CETRA[2020*] 20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

THE DEVELOPMENT OF INTEGRATED ROAD CONDITION MONITORING SYSTEM FOR DEVELOPING COUNTRIES USING SMARTPHONE SENSORS AND DASHCAM IN VEHICLES

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Abstract

In developing countries like Timor-Leste, regular road condition monitoring is a significant subject not only for maintaining road quality but also for a national plan of road network construction. The sophisticated equipment for road surface inspection is so expensive that it is difficult to introduce them in developing countries, and the monitoring is usually achieved by manual operation. On the other hand, the utilization of ICT devices such as smartphones has gained much attention in recent years, especially in developing countries because the penetration rate of the smartphone is remarkably increasing even in developing countries. The smartphones equip various high precision sensors, i.e., accelerometers, gyroscopes, GPS, and so on, in the small body in low price. In this project, we are developing an integrated road condition monitoring system that consists of smartphones, dashcams, and a server. There are similar trials in advanced countries but not so many in developing countries. This system assumes to be used in developing countries. The system is very low cost and does not require trained specialists in the field side. The items that are automatically inspected in this system were carefully selected with the local ministry of public works and include paved and unpaved classification, road roughness, road width, detection and size estimation of potholes, bumps, etc., at present. All the inspected items are visualized in Google Maps, Open Street Map, or QGIS with GPS information. The survey results are collected on a server and updated to more accurate values by the repeated surveys. On the analysis, we use several state-of-the-art machine learning and deep learning techniques. In this paper, we summarize related works and introduce this project's target and framework, which especially focused on the developing countries, and achievements of each of our tasks.

Keywords: road condition monitoring, developing country, smartphone, dashcam, deep learning

1 Introduction

The road condition monitoring is an important task for public institutions of developing countries since the road is an essential part of the country's economic growth and social services development. The road condition monitoring can be done in many ways, from manual inspection to sophisticated equipment. As the sophisticated equipment for road surface inspection is too expensive for developing countries, common ICT devices like smartphones can be an alternative utility. The penetration rate of the smartphone is remarkably increasing even in developing countries, and it equips with high precision sensors at a low price. There are differences in inspection items of road maintenance between advanced and developing countries, and we need to select the inspection items carefully. In advanced countries, there are relatively many studies on road conditions, whereas little in developing countries. This study is mainly focusing on the road survey in developing countries like Timor-Leste.

Timor-Leste is the newest country and became independent in 2002, located in Southeast Asia, east of Indonesia. It is surrounded by sea waters and has many mountain areas. Most roads pass through mountains and coastal regions, and 70 % of about 1.3 million inhabitants live in rural areas, and the agricultural sector is the main contributing factor in their daily lives. Presently, Timor-Leste has more than 6,000 km of road network. It comprises 1,426 km of national roads, 869 km of district roads, 716 km of urban roads, and more than 3,000 km of rural roads that are still unpaved [1–3]. More than half of national roads have not been paved. As a tropical region, Timor-Leste road gets damaged by heavy rain. Furthermore, Timor-Leste has many unstable slopes for its steep ground and fragile geology. Frequent landslides and rocks fall during rainy seasons cover the roads and destroy all the road structures. Therefore, in developing countries like Timor-Leste, regular road condition monitoring is a significant subject not only for maintaining road quality but also for the national plan of road network construction in line with the target on a Timor-Leste strategic plan by 2015-2030 [1].

Unlike advanced countries, first of all, the survey has to be conducted following with specifying the segments of paved and unpaved road in Timor-Leste because there remains very old damaged paved road which was constructed when Timor-Leste was a part of Indonesia, and the survey has not finished after the independence. Furthermore, the road width of both paved and unpaved is also an important item to inspect. Therefore, our survey starts from the classification of road sections into 'paved' and 'unpaved', and then we estimate the width and roughness level as their status. The detection and size estimation of potholes and cracks are also the items which we inspect. Road facilities such as drainage, bridge, culverts, retaining wall, Gabion and landslide will also be considered in future of this projects.

As related works, Tai et al. studied to utilize smartphone fixed on a motorcycle to collect acceleration and location data, and analysed to detect road anomalies [4]. The identification of braking events and bumps on the road were achieved in [5], as frequent braking indicates congested traffic conditions and bumps characterize the type of road. In [6], the authors developed a mobile application to identify road defects. They discussed the threshold for the detection of defects depending on external factors such as vehicle types, road surface, driving style, and suspension type. The images captured by a smartphone and deep neural networks were used for road damage detection and damage type classification in [7]. In [8], a design of a system for collaborative monitoring of road roughness levels was introduced. In the study, an android smartphone software was developed, and collected data from several types of smartphones, vehicles, and drivers and the results were summarized on Google Map. Cruz J et al. introduced a low-cost road roughness survey system that consists of a smartphone and geographic information system [9]. The system used to estimate the roads roughness and visualize their status on GIS System. Investigation of measured pavement roughness by smartphone with user option is also discussed in [10]. Most of these studies mentioned above focused mainly on developing standalone system inspection using mobile sense and image based on road paved to identify the location of anomalies and estimating road Roughness, and not including road unpaved and estimation of road width.

