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A STUDY ON THE DETERMINATION OF THE REAL-WORLD DRIVING CHARACTERISTICS OF MOTORCYCLES IN HANOI

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Abstract. The transport sector has been considered as one of the primary reasons of the situation of rapid climate change. This paper aims to determine the real-world driving characteristics of motorcycles (MCs) in Hanoi to support further studies on MCs' emissions and fuel consumption. An infrared sensor was installed directly on the wheel of the test MC to record the revolving speed of the wheel. After that, the instantaneous speed of the test MC was calculated and pre-processed. Only about 0.82% of total data points were detected as error points and processed. Twenty-five driving kinetic parameters were calculated based on the processed instantaneous speed data to reflect the real-world driving characteristics of MCs in Hanoi. The change in the real-world driving characteristics of MCs in Hanoi from 2009 to 2020 has been recognized, particularly the share of the time proportion in different operation modes. The time proportion of the acceleration, deceleration, cruising, creeping, and idling modes in the real-world driving characteristics of MCs in Hanoi is 35.51%, 34.52%, 11.23%, 12.01%, and 7.13%, respectively. The average speed of MCs in Hanoi is about 20.49 kph. The VSP distribution in the real-world driving data of MCs in Hanoi is concentrated mainly at the bins relating to idling and low speeds.

Keywords: driving characteristics, fuel consumption, emission, motorcycle, Hanoi.

1. INTRODUCTION

Nowadays, humanity is facing rapid climate change and fossil fuel depletion, in which Vietnam is one of the countries most affected by climate change. The transport sector has been considered as one of the primary contribution sources causing this situation [1]. The rapid increase in transport demand has been raising the total number of motor vehicles and consumed fuel.

In Hanoi, up to 2018, the total registered road motor vehicles reached more than 6.6 million registered vehicles, in which the share of motorcycles (MCs) is above 90% [2]. In which, the average in-use rate of MCs in Hanoi is about 41% [3]. The average annual growth rate of MCs in Hanoi is approximate 9% in the period of 2005-2018 [2]. As an undesirable consequence, the rapid increase in MCs population not only increases the demand for fuel consumption but also causes serious environmental pollution. Only for idling mode, it was estimated that about 6.5 kt CO, 57.1 kt CO_2, 1.1 kt HC, and 0.2 kt NO_x were discharged from the MC fleet in Hanoi in the year 2018 [4]. In fact, the MC fleet in Hanoi had contributed to a proportion of particulate matter (PM_{10}) that was equivalent to 15% of the total PM_{10} component from the bus fleet in Hanoi [5]. In addition, MC had discharged about 36% of carbon dioxide (CO_2) and more than 90% of air toxics of the total pollutants from MCs, vans, and trucks [6]. Therefore, it is necessary to closely control the emission and fuel consumption related to the MC fleet in Hanoi.

In fact, the fuel consumption and emission of vehicles depend strongly on their real-world driving characteristics. So, these driving characteristics have been used as the input data of all software simulating the vehicle emission. However, the real-world driving characteristic of the vehicle is very different between countries, even when between the other regions of each country [7, 8]. Therefore, it is essential to study the real-world driving characteristics of each kind of vehicle for specific areas.

In Vietnam, until now, only two previous studies have been focused on the real-world driving characteristics of MCs, in which one focused on the MC fleet in Hanoi [8], and another focused on the MC fleet in Ho Chi Minh City [9]. The study of Tong et al. (2011) used 12 parameters among the total 33 driving kinetic parameters to capture the real-world driving characteristics of MC in Hanoi. In contrast, the study of Dung et al. (2015) used only one among the total 33 driving kinetic parameters to capture the real-world driving characteristics for the MC in Ho Chi Minh city. Therefore, this study aimed to determine the real-world driving characteristics for the MC in Hanoi in which all driving kinetic parameters were taken into consideration, especially the vehicle-specific power (VSP) due to its ability to reflect well the influence of the real-world driving characteristics on the emissions and fuel consumption of vehicles [7, 10-14].

