Development of data acquisition system for Hybrid Electric Vehicles to measure CO2 emissions in developing south-east Asian cities

Paper Identification number: YRF13-033

Benjamin BÖRNGEN-SCHMIDT[1], Testsuhiro ISHIZAKA[2], Shota TOMA[3], Atsushi FUKUDA[4]

[1]Department of Multimedia Communication, Faculty of Computer Science
Technical University of Darmstadt, Germany
Telephone +49-6151-16-6150, Fax. +49-6151-16-6152
E-mail: boerngen-schmidt@stud.tu-darmstadt.de

[2]Department of Transportation Systems Engineering
College of Science and Technology, Nihon University, Japan
Telephone +81-47-469-5355, Fax. +81-47-469-5355
ishizaka.tetsuhiro@nihon-u.ac.jp

[3]Department of Transportation Systems Engineering
College of Science and Technology, Nihon University, Japan
Telephone +81-47-469-5355, Fax. +81-47-469-5355
cssy12015@g.nihon-u.ac.jp

[4]Department of Transportation Systems Engineering
College of Science and Technology, Nihon University, Japan
Telephone +81-47-469-5355, Fax. +81-47-469-5355
fukuda.atsushi@nihon-u.ac.jp

Abstract

Emission reduction from vehicles have been a major concern in both industry and research over the last few decades. Development of efficient engines through technical innovations such as downsizing and turbocharging have been crucial to reducing emissions as well as other regulatory measures and management for traffic-policy. Recently development of hybrid electric vehicles seems to be most feasible in terms of economy comparing with other innovation power unit such as fuel cell engines. Yet it is not clear how the actual impact of hybrid electric vehicles is in south-east Asian cities. Since most south-east Asian cities do not have a roadside sensor infrastructure and such infrastructures only provide an outside view. The problem with an outside view is, that the actual inner states of the vehicle, like fuel consumption, engine load etc., remain unknown. For this purpose a system should be developed to sample data from within the vehicle and transmit it to a backend. The Paper describes first the objectives and hypothesizes of the carried out experiment and second the used technology to sample and verify the before stated hypothesizes.

Keywords: carbon dioxide emission, estimation, HEV, mobile sensor probe, road network, traffic

1 Introduction

Carbon dioxide reduction has been a major concern in both research and industry over the last decades. In the vehicle industry efforts were made to build more efficient engines and use aerodynamics to minimize the drag of passenger vehicles. The next evolution was the introduction of hybrid electronic vehicles (HEV), which featured a common internal combustion engine (ICE) as well as a motor which facilitated the ICE during acceleration. The current next step is to build passenger cars, which are only powered by a motor.

Various researches have shown, that HEV can reduce the emitted carbon dioxide of round about 30% [1]. But yet it is unclear how the impact HEV, especially in south-east Asian cities.

Within this paper a possible solution should be discussed how data can be collected from HEV in a long term experiment. The Paper therefore first introduces the research topic and its goals, second a from the research topic derived project. After the project has been introduced a hardware requirement analysis is carried out to identify the determinants. Based on the determinants hardware will be searched and evaluated. Within the hardware evaluation only current available hardware is considered, since this project should be conducted in the near future. After possible hardware for integration has been evaluated and chosen, the current thoughts of how to realize such a system will be discussed.

2 Research topic

The overall goal is to determine how much carbon dioxide is emitted by vehicles in the current traffic situation in developing south-east Asian cities like Bangkok and Khon Kean. This knowledge then should be used to create an estimation model which then could be used to minimize the carbon dioxide pollution. The highest potential to reduce vehicles carbon dioxide emission lies within the reduction of overall fuel consumption of vehicles. Another potential in reducing the carbon dioxide emission lies within the optimization of the road network [2].

Hybrid Electric Powered (HEV) vehicles have kicked off a “green power” trend. HEV are considered to have a better fuel efficiency, since acceleration of the vehicle is aided by a motor. During congestion situations a lot of acceleration and deceleration events occur. These stop-and-go events consume fuel inefficiently due to the characteristics of combustion engines [3]. So in such situations the aid of a motor could mitigate the inefficient fuel consumption [1, 4].