In this project, we are developing an integrated road condition monitoring system focused on the use in developing countries. The system consists of smartphones, dashcams, and servers for analysis and data visualization. The smartphone and dashcam are set inside of a vehicle, e.g., dashboard, and by adhering to the front window of a car. To estimate the road condition continuously and detect several types of abnormalities of the road, recording data is sent to a server with global positioning system (GPS) information.

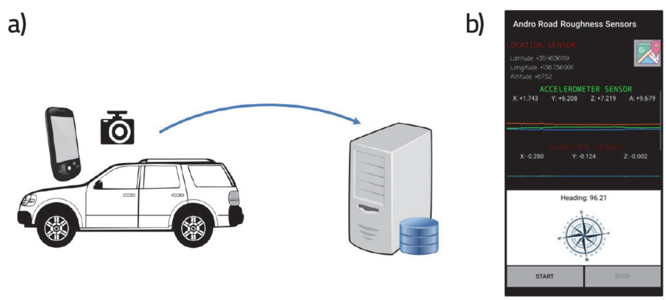
The android smartphone application which we developed will be installed in common types of smartphones, and recording will be achieved with common types of vehicles. The dash-cam is used to record video of the road simultaneously with the smartphone in the running vehicle for visual inspection and other estimation. This system is very low cost and does not require trained specialists in the field side. In this paper, first, we will introduce the whole objective and framework of this project. Then, the progress so far [7, 11, 12, 13] will be described. As machine learning techniques, we have tried several types of them on road surface estimation and compared the performances so far. The results of the comparison of each technique are also discussed in this paper. The team of this project consists of faculty of engineering of Gifu University and National University of Timor-Leste, with Department of Roads, Bridges and Flood Control (DRBFC) of the Ministry of Public Works in Timor-Leste, under the support of the Japan International Cooperation Agency (JICA).

2 Method and result

2.1 Framework of the system

This system consists of smartphones, dashcams, and servers (Fig. 1a). On each smartphone, the android application software which we developed is installed (Fig. 1b). The smartphone is fixed on the dashboard while the dashcam adheres to the front window of the vehicle. The application software monitors sensor data and records the data in 100Hz sampling frequency. Basically, the smartphone does not perform any calculation to prevent it from being hot in long recording and because the raw data size is not so big. On the server, the collected data is analysed and visualized in Google Map, Open Street Map, or QGIS with colours (Fig. 2).

Figure 1 a) Data collection is achieved by smartphones and dashcams which placed on dashboard of vehicles.



The recording data is sent to a server and analysed. b) A screenshot of the android application developed for this project.

The outline of the system is illustrated as a flowchart in Fig. 3. The red boxes indicate the procedures which we already developed for the present, and we are still improving. The orange boxes indicate the procedures which require further improvements. The black boxes indicate we have just started to develop. The system roughly consists of two subsystems. In System 1, the smartphone monitors 11-dimensional time series sensor data, including accelerometer, and we analysed paved/unpaved classification, anomaly detection, and roughness estimation for both paved and unpaved. In System 2, we analyse the video data taken by dashcam, and paved/unpaved classification, pothole detection, pothole size estimation, and road width estimation were performed. The smartphone and dashcam recording are made simultaneously, and we use each data complementary. On the server, averaging is achieved on the same road recording to decreases errors of individual recording.

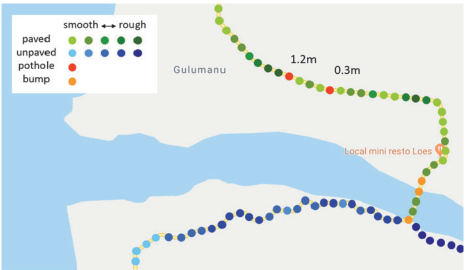


Figure 2 The collected data is visualized on map such as Google map, Open Street Map, or QGIS

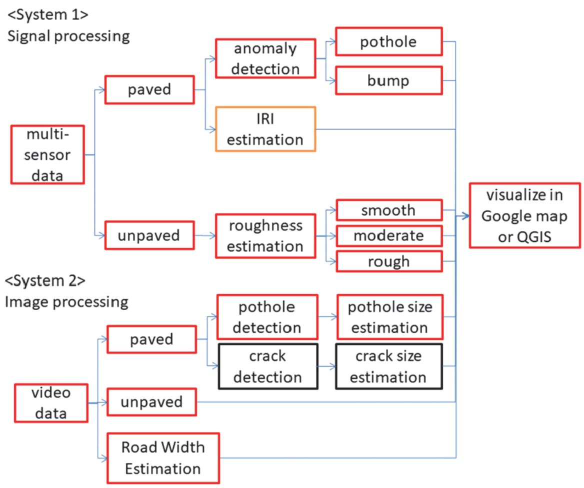


Figure 3 Flow chart of the system. The procedures with red and orange boxes indicate we have already developed. The orange boxes are procedures which require further improvements.