In studies related to the real-world driving characteristics of the vehicle, the on-road driving data known as the profile of instantaneous speeds versus time have to be collected first. For collecting the profile of the on-road instantaneous speed, there are two primary approaches used, including the chase car method and the on-board measurement [15]. In the chase car method, a driver is trained carefully to follow closely behind the target vehicle (lock condition). When the target vehicle is not available (non-lock condition), the trained driver must overcome all vehicles which have overcome their vehicle to continue following the target vehicle closely. This is very difficult for the trained diver to follow the target closely in the high traffic density condition as Hanoi. Hence, the quality of collected data could be affected strongly. In contrast, the on-board measurement method has higher accuracy because the data logger is attached directly to the test vehicle. By this way, the on-board measurement method can overcome the time delay related to the driver response and the overestimation of accelerations [15, 16]. In fact, the data logger and the Global Positioning System (GPS) are two on-board measurement techniques that are used commonly for capturing the instantaneous speed of a vehicle. In which, the quality of GPS-collected data is highly influenced by the surrounding environment, such as the atmosphere and buildings that could cause the multi-path signal reflection and the urban canyon phenomenon [17, 18]. Therefore, many earlier studies have used the data logger by plugging directly into the OBD or CAN to collect the instantaneous speed. However, this is not suitable for MCs because of lacking the on-board diagnostics (OBD) or the control area network (CAN) for most MC.

After things considered above, the non-contact sensor has been used for determining the instantaneous speed of MC in this study to tackle both the high data quality and practicality. In fact, this technique has been used widely for collecting vehicle speed in many recent studies, such as Le et al. (2013), Seedam et al. (2015), Satiennam et al. (2017), and our recent study [22].

2. METHODOLOGY

The overall methodology used to determine the real-world driving characteristics of MCs in Hanoi is presented in Fig.1 below.

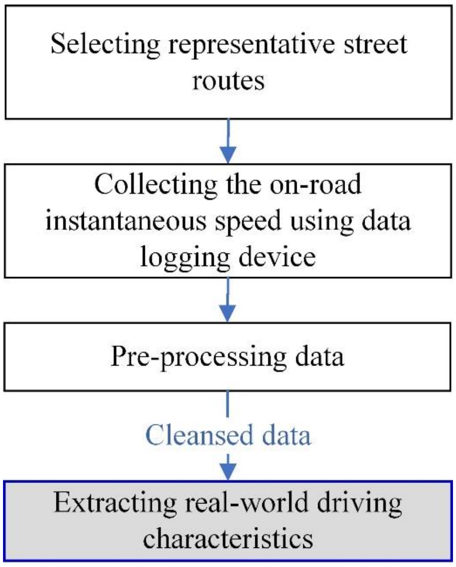


Figure 1. Overall study methodology.

2.1. Route selection

The routes are commonly selected based on the judgment of researchers, such as relying on home-to-work trips, the difference in population density, and road classifications. These factors need to be carefully considered in selecting routes for study [7, 16]. According to a previous study by Le et al. (2013), the Hanoi region is classified into small sectors based on differences in economic conditions and sector growth history consisting of the old town, old street, old inner city, and new regions. The disparity between these sectors could result in significant differences in on-road driving characteristics. Therefore, ten routes were selected among the four regions above to collect the on-road driving data, as presented in Fig. 2.

Figure 2. The regions for collecting the on-road driving characteristics.

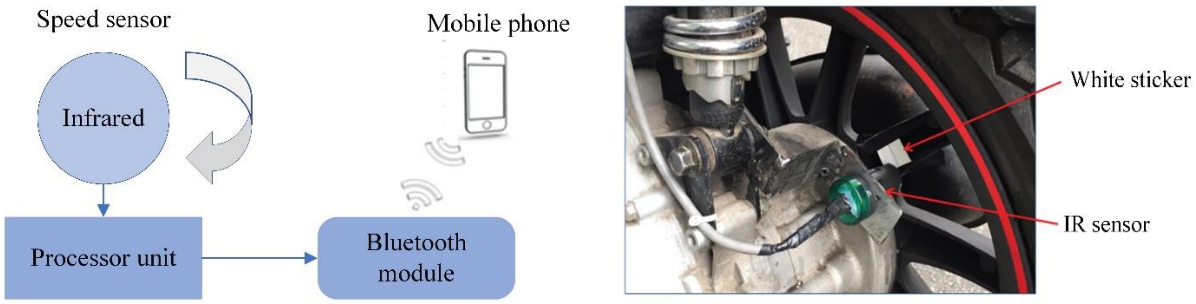
2.2. Collecting data

Testing motorcycle: An in-used MC with a port fuel injection, Honda Lead, was selected for this study. This MC branch has been estimated as being one of the fuel efficiency vehicle branches in Vietnam. The specifications of the testing MC are presented in Table 1.

Table 1. Specifications of the test motorcycle.

