 15, 16	0.1348	0.1888	0.0064	27.83	0.63	-0.67	12.8	35.9	32.9	1,295
Middle FC	5, 6, 13, 14, 18, 19, 22, 23, 24, 30	0.1507	0.2269	0.0070	25.99	0.61	-0.64	19.1	32.5	30.2	1,165
High FC	1, 2, 4, 8, 10, 12, 17, 20, 21, 25, 26, 28, 29	0.1745	0.2653	0.0077	23.71	0.58	-0.61	23.4	30.5	27.8	1,045

Remark: FC: Fuel consumption (ml/kg·km), CO_2: CO_2 Emission (g/kg·km), CO: CO Emission (g/kg·km), V: Average running speed, excluding idle periods (km/h), ACC: Average acceleration or Rate of change of speed above 0.27 (m/s^2), DEC: Average deceleration or Rate of change of speed below -0.27 (m/s^2), Pi: Time spent at Idle or Portion of time at zero speed (%), Pa: Time spent in acceleration or Portion of time accelerating for ≥ 0.27 m/s^2 (%), Pd: Time spent in deceleration or Portion of time decelerating for ≤ -0.27 m/s^2 (%), M: Average Momentum (kg·m/s).

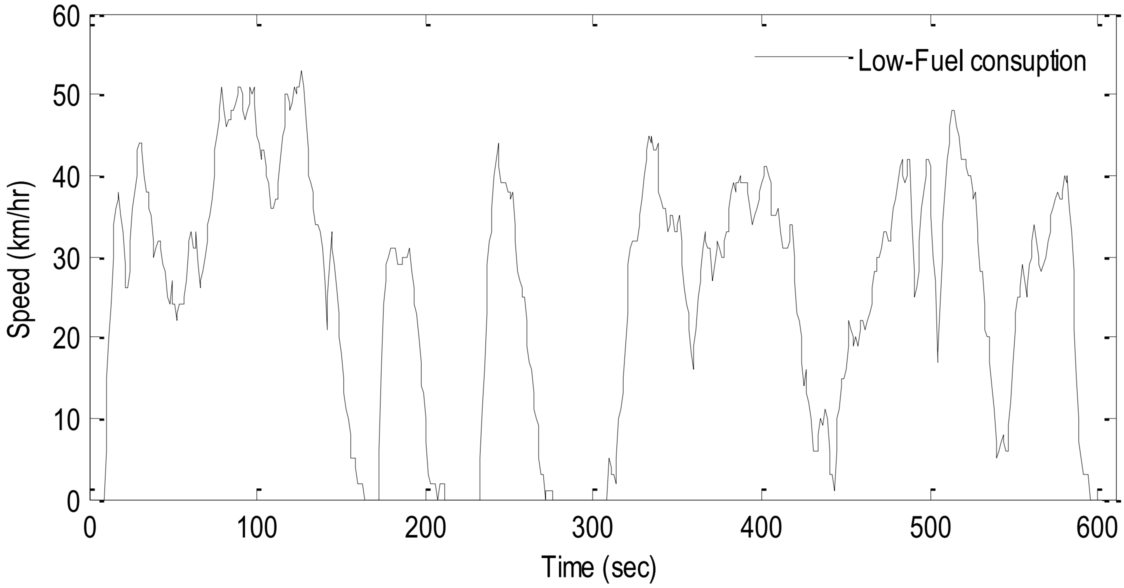
3.3 Results of development of Eco-driving cycle for motorcycle

The on-road driving data of low fuel consumption group was further applied to develop the Eco-driving cycle for motorcycle. As running result of algorithm of driving cycle development, its target parameters were quite close to those of the collected driving data with 2.0% average error as presented in Table 3-4.

Tables 3-4 Result of running algorithm for driving cycle development

Parameter	Target	Developed	Error (%)
Average Speed (km/h)	24.08	24.78	2.91
Average Running Speed (km/h)	27.80	28.68	3.19
Average Acceleration (m/s^2)	0.63	0.63	1.18
Average Deceleration (m/s^2)	-0.67	-0.65	3.12
Idle Time (%)	12.98	13.29	2.39
Cruise Time (%)	18.18	18.11	0.42
Acceleration Time (%)	35.63	35.22	1.17
Deceleration Time (%)	32.8	33.06	0.79
Average Error (%)	-	-	1.97

The developed Eco-driving cycle of motorcycle is displayed in Figure 3-1. This driving cycle has a 24.78 km/h average speed, a 28.68 km/h average running speed, 0.63 m/s^2 average acceleration, -0.65 m/s^2 average deceleration, 13.29% idle time, 18.11% cruise time, 35.22% acceleration time and 33.06% deceleration time, a 53 km/h maximum speed, a 2.778 m/s^2 maximum acceleration and a -2.778 m/s^2 maximum deceleration with 602 sec cycle time duration, and an 4.143 km distance.



