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Research Paper

Automatic detection of pavement crack feature on images taken from specialized road surface survey vehicle

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Approaching to PDCA (Plan - Do - Check - Take Action) in management of infrastructure asset requires digital transformation, sufficient data and strong database supporting management, analysis as well as creation of data-driven decision making tools. For pavements, data including condition indicators such as roughness and rutting depth are collected automatically during the survey vehicle travelling. However, pavement crack ratio and crack features of pattern and segmentation have not been detected by the system but manual in the case in Vietnam. The paper presents result of research on algorithm of statistic machine learning model in AI applying deep learning algorithm to automatically detect crack feature on pavement photos for enhancement of the performance and productivity of current survey technology. In the research, a deep architecture using convolutional neural network (CNN) for crack segmentation on gray scale images has been developed. The results show the CNN model for crack segmentation is better than other methods using traditional digital processing such as the Gabor filters or threshold and machine learning such as Adaboost.

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1 Introduction

It goes without saying that a road network is one of the most important infrastructure facilities to support our economic activities and daily life. Recently, the importance of asset management for optimization of the methods to maintain road facilities, of which amount are growing, has been recognized, and asset management systems have been introduced in many countries. Asset management means an aggregation of decision making for sustainable and long-term road maintenance activities to optimize maintenance works for road facilities under a variety of conditions and constraints. Also, rational decision-making is required to select the best strategy to achieve the asset management goals and objectively evaluate the process of decision-making. For road asset management, it is indispensable to keep up with the latest information on asset

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inventory, inspection results and repair history of huge stocks of facilities, and to monitor the conditions to keep the objective service level of road network.

However conventional inspection method often requires large amount of time and human resources which hesitate road operators to update the information on time. In order to facilitate the collection, pavement survey technology of inspection vehicle had been successfully transferred and applied in Vietnam recently. Thanks to technology innovation, good survey systems have been developed and introduced with the common scheme of integration all necessary equipment for pavement surface condition surveying in a survey vehicle that helps to accumulate data such as pavement roughness, rutting and pavement photos while traveling on the road in normal speed. To obtain pavement crack feature such as crack ratio, technicians are allocated to manually detect cracks on screens of collected pavement photos. In average, eight working man-days of crack analysis is requested for data collected in one eight hours-operation shift of of the survey vehicle [1-3]. Solving the current problem of low productivity and intensive labor-demanding of the current technology in road surface surveying is the objective of the research.

2 Pavement condition inspection technology and current practice of crack analysis

2.1 Pavement condition inspection technology

This section mainly describes one typical pavement condition inspection technology that has been applied in Vietnam since 2012. Specialized road surface survey vehicle provided by Japan International Cooperation Agency (JICA) to Directorate for Roads of Vietnam (DRVN) is manufactured by PASCO Corporation comprising of two sub-systems: (i) inspection vehicle for data collection, and (ii) data analysis and processing system.

As shown in Fig. 1, there are five main components of the equipment [1]: GPS antenna to collect signal from satellites; the front camera which captures road images in front of the vehicle during traveling capturing interval of five meters for one image; four pavement surface cameras capture pavement images during traveling at high resolution, include sunshine mode and shadow mode with capturing interval of one meter for one image each camera; the laser scanner can light beam for 4.8 meters to collect the shape of cross sections; the laser displacement sensor's function is measuring the longitudinal profile and coordinates with Internal Measurement Unit (IMU) which is acceleration machine, to calculate pavement roughness IRI.

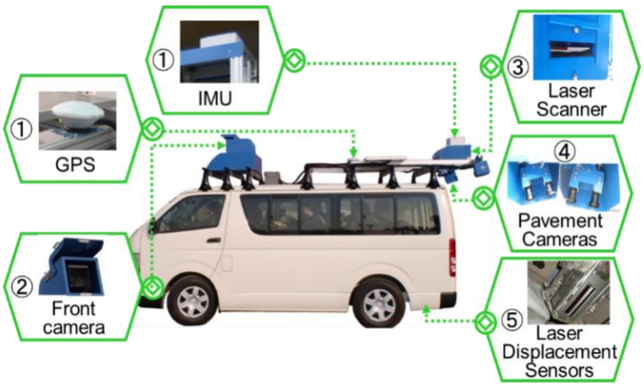


Fig. 1 – Pavement inspection vehicle (Real-Mini).

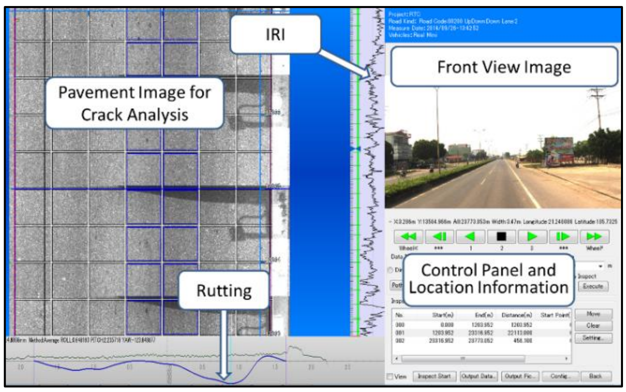


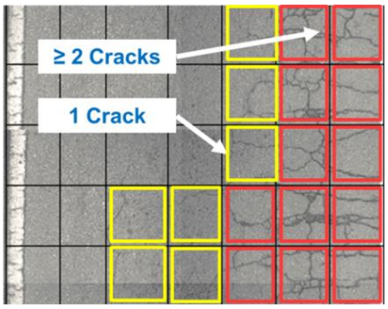
Fig. 2 – Interface displaying system of collected data.