Branch and model	**Honda Lead 125**
Engine	Gasoline, 4 strokes, 1 cylinder, spark ignition
Model year	2017
Mileage	150,000 km
Displacement	124.92 cc
Bore x Stroke	52.4 mm x 57.9 mm
Compression ratio	11:1
Max power	8.45 kW/8500 rpm
Max torque	11.6 Nm/5000 rpm
Fuel system	PGM-FI
Transmission system	Automatic

Collecting real-world driving data: As mentioned above, the on-road measurement method was used to collect the real-world driving data for MC in Hanoi. The on-board measurement techniques used commonly for collecting the instantaneous speed of vehicles consist of using a data logger and Global Positioning System (GPS). In fact, the quality of data collected by using GPS depends heavily on the surrounding environmental conditions, such as the atmosphere and buildings, which could cause the multi-path signal reflection and the urban canyon phenomenon [17, 18]. In contrast, using the data logger can overcome these limits, but this method requires a higher experiment cost [16-18]. Many previous studies have used the data logger by plugging directly into the on-board diagnostics (OBD) to collect the instantaneous speed. However, this approach is only suitable for cars, trucks, or buses but not for MC because of lacking the OBD in most MCs. Therefore, to tackle both the high data quality and practicality, the non-contact sensor has been used to determine the instantaneous speed of MC in this study. This technique has been used successfully for collecting the speed of MC in many recent studies, such as Le et al. (2013), Seedam et al. (2015), Satiennam et al. (2017), and our recent study [22]. The principle diagram and the connection of the data logging device on the test MC are shown in Fig. 3. Further detail on the active principle of the data logging device was presented in Duc et al. (2020).



(a) Principle diagram of the data logging device (b) Installing sensor on the test vehicle

Figure 3. The data logging device.

Collecting the real-world driving data was carried out during the period May 2021 to July 2021 for both at rush and off-peak times to gain the effect of traffic density on the operation characteristics of the test MC. In addition, only one driver conducted the whole on-road measurements process to ignore the impact of driver behavior.

2.3. Pre-processing data

The collected datasets by using the data logging device have to be processed to eliminate outliers and denoise noise. The pre-processing process was designed to minimize errors while the data integrity was retained. Overall steps of the pre-processing process were designed based on the logic of increasing complexity as follows:

- Replace outlying speed values
- Calculate the instantaneous acceleration
- Repair outlying instantaneous power values
- Denoise and smooth the instantaneous speed signals

In the first step, the outlying speed in the collected instantaneous speed series were identified and removed based on the limit of speed. By this way, a gap was created at the position of these outliers. The speed values at these gaps were found again by using the estimation algorithm of missing data developed by Selesnick (2013).

The remaining random errors in the speed series would be continuously removed by searching for errors in the second dataset of instantaneous engine power. The derivative with respect to the time of the instantaneous speed, called the instantaneous acceleration, would be checked to ensure that the recorded speed matches the expected engine power. The instantaneous acceleration was used to calculate the engine power of the vehicle as follows [25]:

$$P = 1.08 \times m \times VSP \quad (1)$$

Where: P is the engine power (kW), m is the vehicle mass (tons), and VSP is the vehicle-specific power (kW/ton) calculated by using the equation of VSP given in Table 3 below.

In this step, the filter was designed to check the aberrant values in the secondary dataset calculated above and correct the error of speed values at corresponding points on the speed dataset. For this approach, if the value of engine power at any point is more than the maximum engine power of the test vehicle, the engine power at that point is considered abnormal. After that, the filter would delete the speed values at corresponding positions with the positions of these abnormal values in order to generate gaps. These created gaps are filled using the algorithm of Selesnick (2013) as presented above.

In the final step of the filtration process, the instantaneous speed was smoothed to remove any underlying noise that remained in this dataset.

All filter steps have been explained more clearly in the study of Duc et al. (2020). The entire steps above were developed on the Matlab software.

2.4. Extracting real-world driving characteristics

The processed data was used to calculate the kinematics parameters of the real-world driving data of MC in Hanoi. These parameters are presented in Table 2. The definitions of these parameters are applied to a velocity profile consisting of *n* data rows of time t_i in second and speed v_i in kph, with $1 \leqslant i \leqslant n$, as presented in Table 3 [26, 27].

Table 2. The kinetic parameters of the driving cycle.

