Design and reliability analysis on internet-based real-time fuel consumption reporting system

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Abstract. The objectives of this study are (i) to design and fabricate the internet-based real-time fuel consumption reporting system and (ii) to evaluate reliability of the reporting system. Real-time fuel consumption rate of the testing vehicle which was measured from fuel injector control signal by the real-time fuel consumption meter proposed in the previously research was used to be the data for reporting by the internet-based real-time fuel consumption reporting system fabricated in this study. A universal asynchronous receiver transmitter (UART) protocol which is a computer hardware device for synchronous serial communication was used to communicate and transmit data between devices and operation of the system was controlled by the Arduino Mega 2560 microcontroller. Then, the Quectel BC95-B8 module was used to transmit data for recording on virtual database through narrow band internet of thing (NB-IoT) technology which operates in the 900-MHz frequency band. The results could be concluded that (i) the average fuel consumption rate shown on the ThingsBoard application was less than the calculated fuel consumption for about 11.6% due to number and duration of disconnection of the NB-IoT module. (ii) When data is remotely observed via internet connection, it was found that the data displayed in the database has a lag time for less than 9 seconds due to latency of data transmission system. From these points, the system proposed in this study was acceptably to be installed onto truck fleet in private or small-scale carriers for real-time monitoring and internal data collecting applications. However, reliability in data communication and additional feature to reduce data losing were strongly recommended to be applied on the system before it could be extended to be used in larger scale carriers.

Keywords: Internet-based real-time reporting system, Real-time fuel consumption rate monitoring system, Internet of things, Microcontroller, Reliability of reporting system

1. Introduction and its significance

Driving behavior of drivers is the important factor which affects to fuel consumption rate of vehicles [1-3]. Therefore, other people rather than the driver such as owners of transportation businesses would like to reduce the fuel consumption rate of their vehicles by controlling the driving behavior of drivers. However, the past study [4] reported that the characteristic of a fuel injector, such as, structure of the
fuel injector, percentage of injector’s duty cycle, pressure difference between a fuel rail and an intake manifold, fuel temperature, flow pattern of intake air, heterogeneous fuel and air mixture, etc., are the major factor that causes the actual fuel injection rate to diverge from the one corresponding to the injector’s control signal. Therefore, in order to enhance the accuracy and the reliability of the fuel consumption monitoring system using fuel injector’s control signal, the characteristics of fuel injector are always needed to be considered simultaneously. In order to control the driving behavior of drivers, the real-time fuel consumption rate of their vehicles is the most important information and it must be remotely observed from anywhere via internet connection [5].

Aforementioned reason, it became the significance of this study with objectives as: (i) to design and fabricate the internet-based real-time fuel consumption reporting system and (ii) to evaluate reliability of the reporting system.

2. Experimental details
Experimental setup and procedures for design and reliability analysis on the internet-based real-time fuel consumption reporting system were divided into two parts corresponded with the objectives of this study as follows:

2.1 Fuel consumption monitoring system
Major components of the fuel consumption monitoring system are shown in Figure 1 and details are listed as follows.

1) A microcontroller (Arduino, Mega 2560) was used as a central processor of the system. Electrical power was supplied by a separated power storage (Eloop, E12, 5 VDC, 2.1 A, 11,000 mAh) to prevent interference from the engine. Since voltage of the fuel injector’s control signal in the tested vehicle varied in range between 12 V and 14 V, which was higher than the maximum voltage of 12 V that the microcontroller properly operated, the voltage of the measured control signal was regulated to be the logic TTL signal or the pulse signal with voltage fluctuating between 0 and 5 VDC by (2) a voltage regulator (Sila, MM-DCIN V2.0). Velocity and position coordinates of the tested vehicle were obtained from (3) a global positioning system (GPS) module (ETT, ET-Mini GPS). After the microcontroller processed the measured control signal and velocity in conjunction with the fuel injector’s characteristic correlation obtained from the previous study [4], the measured and calculated data were show on (4) a LCD display with 4 lines of 20 characters. A casing of the display could be attached onto a windshield in a position that a driver could observe clearly. In addition, the system also functioned as a data logger as the measured and calculated data could be stored in the SD card by using of (5) a SD card module (Adafruit, Data logging shield) with real time clock (RTC) for further data analyses.