However, the impact of HEV on environment, such as air pollution and carbon dioxide emission reduction, in the whole road network has been never revealed in a long term comparison experiment because of two reasons. The first reason is that the question about how much HEV can reduce fuel consumption has not been fully revealed compared to fuel cell vehicles (FCV). The fuel consumption of HEV is sensitively depending on traffic situation. Therefore the estimation of fuel consumption on each traffic situation needs to be precisely conducted. The other reason is that the percentage of each traffic situation, like congestions, partially congested or flowing, in whole road network is unknown. In the context of traffic situation the knowledge of queue length is also of interest. While vehicles queue they have a velocity of 0, but during this time FCV still consume fuel. HEV on the other hand do not consume any fuel, but only use its motor to move. The queue length therefore does have an impact when comparing and estimating the carbon dioxide emissions of HEV and normal vehicles. One way to measure carbon dioxide emissions is the calculation of the vehicle specific power (VSP), since the VSP has a high correlation with carbon dioxide emissions [5].

An idea to estimate percentage of each traffic situation is to use probe-vehicles for data collection. In the case of Bangkok, there are two key projects currently carried out for data collection from probe-vehicles. A correlation of data taken from these project with a data set collected from HEV probe-vehicles could clarify the impact of HEV on fuel consumption reduction dynamically on the whole road network.

The final aim of the research topic is to estimate the impact of HEV on the whole road network. The collected data from the probe vehicles will be used in models like EcoGest, CMEM and ADCISOR to estimate their carbon dioxide emissions [6]. Finally this estimation should be compared with data taken from the other previously mentioned projects.

3 Research project

To be able to further analyze such an impact of HEV we want to collect real-life data. As possible data sources were identified road side sensors, intelligent navigation systems, dedicated sensor equipment and the internal vehicle sensors. Road side sensor are problematic in two respects. First cities like Bangkok or Khon Kean do not have such an infrastructure and secondly they only provide an outside view on the vehicle, so internals like current fuel consumption remain unknown. Intelligent navigation systems could provide data about the traffic situation and even fuel consumption, but the software is a closed systems and would have to be changed by the manufacturer. Dedicated sensors could directly measure carbon dioxide emissions and the traffic situation. But regarding a long term evaluation, such dedicated external sensors have some drawbacks, like high cost and the non-trivial installation on the vehicle itself. A vehicle itself features a variety of sensors which are all interconnected using an information bus within the car. Although using the internal sensors does not provide exact information on the carbon dioxide emission, like dedicated sensors could, but a good approximation is feasible with measurements like the VSP.

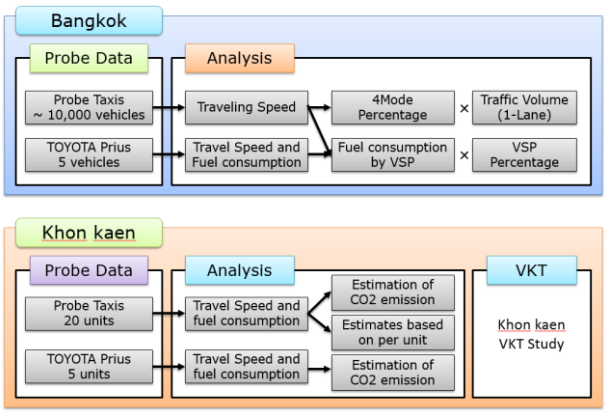

Figure 1: Research Project

Therefore, this paper focuses on potential hardware to collect fuel consumption data from HEV with online data transmission for long time experiment. The objective of this paper is to examine hypothesizes of the carried out experiment and second the used technology to sample and verify the before stated hypothesizes.

4 Hardware

To be able to collect primary grade data form vehicles additional hardware has to be integrated. This hardware will act as a collection unit (CU). Its main purpose is so collect data from various sources. This data then should be stored locally and also be transmitted to a server backend. The following sections describe the requirement analysis, evaluation and selection process for the hardware.

4.1 Hardware requirements analysis

The hardware requirements a derived from field of usage and atomic measurements that should be collected. Since the hardware will be placed within a vehicle, there are some constraints to adhere to. One of the important constraints is the power supply and the power consumption of the CU. While the car is running, thus generating power through a dynamo, the power consumption of the CU is negligible. Problematic are times when the dynamo is not running, thus no power is generated, and the battery of the vehicle has to be used as power source for the device. In the latter condition the device should be able to safely power down to safe energy.

Since in the research it is of interest to know the whereabouts of the probe vehicle it should be possible to use systems like GPS or any other system with which it is possible to determine the current location. With the knowledge of the current position of the probe vehicles conclusions about the traffic situation in the whole road network can be made.