No.	Parameter	Abbreviations	Units
1.	Total time	T_{total}	sec
2.	Acceleration time	T_{acc}	sec
3.	Deceleration time	T_{dec}	sec
4.	Cruising time	T_c	sec
5.	Creeping time	T_{cr}	sec
6.	Idle time (speed = 0)	T_i	sec
7.	Time proportion of idling mode	P_i	%
8.	Time proportion of acceleration mode	P_a	%
9.	Time proportion of deceleration mode	P_d	%
10.	Time proportion of cruising mode	P_c	%
11.	Time proportion of creeping mode	P_{cr}	%
12.	Total distance	dist	km
13.	Average trip speed	V_1	kph
14.	Average driving speed	V_2	kph
15.	Maximum speed	V_{max}	kph
16.	The standard deviation of speed	Vsd	kph
17.	95th percentile of speed	P95V	kph
18.	Maximum acceleration	acc_{max}	$m.sec^{-2}$
19.	Minimum acceleration	acc_{min}	$m.sec^{-2}$
20.	Acceleration average	AccAv	$m.sec^{-2}$
21.	Average positive acceleration	AccPosAv	$m.sec^{-2}$
22.	Average negative acceleration	AccNegAv	$m.sec^{-2}$
23.	Root mean square of acceletration	RMSA	$m.sec^{-2}$

24.	95th percentile of positive acceleration	P95PosAcc	$m.sec^{-2}$
25.	95th percentile of negative acceleration	P95NegAcc	$m.sec^{-2}$
26.	The standard deviation of acceleration	AccStd	$m.sec^{-2}$
27.	Number of stops	N_{stop}	-
28.	Number of stops per km	N_{rate}	/km
29.	Maximum VSP	VSP_{max}	$W.kg^{-1}$
30.	Minimum VSP	VSP_{min}	$W.kg^{-1}$
31.	Average positive VSP	VPSpos_av	$W.kg^{-1}$
32.	Average negative VSP	VSPneg_av	$W.kg^{-1}$
33.	Positive kinetic energy	PKE	$m.sec^{-2}$

Table 3. Definitions of driving cycle kinematic parameters.

Parameters	**Definitions**
Total distance	$Dist = (t_2 - t_1)\frac{v_1}{3.6} + \sum_{i=2}^{n}(t_i - t_{i-1})\frac{v_i}{3.6}$
Total time	$T_{total} = t_2 - t_1 + \sum_{i=2}^{n}(t_i - t_{i-1})$
Cruising time	$T_c = \begin{Bmatrix} t_2 - t_1 \ (\lvert a_1 \rvert < 0.1m/s^2 \text{and } \mathrm{v}_1 > 5\mathrm{m/s}) \\ 0 \ (else) \end{Bmatrix} + \sum_{i=2}^{n}\begin{Bmatrix} t_i - t_{i-1} \ (\lvert a_i \rvert < \frac{0.1m}{s^2} \text{and } \mathrm{v_i} > 5\mathrm{m/s}) \\ 0 \ (else) \end{Bmatrix}$
Creeping time	$T_{cr} = \begin{Bmatrix} t_2 - t_1 \ (\lvert a_1 \rvert < 0.1m/s^2 \text{ and } \mathrm{v}_1 < 5\mathrm{m/s}) \\ 0 \ (else) \end{Bmatrix} + \sum_{i=2}^{n}\begin{Bmatrix} t_i - t_{i-1} \ (\lvert a_i \rvert < \frac{0.1m}{s^2} \text{and } \mathrm{v_i} < 5\mathrm{m/s}) \\ 0 \ (else) \end{Bmatrix}$
Acceleration time	$T_{acc} = \begin{Bmatrix} t_2 - t_1 \ (a_1 > 0.1 \ m/s^2) \\ 0 \ (else) \end{Bmatrix} + \sum_{i=2}^{n}\begin{Bmatrix} t_i - t_{i-1} \ (a_i > 0.1 \ m/s^2) \\ 0 \ (else) \end{Bmatrix}$
Deceleration time	$T_{dec} = \begin{Bmatrix} t_2 - t_1 \ (a_1 < -0.1 \ m/s^2) \\ 0 \ (else) \end{Bmatrix} + \sum_{i=2}^{n}\begin{Bmatrix} t_i - t_{i-1} \ (a_i < -0.1 \ m/s^2) \\ 0 \ (else) \end{Bmatrix}$
Idling time	$T_i = \begin{Bmatrix} t_2 - t_1 \ (v_1 = 0 \ and \ a_1 = 0) \\ 0 \ (else) \end{Bmatrix} + \sum_{i=2}^{n}\begin{Bmatrix} t_i - t_{i-1}(v_i = 0 \ and \ a_i = 0) \\ 0 \ (else) \end{Bmatrix}$
Time proportion of cruising mode	$P_c = \frac{T_c}{T_{total}}.100\%$
Time proportion of creeping mode	$P_{cr} = \frac{T_{cr}}{T_{total}}.100\%$
Time proportion of acceleration mode	$P_a = \frac{T_{acc}}{T_{total}}.100\%$
Time proportion of deceleration mode	$P_d = \frac{T_{dec}}{T_{total}}.100\%$
Time proportion of idling mode	$P_i = \frac{T_{idle}}{T_{total}}.100\%$
Average trip speed	$V_1 = 3.6\frac{dist}{T_{total}}$