2.2 Fuel consumption reporting system
The calculated data obtained from the fuel consumption monitoring system as described in Section 2.1 were transmitted to the fuel consumption reporting system. Design and reliability analysis on the system were divided into two parts corresponded with the objectives of this study as follows:

2.2.1 Data transmission
Fuel consumption reporting system was designed and fabricated based on the Arduino Mega 2560 microcontroller. The measured data were received from the fuel consumption monitoring system as stated in the previously section by asynchronous serial communication. Then, the measured data were transmitted to be shown and recorded in the ThingsBoard cloud server through the narrow band internet of things module (Quectel NB-IoT, BC95-B8) as shown in Figure 2. The wiring diagram between devices for data transmission was shown in the Figure 3. The NB-IoT module was developed to meet requirement of the low power wide area (LPWA) technology. The advantages of this technology consisted of offering long battery life due to low power consumption and transmitting data over long distances. In contrast, it transmitted data at low bit rate, which was 24.00 kbps for
downloading and 15.63 kbps for uploading. The bandwidth was about 200 kHz. Hence, it could be seen that the NB-IoT was suitable to use for small data size communication between devices.

**Fig. 1** Components of the fuel consumption monitoring system

**Fig. 2** Fuel consumption reporting system

![Wiring Diagram](image)

**Fig. 3** The wiring diagram between devices for data transmission

### 2.2.2 Dashboard design
Dashboard of ThingsBoard cloud server was designed to display measured data of fuel consumption reporting system as mentioned in the previously section. Owners of transportation businesses can be observed the real-time data and history data to effectively improve driver behavior in driving. Type of data displaying on dashboard consisted of real-time data, profile data, average data and summation data as shown in Table 1. After that, data displaying on dashboard and LCD display of fuel consumption monitoring system were compared.

| no. | Displayed data                  | Type of data       |
|-----|---------------------------------|--------------------|
|     |                                 | Real-time | Profile | Average | Summation |
| 1   | Vehicle velocity, km/hr         | ✔         | ✔        | ✔        | N/A       |
| 2   | Engine speed, rpm               | N/A       | ✔        | ✔        | N/A       |
| 3   | Fuel injection rate, cc/s       | ✔         | ✔        | ✔        | N/A       |
| 4   | Fuel consumption rate, km/L     | ✔         | ✔        | ✔        | N/A       |
| 5   | Total fuel injection volume, L  | N/A       | N/A      | N/A      | ✔         |
| 6   | Total distance, km              | N/A       | N/A      | N/A      | ✔         |

After that, the internet-based real-time fuel consumption reporting system as mentioned above was installed on a tested vehicle (Mitsubishi Triton, Model year 2011) for on-road test. The procedure of testing was repeatedly conducted for 3 rounds in order to increase the reliability of the data. The distance of testing route was 56, 39, and 45 km. After the tested car reached the end of each test, actual fuel consumption rate (Actual FC) was calculated by measuring the fuel volume, which was refilled to the reference point of fuel tank. Then, the Actual FC was compared with fuel consumption rate
calculated from the data measured and stored in the SD card by the fuel consumption monitoring system (Calculated FC) and was compared with fuel consumption rate which was recorded and shown by the ThingsBoard application (ThingsBoard FC).

3. Results and Discussions
Results and discussions were divided into two parts corresponded with the objectives of this study as follows:

3.1 Fuel consumption monitoring system
The fuel consumption monitoring system module was designed to measure and calculate real-time data of tested vehicle; such as, the fuel consumption rate (FC) in unit of km/L, the fuel injection rate (FI) in unit of cc/s, vehicle velocity in unit of km/hr, etc. These calculated data were selected to be shown on LCD display as shown in Figure 4. Beside these displayed data, other measured data; such as, engine speed, GPS location, trip distance, etc. were transmitted to the reporting system module.

![Fig. 4 LCD display on fuel consumption monitoring system](image)

![Fig. 5 Comparison on actual, calculated and ThingsBoard fuel consumption rates.](image)

The results obtained from the on-road test are shown in Figure 5. They were found that, the average actual FC of tested vehicle obtained from each test round was 10.8, 11.6, and 13.4 km/L, respectively. In same way, the calculated FC, which was measured, internally calculated, and recorded on the SD card by the fuel consumption monitoring system was 9.3, 11.0, and 12.4 km/L, respectively. The calculated FC tended to be slightly lower than the actual FC for each test round with an average discrepancy about 9.5% of the actual FC. Since, the fuel injectors of the tested vehicle have been used for long time, which was affected to discrepancy of fuel injection volume of the fuel injector. Moreover, the discrepancy was affected by delay time of a fuel injector’s needle lifting, which was longer than the one used in the experiment to investigate the characteristic correlation of the fuel injector since the injectors installed in the engine on the tested vehicle has longer operation time than the one used in the laboratory. The discrepancy could be reduced by refined tuning on the characteristic correlation. However, the present discrepancy was in accepted range for usual fuel consumption rate monitoring system.