V_{max}= 53 km/hr, Acc_{max}= 2.778 m/s^2, Dec_{max}= -2.778 m/s^2, Length= 602 s, Distance= 4.143 km

Figure 3-1 Developed Eco-driving cycle of motorcycle

3.4 Design of automatic Eco-driving behavior guide system

This study designed a prototype of automatic eco-driving behavior guide system for motorcycle. The developed Eco-driving cycle for motorcycle is combined into a prototype of automatic Eco-driving behavior guide system. The information of average running speed, average acceleration and average deceleration of Eco-driving manner is informed to a riding motorcyclist for minimizing fuel and emissions. The guide system consists of a microcontroller, a LED display, a hall-effect sensor, a GPS sensor and a Micro SD card. The microcontroller processes the data transferred from a hall-effect sensor to calculate instantaneously speed, acceleration, and deceleration of driving motorcycle. This information is instantaneously displayed on a LED display. Simultaneously, the microcontroller compares instant speed, acceleration and deceleration of driving motorcycle with Eco-speed, acceleration and deceleration and displays LED lights to inform a motorcyclist for his driving behavior. The green light represents eco-driving behavior (low fuel consumption). The red light represents non-eco-driving behavior (high fuel consumption). The prototype of Eco-driving behavior guide system is displayed in Figure 3-2.

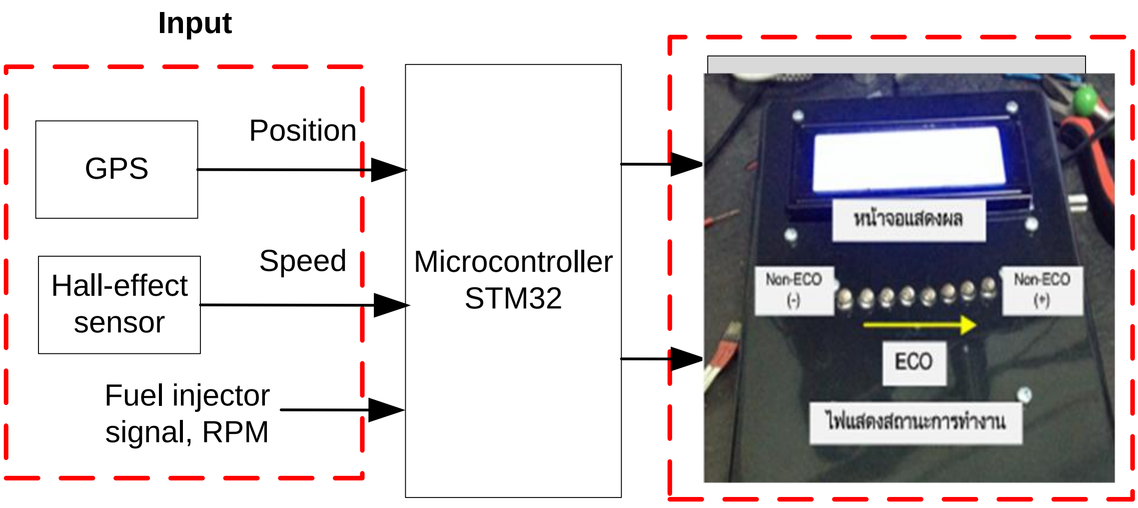


Figure 3-2 Prototype of Eco-driving behavior guide system

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

This chapter describes the conclusions of this study and explains the recommendations for the further studies.

4.1 Conclusions

This study developed the eco-driving cycle for motorcycle for a prototype of automatic eco-driving behavior guide system in motorcycle for reduction of fuel consumption and emissions. The 30 sample drivers were selected to ride on the selected corridor in Khon Kaen city to collect the on-road driving data. The developed Eco-driving cycle for motorcycle has a 53 km/h maximum speed, a 2.778 m/s^2 maximum acceleration and a -2.778 m/s^2 maximum deceleration with 602 s cycle time duration, and a 4.143 km distance. The designed automatic eco-driving behavior guide system can inform and guide a motorcyclist for achieving Eco-driving behavior to reduce fuel consumption and emissions.

4.2 Recommendations

The future study is to test the prototype of automatic eco-driving behavior guide system by installing on a motorcycle driving in automotive laboratory and then on real-world road.

Another future study on the providing of advanced information regarding signal phases and timing to vehicles travelling on a signalized corridor, extending from cars (Barth et al., 2011; Xia et al., 2011) to motorcycles, ought to be evaluated for its concept, whereby the motorcyclist would adjust his velocity for the minimizing of stopping time at a signalized intersection.

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