Average driving speed	$V_2 = 3.6\frac{dist}{T_{drive}}$
Standard deviation of speed	$\sigma_v = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} v_i^2}$
Acceleration average	$AccAv = \frac{1}{N}\sum_{i=1}^{n} a_i$ (with N = T_{total})
Average positive acceleration	$AccPosAv = \left(\sum_{i=1}^{n}\begin{Bmatrix}1(if\, a_i > 0)\\0(else)\end{Bmatrix}\right)^{-1} \times \sum_{1}^{n}\begin{Bmatrix}a_i(if\, a_i > 0)\\0(else)\end{Bmatrix}$
Average negative acceleration	$AccNegAv = \left(\sum_{i=1}^{n}\begin{Bmatrix}1(if\, a_i < 0)\\0(else)\end{Bmatrix}\right)^{-1} \times \sum_{1}^{n}\begin{Bmatrix}a_i(if\, a_i < 0)\\0(else)\end{Bmatrix}$
Standard deviation of acceleration	$AccStd = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} a_i^2}$
Number of stops	$Nstop = \sum_{i=1}^{n}\begin{cases}1(\{v_i = 0 \land a_i = 0\} \land \{v_i \neq 0 \lor a_i \neq 0\})\\0(else)\end{cases}$
Stops per km	$Nrate = 1000\frac{stop\_nr}{dist}$
Positive kinetic energy (PKE)	$PKE = \frac{1}{dist} \times \sum_{i=2}^{n}\begin{Bmatrix}v_i^2 - v_{i-1}^2(if\, v_i > v_{i-1})\\0(else)\end{Bmatrix}$
Root mean square of acceletration (RMSA)	RMSA = $\sqrt{\frac{1}{T}\int_0^T a^2.dt} = \sqrt{\frac{1}{N}.\sum_{i=1}^{N} a_i^2}$ Where: N = T = T_{total}
Vehicle specific power (VSP)	$VSP = v(1.1 \times a + 9.81 \times a\,tan(sin(grade)) + 0.132) + 3.02 \times 10^{-4}v^3$ Where: v is vehicle speed (m/s); a is vehicle acceleration (m/s^2); grade is the grade of road (degrees) (~ 0 for urban road)..

3. RESULTS AND DISCUSSION

3.1. The developed MATLAB Toolbox

In this study, a Matlab toolbox was developed to support the data pre-processing process. Fig.4 shows the detailed step in this toolbox. In this tool, there are three main steps: input data, processing data, and viewing results. This toolbox is very friendly for users as they only need to input parameters by themselves, then they can get detailed results of the pre-processing data. The processed data will be saved in the same pathway that the MATLAB tool is stored.