3.2 Fuel consumption reporting system
The fuel consumption reporting system was designed to demonstrate the calculated FC through the dashboard of ThingsBoard cloud server. The dashboard could be shown all measuring data as shown in Table 1 in real-time, which were transmitted from the fuel consumption reporting system module, as shown in Figure 6. The history of the data could be selected to be shown within any duration.
Subsequently, average vehicle velocity in unit of km/hr, average engine speed in unit of rpm, average fuel injection rate in unit of cc/s, and average fuel consumption rate in unit of km/L along the selected duration were displayed on the dashboard. The results were shown that, the ThingsBoard FC displayed on dashboard had average lag-time about 9 s, which was compared to the calculated FC displayed on the LCD display of the fuel consumption monitoring system for each measurement cycle, since the NB-IoT network has high latency for data transmission. This effect caused lag-time of data transmission and displaying to occur. Moreover, the ThingsBoard FC for each test, which was recorded and shown on the ThingsBoard cloud server was 9.4, 8.9, and 10.6 km/L, as shown in Figure 5. The ThingsBoard FC was lower than the calculated FC for about 1.2% 18.6%, and 15.0%, respectively for each test round. These differences were related to be an average discrepancy of about 11.6% of the calculated FC. Since the NB-IoT technology used relatively narrow bandwidth for data communication, the fuel consumption reporting system module found to be frequently disconnected from and re-connected to the ThingsBoard cloud server, especially when large number of NB-IoT modules were connected to the server in the meantime. This caused transmitted data to be lost. Sample of data shown on the ThingsBoard cloud server during the disconnection period are emphasized between dashed lines as in Figure 6a. From this problem, transmitted data during disconnected period were not recorded and shown on the dashboard. When history of the data was consequently selected, the discrepancy of the ThingsBoard FC could be observed. The discrepancy could be in either way, higher or lower than the calculated FC. It depended on the actual FC during the disconnection period. As above mentioned, it could be solved by using more effective networking protocol to prevent the network disconnecting problem during data transmission. However, the present discrepancy was in accepted range for usual fuel consumption rate reporting system but it was not acceptable for data analysis point of view.

4. Conclusions
Design and reliability analysis on the internet-based real-time fuel consumption reporting system has been designed and fabricated to be used for the real-time monitoring and internal data collecting of private or small-scale carriers. The NB-IoT module was used as the fuel consumption reporting system to transmit the measured and calculated data to the ThingsBoard cloud server for data displaying and recording. It was concluded from the on-road test that the average fuel consumption rate calculated from the fuel injector’s characteristic correlation by the fuel consumption monitoring system was less than the actual one for about 9.5% due to the delay time of a fuel injector’s needle lifting. Moreover, the ThingsBoard FC displaying had lag-time for about 9 s, which was compared to the calculated FC in each measurement cycle, since NB-IoT network has high latency for data transmission. The average fuel consumption rate shown on the ThingsBoard application was less than the calculated fuel consumption for about 11.6% due to number and duration of disconnection of the NB-IoT module and the ThingsBoard cloud server. This issue could be diminished by using more effective networking protocol for data transmission.

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Fig. 6 The data reporting dashboard on the ThingsBoard web-based application

References
[1] Lalwani M, Singh M, Conventional and renewable energy scenario of India: present and future, Canadian Journal of Electrical and Computer Engineering, vol. 1, no. 6, pp. 122-140, 2010.
[2] Min Z, Hui J, Wenshuo W, A review of vehicle fuel consumption models to evaluate eco-driving and eco-routing, Transportation Research Part D, vol. 49, pp. 203-218, 2016.
[3] Dohler M, Takehiro N, Afif O, Jose M, Patrick M, 5G mobile and wireless communication technology, Cambridge University Press, pp. 1-48, 2016.
[4] Kammuang-lue N, Boonjun J, Fuel consumption monitoring system using control signal and characteristic correlations of fuel injector, RMUTP Research Journal, vol. 12, no. 2, pp. 47-59, 2018.
[5] Eric W, Xingqin L, Ansuman A, Asbjörn G, Yutao S, Yufei B, Johan B, Hazhir R, A primer on 3GPP narrowband internet of things, IEEE Communication Magazine, vol. 55, no. 3, pp. 117-123, 2017.