To be able to collect further information, than just the current position of the vehicle, access to the vehicles information bus is needed. In most of the current vehicles the information bus is realized using the CAN-Bus or similar system. Problems in combination with information busses like CAN is that manufactures do not disclose how transmitted data is structured. So it is not possible to extract any information by directly tapping into

the information bus. A possible alternative is the OBD-II standard, which is primarily used for vehicle diagnosis. The OBD-II standard defines so called Parameter IDs (PID) codes [1] which can actively poll data from ECUs (Electronic Control Unit). The PIDs which can be collected from the OBD-II are mainly concerning the powertrain, which aligns with the data that should be collected for the previous mentioned research topic.

Another requirement is the recording and storing of collected data. As mentioned later, the hardware should also transmit the collected data near real-time to a server backend. But since there is now guarantee, that data will or can be transmitted correctly, the collected data should be stored locally. Also to be able to verify the gathered information after the end of the data collection the historical atomic data is needed. One major concern about the local data storage is the available space, since the data collection will be conducted over several months. Therefore the possibility to store collected data on a memory card is a further requirement for the hardware.

As stated before the data collection will be carried out over a longer period. During this time, it would be helpful for the data evaluation to transmit the collected data to a server backend. The preliminary evaluated data then can be used to adjust the test schedule. Since the hardware will be installed within a vehicle and maybe in a place where it is not easily reachable it would be best to use wireless communication. Wireless communication can be realized using Bluetooth, Cellular Network or WLAN. Looking at the possibilities the Cellular Network seems to be best fit. It can volitional create an internet connection and has a great signal coverage. A limitation, generated by the uplink quality and speed, is the amount of data that can be transmitted over the mobile data network. This limitation can be overcome by using UMTS or LTE cellular networks.

[1] SAE J1979 / ISO 15031-5

The accelerometer provides information about whether the vehicle is accelerating or decelerating. This information can be used in the estimation model to differentiate between load conditions of the engine.

In the case that current available software for the chosen hardware does not cover all requirements of the project, custom software has to be developed. In order to be able to develop custom software a development environment for the hardware has to be available.

As a nontechnical requirement, the price of the hardware has been considered as well. The cost-performance ratio of a solution is an indicator on how much vehicles can be equipped with CUs under a given budget.

4.2 Hardware search and evaluation

To find suitable hardware an online search has been conducted based on the previous mentioned hardware requirements. As search keywords the following have been used “GPS GRPS (CAN|OBD)” and “GPS (UMTS|HSDPA|3G) (CAN|OBD)”. Also alternatives like using a Smartphone as CU and connecting devices to in utilizing its wireless communication capabilities, as well as creating custom hardware have been considered in the evaluation. The following listing shows the criteria under which the found hardware has been evaluated and ranked.

1. CAN/OBD-2 communication
2. Local Storage
3. GPS
4. 3G Network
5. Accelerometer
6. Development Environment[2]
7. Price

One of the main problem with most of the found hardware was, that it is intended to be used

[2] Has only been taken in consideration, if the current software did not provide the necessary functionality

as tracking devices. Such tracking devices mostly offer most of the features stated in points 1-5, but lack the possibility to customize their behavior to fit the projects requirements. Also most of the devices rank in price regions around 1200 EUR or 1500 US Dollar making them uneconomical for research purposes. The solution to use smartphones as CU also is pricy with around 600 EUR or 750 US Dollar per device, but after conducting the research it is possible to sell such devices again. Also to be able to use the smartphones GPS efficiently it should be placed within the front shield. This though introduces the problem of overheating caused by direct exposure of smartphone to sunshine.

4.3 Hardware Selection

After identifying possible hardware and carefully evaluating it, the choice was between one of the dedicated device from Berger called ISIM wireless and a Raspberry Pi with an additional GPS and UTMS module. The Berger ISIM as well as the Raspberry Pi Solution cover nearly all of the above stated requirements. The biggest trade-off with the ISIM wireless is its cost-performance ratio. The Raspberry Pi on one hand has a good cost-performance ratio, but on the other hand the development of software from the scratch introduces a huge effort. In the end the cost-performance ratio did outweigh the overall advantage of a dedicated hardware and it was decided to choose the Raspberry Pi as basis for development.

5 Custom solution development

This chapter covers the current plan and development status[3] of the custom software for the Raspberry Pi. Since it is in a very early development phase only some basic tests, like verifying that hardware works, have been carried out. Within this chapter first the overall system structure will be described. Later selected parts of the system are described in detail.

5.1 Overall system structure

The system is a 4-Tier system (cf. Figure 2) which is structured in a collector-server-client architecture. The first tier are the CU in the vehicles which does nothing more than the bare data collecting. The collected data then is send to the second tier. The second tier is the main data storage layer. The third and fourth tier are an application and a representation layer, which will give access to the collected data.