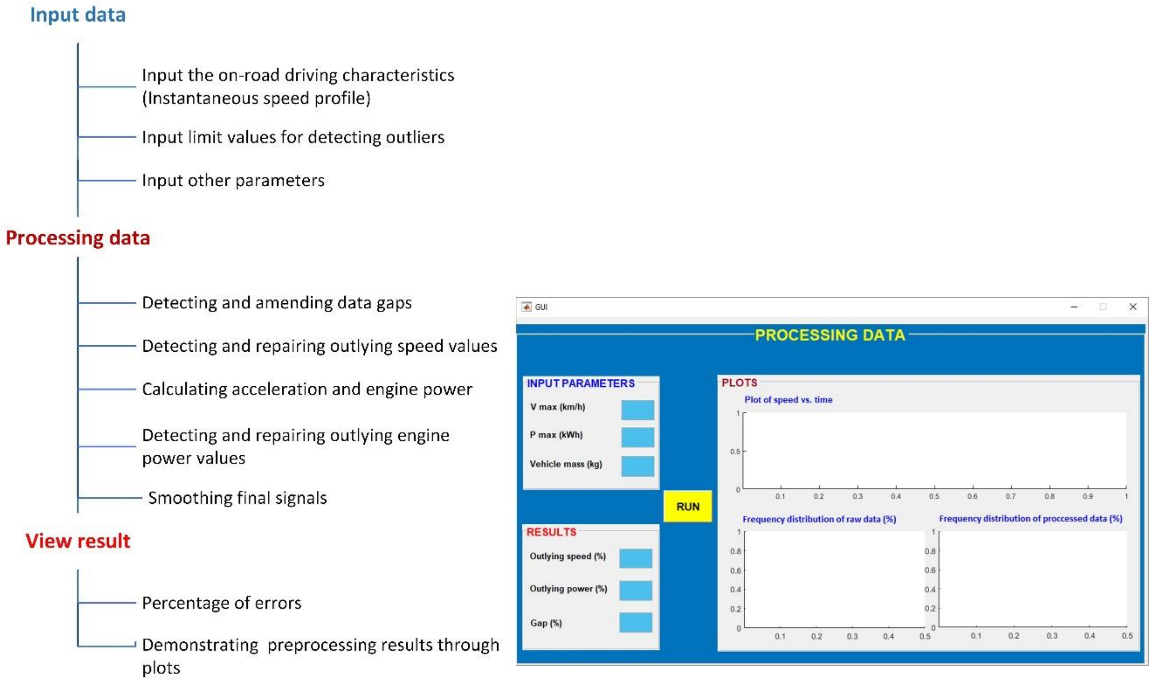


Figure 4. Process and interface of the toolbox.

3.2. Ratio of random errors

The limit parameters related to the test MC characteristics and the speed limit in urban Hanoi were used to set up the limit for detecting and repairing outliers in the speed profile, as shown in Table 4.

Table 4. Filtration limits.

Parameters	***Limit value***
Speed limit	60 km/h
Max engine power	8.60 kW

The ratio of random errors related to the outlying speed values and data gaps in the speed profile is shown in Fig. 5.

It can be seen from the pre-processed data results presented in Fig. 5, the percentages of misleading points related to the outlying speed and gaps in the recorded datasets are pretty small, only holding 0.82%. In which the random errors mainly relate to outliers in the speed profiles, approximately 0.77%. The percentage of gap data points is almost zero. The random errors in the speed profile collected by the data logging in this study are approximately 8.5 times smaller than that collected by using GPS, as presented in [28].

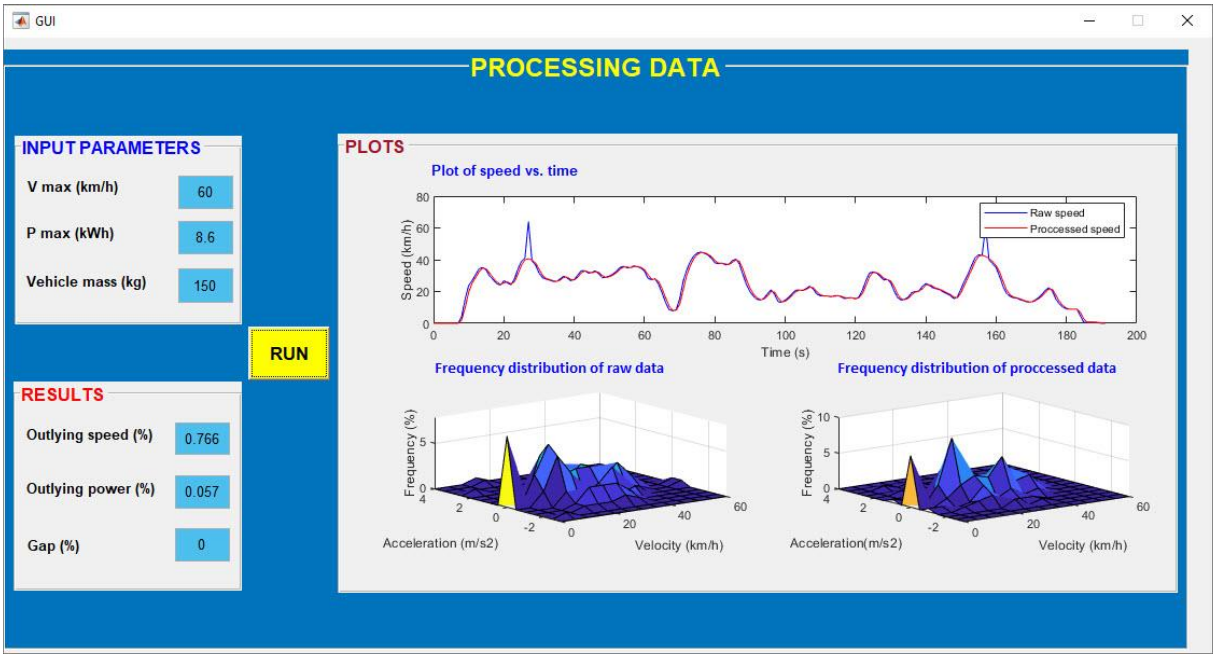


Figure 5. Display of the data pre-processing results.