2.2 Data acquisition

The smartphone is fixed on the dashboard of the vehicle by curing tape. The smartphone must be placed tightly on the dashboard to get good analytical results. The android smartphone application which we developed records 11-dimensional data every 10 msec, i.e., acceleration (x, y, z), gyroscope (x, y, z), GPS (latitude, longitude, altitude), compass and timestamp. The dashcam is attached to the front window to take video in front view with 30 fps FHD format.
The data recording was conducted in the Timor-Leste road network, including national roads, district roads, and rural roads. The roads have various types of the condition such as unpaved or paved with potholes and bumps. In practical use, the application will be used by various types of vehicles and with different velocities. To develop a system that is robust for various types of vehicles and speed, we took data using six types of vehicles and with different velocities on the same road. The total length of recording is about 1,000 km of road in Timor-Leste.

2.3 Data pre-processing

First, we make the rotation for the 3D time series data to normalize the posture of the smartphone. We applied 5Hz LPF on each time series data. For classifications, we used a total of 130 features, which include mean, variance, standard deviation, mean absolute deviation, maximum, minimum, root mean square, signal magnitude area, interquartile range, correlation coefficient, energy, entropy, and skewness [11, 13], both in time and frequency domain after applying window.

2.4 Classification of paved and unpaved road

We tried two approaches to classify paved and unpaved roads, that is, signal processing of accelerometer data taken by smartphone and image processing of images clipped from dashcam video. In both of them, we used machine learning techniques. We assume that this system will be used by several types of cars derived by unspecified drivers without specialized training in the usage of the survey system. To achieve the robustness of the system in use, the machine learning techniques on the classification of road status are efficient. We compared the performance of three types of machine learning techniques on the classification of paved and unpaved using accelerometer data, i.e., SVM, HMM, and Residual Neural Network (ResNet) [11]. As a result, we got 97 % of classification precision by signal processing using ResNet. Regarding the image processing approach, we used a convolutional neural network (CNN) [12]. As a result, we could classify the paved and unpaved in various conditions of the road such as wet, muddy, dry, dusty, and shady over 96 % of precision [12]

2.5 Roughness estimation

The roughness estimation is one of the most challenging issues to solve in this type of project because the vibration of the vehicle depends on many factors such as suspension type, tire, body stiffness of car, vehicle speed, the way of driving, and so on. There are many trials to estimate International Roughness Index (IRI) using a smartphone, but usually, they require calibrations or car type manual selection. In this study, we are trying to estimate individual parameters also by machine learning. At present, we are using a regression function which manually found for each vehicle.

2.6 Anomalies detection

The existence of anomalies such as potholes and bumps on paved road sections are examined after the classification of paved unpaved road. As detection algorithms, we compared i) the combination of K-Nearest-Neighboured (KNN) and Dynamic Time Warping (DTW), ii) the combination of KNN and Euclidean Distance, and iii) SVM. As a result, we got the best performance by using i) the combination of K-Nearest-Neighboured (KNN) and Dynamic Time Warping (DTW) for detection [11].

2.7 Pothole Detection by image processing

This task is conducted after the classification of paved and unpaved roads on the road images. All the images are clipped from the dashcam video every 10m. The paved road images then feed to the model for detection of existing potholes. The amount of 13,244 training set and 3.250 validation set images were used for building the model. We used LeNet 5 [14] based model for this task. We compared our proposed system with other conventional machine learning methods such as Support Vector Machine (SVM) to evaluate the effectiveness of the proposed system,. As a result, SVM got 88.2 % of accuracy. On thesother hand, our model outperformed the SVM method by achieving 99.8 % accuracy [7].

2.8 Road width and pothole size estimation

We identified the area of width and pothole in the front view image taken by dashcam by semantic segmentation by deep learning. To estimate the real size of them, we need to transform the front view image to bird's-eye-view image. For the transformation, we have to find the vanishing point to estimate the depression angle of the dashcam. However, unlike advanced countries, we cannot use Hough transform in rural areas of developing countries. We proposed to use optical flow to find the vanishing point [15].

2.9 Visualization

The final task of the procedure is to visualize the analytical results in a map such as Google Map, Open Street Map, or QGIS. We are using each of them depending on the situation because each of them has advantages and disadvantages. Figure 3 is an example of a visualization of the analytical results in Timor-Leste.
Figure 4. (a) Visualization of the analytical results in Timor-Leste about road type and roughness in Open Street Map. (b) First, the road type is categorized into paved and unpaved and roughness is estimated in each road. Anomalies such as bump or pothole are also detected.

3 Summary and discussion

In developing countries, the utilization of the smartphone on social development has much potential. This is because the smartphone has a variety of high technology sensors and network connectivity in a small body, and the penetration ratio of the smartphone on the nation is very high even in countries with weak economic infrastructure. The main tools of this project are smartphones, dashcams, and state-of-the-art data science techniques. As the inspection items are different between advanced and developing countries, we had many discussions with the local public department in charge of road maintenance. In this paper, we introduced the whole picture of this project and achievements in Timor-Leste. The system can be used in other developing countries by fine adjustment according to each situation.

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