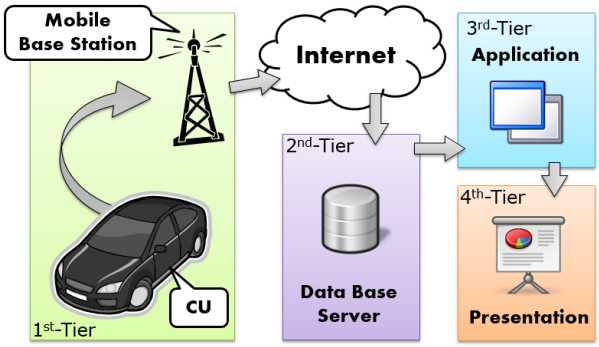

Figure 2: 4-Tier system structure

As mentioned in the previous chapter a Raspberry Pi will be used as CU (cf. Figure 3). On the Raspberry Pi an external GPS and 3rd generation cellular network module form Cooking-Hacks will be attached to GPIO Ports. On top of that a 3-axis accelerometer will be placed. The whole system will be either powered by a combination of a battery power-pack, which can supply 5V@1A for about 2h and is charged by a USB gadget charger. The power-pack is necessary since the power to the vehicles gadget port will be cut once the vehicle is turned off, but the system will need some time longer to shut down. As alternative solution the CU could be directly attached to the vehicles internal battery, which can supply enough power. If the CU however enters a stall state where it does not power down itself it would drain the battery of the vehicle. So with this solution there must be found a way to trigger a force shutdown of the CU. The communication with the OBD-II port of the vehicle will be done using a USB-2-RS232 adapter with an ELM327 or compatible chip will be used.

[3] Current development can be found under https://github.com/boerngen-schmidt.

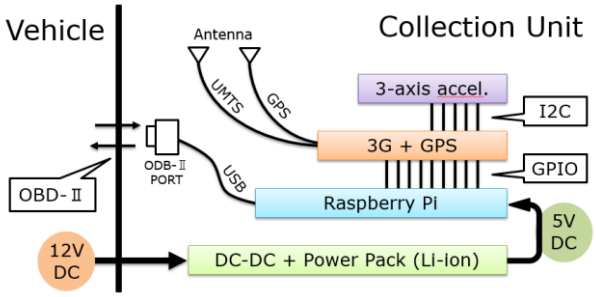

Figure 3: CU hardware layout

The backend will consist of an application server and a database server. For the database a normal SQL based one like MySQL or a similar one will be used. The application server has two main tasks to fulfill. First task is to receive the data from the various CUs and prepare it to be inserted into the database. Second task is to use the previously stored data to calculate measurements like VSP and combine data from other projects. The generated information by the application layer is then provided to the presentation layer.

5.2 Software Design

A main part in creating a CU is the creation of its custom software. Currently there are a few known projects which have a similar purpose, but are not usable as a basis for software development [7, 8]. So the whole software package for the project will be developed from scratch.

First question that had to be answered was which operating system should be used. For the Raspberry Pi there are Linux and BSD based OS as well as an Adroid port. The choice was made to use Raspbian, a Debian Linux ARM port. Raspbian offers a good driver support and a variety of software packages. Since the Raspberry Pi will be used for sampling data, it might be better to use a Real-Time OS later on, but in the current development phase the main goal is to create a running system.

The sampling application itself will be fully written using C++11 standard as programming language. C++11 is a revise of the former C++0x standard and offers further improvements in language constructs. Also C++ offers an object orientated approach and, as well as the C language, a close to hardware programming which minimizes the overhead and improves performance, compared to solutions based on python. Using an Object orientated approach also offers the benefit of being able to adapt to new hardware, since these can be represented by objects which use a uniform interface. Figure 4 shows how these objects are used within the application flow of the CU. As a special