3.3. Real-world driving characteristics of MC in Hanoi

The processed dataset was used to calculate the real-world driving characteristics of MC in Hanoi, as presented in Table 5. Note that among 33 parameters as shown above, five parameters (consisting of T_{total}, T_{acc}, T_{dec}, T_{cr}, T_c, T_{idle}, Dist, and N_{stop}) are only suitable for reflecting a fixed driving cycle/test cycle because they are dependent not only on driving characteristics but also on route length. If the route length is not defined, it is therefore preferable to utilize parameters relating to the fraction of time and the number of stops per kilometer rather than absolute values. As a result, five parameters are not discussed in Table 5.

Note: [(a)]The average values of real-world driving datasets collected in 2021; CEMDC is the Centre for Environmental Monitoring Motorcycle Driving Cycle for motorcycles in Hanoi developed by Tong et al. (2011) [8], in which the real-world driving data was collected in 2009; WMTC is the World Motorcycle Test Cycle used to measure fuel consumption and emissions in motorcycles; [(b)] includes the cruising and creeping modes; the blank denotes that the data is not available.

As can be seen from Table 5, although the average speed of MCs in Hanoi did not change much between 2009 and 2021, the time proportion of operation modes changed. The time proportion of steady mode of real-world driving characteristics in 2021 is about 10.1% higher than one in 2009. In contrast, the time proportion of the idling mode of real-world driving characteristics in 2021 is about 3.2% less than one in 2009. These results are suitable because Hanoi has been improving remarkably in the urban traffic infrastructure as well as the urban traffic organization. A higher difference has been found when comparing the driving characteristics of the MC in Hanoi and ones of WMTC. The highest difference relates to the number of stops per travelled kilometer, and the second-highest difference relates to the average driving speed. In addition, the distribution of VSP bins, which relates to the vehicle emission closely, between the real-world driving characteristics of MCs in Hanoi and those of WMTC is also remarkably different (see Fig. 6).

Table 5. The real-world driving characteristics of MC in Hanoi.

Parameter	***Units***	***This study[(a)]***	***Other driving cycles***		***Comparison with other driving cycles (%)***	
			CEMDC	WMTC	CEMDC	WMTC
Time proportion of acceleration mode	%	35.11	36.9	39	-4.9	-10.0
Time proportion of deceleration mode	%	34.52	34.3	30.17	0.6	14.4
Time proportion of cruising mode	%	11.23	21[(b)]	24[(b)]	10.1[(b)]	-3.2[(b)]
Time proportion of creeping mode	%	12.01				
Time proportion of idling mode	%	7.13	7.7	-7.0	-7.4	1.9
Average trip speed	kph	20.59	20.1	54.7	2.4	-62.4
Average driving speed	kph	21.09	21.2	58.78	-0.5	-64.1
Standard deviation of speed	kph	10.45				
Maximum speed	kph	41.47		94.91		-56.3
95th percentile of speed	kph	35.99				
Maximum acceleration	$m.sec^{-2}$	2.41				
Minimum acceleration	$m.sec^{-2}$	-2.19				
Acceleration average	$m.sec^{-2}$	0				
Average positive acceleration	$m.sec^{-2}$	0.36	0.42	0.447	-14.3	-19.5
Average negative acceleration	$m.sec^{-2}$	-0.36	-0.46	-0.502	-21.7	-28.3
Standard deviation of acceleration	$m.sec^{-2}$	0.51				
95th percentile of positive acceleration	$m.sec^{-2}$	1.06				
95th percentile of negative acceleration	$m.sec^{-2}$	-0.98				
Number of stops per km	/km	0.9		0.33		172.7
Positive kinetic energy (PKE)	$m.sec^{-2}$	0.34		0.38		-10.5
Root mean square of acceletration (RMSA)	$m.sec^{-2}$	0.51				
Vehicle specific power (VSP):	$W.kg^{-1}$					
+ Maximum VSP		16.25		36.48		-55.5
+ Minimum VSP		-16.68		-26.5		-37.1
+ Average positive VSP		2.66		5.63		-52.8
+ Average positive VSP		-2.39		-5.76		-58.5

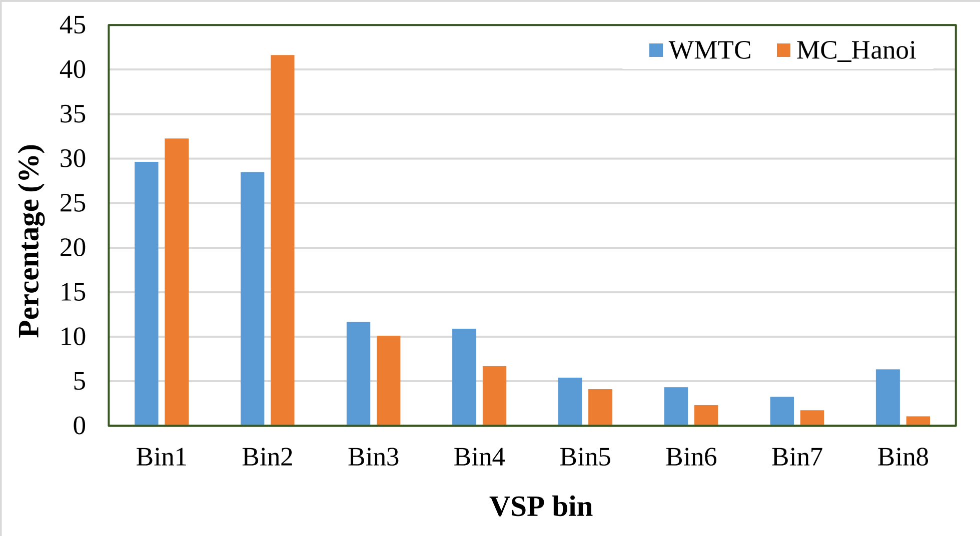


Figure 6. Comparison of VSP bins distribution between the WMTC and the real-world driving data of MC in Hanoi.

As shown in Fig.6, the VSP distribution is most concentrated at Bin 1 (zero power at idling mode) and Bin 2 (very low power). This VSP distribution is similar to the VSP distribution of MC in Ho Chi Minh City found by the study of Dung et al. (2015). The findings reveal that MCs on the road in Hanoi and Ho Chi Minh City frequently encounter traffic congestion due to high vehicle density, limited lane width, and many signalized intersections.

In comparison with WMTC, the VSP distribution of the real-world driving data of the MCs in Hanoi is always higher than one of WMTC. Especially, there is a significant difference in the VSP distribution at Bin 8 (bin that VSP > 13 kW/ton). The distribution of VSP at Bin8 in the real-world driving data of MCs in Hanoi is much less than that in the WMTC. In studies relating to vehicle’s emission, many researchers indicated a strong correlation between VSP and the pollutant emissions of the vehicle; the higher than 10 kW/ton VSP, the smaller the emission [29, 30]. These imply that the actual emission of MCs in Hanoi could be higher than the emission measured according to WMTC. In other words, the real-world driving characteristics of MCs in Hanoi have to be considered in the studies relating to the vehicle's emissions on the road.

4. CONCLUSION

The real-world driving data, the instantaneous speed versus time, of MCs in Hanoi was collected using the data logging installed directly on the test MC. An infrared sensor was used to record the speed of the wheel of the test MC to determine the instantaneous speed. The collected data was processed to remove the random errors and denoise. The percentage of misleading data points detected and repaired is only about 0.82% of total data points. The real-world driving characteristics of MCs in Hanoi have been identified by calculating 25 driving kinetic parameters based on the processed instantaneous speed data. The real-world driving characteristics of MCs in Hanoi in 2021 have changed lightly in comparison with ones in 2009, particularly the share of the time proportion in different operation modes. The time proportion spending for the acceleration, deceleration, cruising, creeping, and idling modes are 35.51%, 34,52%, 11.23%, 12.01%, and 7.13%, respectively. The average speed of MCs in Hanoi is about 20.49 kph. The results have also shown the remarkable difference between the real-world driving characteristics of MCs in Hanoi and the WMTC test cycle. Therefore, researchers are strongly recommended on developing the typical driving cycle in the studies relating to estimating the actual emission of the vehicles. The remarkable difference between the real-world driving characteristics of MCs in Hanoi and ones in WMTC identified in this study is a convincing finding for expanding the further studies on MCs' emissions and fuel consumption under the actual driving conditions of Vietnam.

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