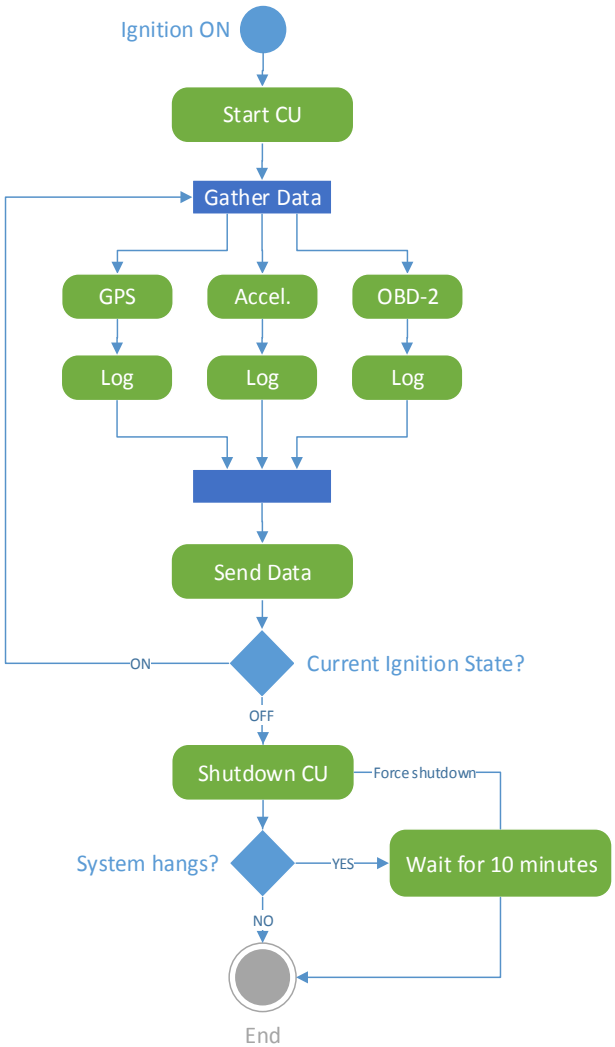

Figure 4: Application flow

6 Conclusion and further development

The usage of a single-board computer like the Raspberry Pi with additional equipment seems to be a reasonable alternative to dedicated hardware. The overall performance-cost ratio of the chosen solution is very high, thus giving the possibility to extend the number of vehicle probes. The Software

used in the project tires to be as generic as possible, so that it is easily possible for related research project to customize the software to its needs. In the current development the major drawback of this solution is the development of the software. But also in terms of hardware there are some obstacles to overcome, mainly in terms of how the CU will be powered and how it is guaranteed that the vehicles battery is not drained.

As stated in in the previous chapter some preliminary tests with the hardware has been carried out. We tested if it is possible to for the Raspberry Pi in combination with an ODB-II dongle to communicate with the ECU of the vehicle. After finding the right parameters for the serial communication, we were able to poll the wanted information from the ECU and display it on the console. Next step is to implement a short C++ application which does the same thing, but without user interaction.

In terms of hardware we try to stick to off the shelf available once, like timers, power converters, antennas etc. to have an as reliable as possible first prototype.

Further testing has to be made if it is feasible to pre-calculate certain values on the Raspberry Pi to lighten the burden of the backend, which is only interested in the aggregated information. Also the hardware part of the device has a lot of optimization and customization potential, which will make the overall CU smaller.

As conclusion it could be said, that from the current point of view there is an easy applicable solution or workaround for the current obstacles, thus the implementation of hardware and software for the CU is highly feasible. Under smooth conditions it should be possible to have a first basic prototype running by the end of August.

7 References

[1] R. K. Ahluwalia, X. Wang, and A. Rousseau, “Fuel economy of hybrid fuel-cell vehicles,” *Journal of Power Sources*, vol. 152, pp. 233–244, 2005.

[2] M. Barth and K. Boriboonsomsin, “Real-World Carbon Dioxide Impacts of Traffic Congestion,” *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2058, no. -1, pp. 163–171, 2008.

[3] S. Williamson and A. Emadi, “Comparative Assessment of Hybrid Electric and Fuel Cell Vehicles Based on Comprehensive Well-to-Wheels Efficiency Analysis,” *IEEE Trans. Veh. Technol*, vol. 54, no. 3, pp. 856–862, 2005.

[4] R. Smit, A. Brown, and Y. Chan, “Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow?,” *Environmental Modelling & Software*, vol. 23, no. 10-11, pp. 1262–1270, 2008.

[5] G. Song, L. Yu, and Z. Tu, “Distribution Characteristics of Vehicle-Specific Power on Urban Restricted-Access Roadways,” *J. Transp. Eng*, vol. 138, no. 2, pp. 202–209, 2012.

[6] C. Silva, T. Farias, H. C. Frey, and N. M. Rouphail, “Evaluation of numerical models for simulation of real-world hot-stabilized fuel consumption and emissions of gasoline light-duty vehicles,” *Transportation Research Part D: Transport and Environment*, vol. 11, no. 5, pp. 377–385, 2006.

[7] Wolfram, *Raspberry Pi Car PC Project.* Available: http://wolframpc.blogspot.jp/p/raspberry-pi-car-pc-project.html.

[8] A. Kehoe and D. O'Regan, *PiMyRide: OBDII Logging on a Raspberry Pi.* Available: http://www.pimyride.com.