Beside preparation work including equipment calibration, the whole process of pavement condition surveying can be divided into three steps of (i) field survey to automatically collect rut depth, roughness IRI, and pavement images for crack analysis, and obtain road coordinates as well as its front images in short interval of five meters; (ii) indoor data analysis focusing on pavement crack analysis on detailed grid 0.5x0.5m and synthetize data in single road segment of 100 meters or 20 meters for surveyed lane; (iii) finally, data processing is implemented to create required dataset of pavement condition for registration in database for various uses [2].

2.2 Current practice of crack analysis

The specialized road surface survey vehicle automatically measures pavement rut depth and roughness IRI while running on roads in normal speed. In case of the third indicator of pavement condition of crack ratio, manual analysis is requested with the support of the sub-system, data analysis, that shows captured pavement images on screen with a mesh of detailed grid 0.5x0.5m. Technicians have a careful look at the screen to decide the crack condition in every single grid that can be one of the following pre-defined cases by proper mouse clicking at the grid: (i) grid without any crack: equivalent crack ratio is zero percent; (ii) grid with one crack: equivalent crack ratio is 60 percent or converted cracking area of 0.15 square meters; (iii) grid with two or more cracks: equivalent crack ratio is 100 percent or converted cracking area of 0.25 square meters.

(a) road front image



(b) pavement image with the mesh of manually detected crack squares on the screen

Fig. 3 – Manual pavement crack analysis.

For a certain pavement analysis area or one road segment, the system calculated total cracking area then equivalent crack ratio based on technicians' manual crack detection and decision. According to the actual implementation of the technology in Japan as well as in Vietnam, on average, to complete manual crack analysis for image data collected in one-shift surveying at the site, it requires eight technicians working in one shift [1]. It is obvious that the above crack analysis results have a high level of detail, which not only helps in maintenance planning but can also be used for preparation of a detailed repair plan. However, such manual analysis method has significantly affected the productivity of the technology and increased the cost of pavement condition surveying: the cost of manual cracking analysis accounts for about 50% of the total in-situ survey cost and in-door analysis.

Thus, the problem statement of researching to improve road surface surveying technology approaching to automatic crack analysis is completely appropriate and has great significance, especially in the context of the huge road network in Vietnam with more than seventy thousand kilometers of national roads, urban roads, provincial roads and expressways with high requirements for management and maintenance.

2.3 The first challenge in automatic detection of pavement crack

For automated detection of road crack, the authors in [3] proposed a method for road crack detection using an ensemble learning algorithm, named boosting in 2016. Boosting is one of the most well-known and effective techniques in machine learning. The success of using boosting for training a face detector [4] has made it widely used for training object detectors. The system integrates image representation for fast computation of features. Then, traditional Haar-like features are employed for image representation. The boosting classifiers are trained on these features and then combined in an efficient way to achieve high performance. A set of experiments have been conducted on selected road images collected by pavement inspection vehicle in Vietnam in some national roads. The results show that the classifier trained by boosting learning algorithm can detect road pavement cracks on images with the high accuracy in case of good pavement images (Fig. 4). However, in the case of image noises such as dark or shiny images or existence of objects such as branches, water streaks, rubber gum, shadow in the images.

In 2018, the authors developed, researched, and tested our method on a real dataset from road surface survey in real conditions in Vietnam, which contain a lot of noise in this image dataset. Machine learning techniques such as: support vector machines (SVM), machine learning, especially the combination learning algorithm Boosting (Adaboost) and deep learning

(Deep learning) to improve the classification efficiency have been experimented. The authors used HoG (Histogram of Oriented Gradients) feature in the SVM method, and Haar-like features in the Boosting method. Besides that, our research uses the latest approaches of machine learning such as multi-layer learning models (also known as deep learning) using convolutional neural networks (CNN). The authors also tested in some pre-trained models and architectures such as: LeNet, VGG. These advanced models may not require another feature extraction method, but they can learn both representation and image classification. Experimental research is performed on real data, on the actual sample size to evaluate and calibrate the parameters, thereby improving the accuracy of the algorithm in machine learning, as well as improving the efficiency of the system. The system automatically detects pavement cracks through dataset (Fig. 5).

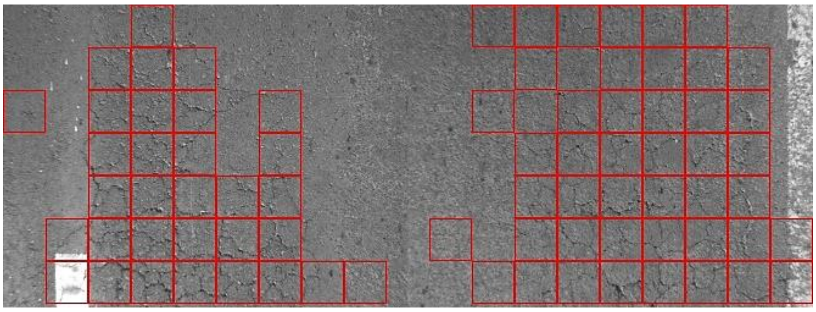


Fig. 4 – Detection of pavement cracks on road surface images by boosting learning algorithm in standard dataset that do not contain noise and artifacts.

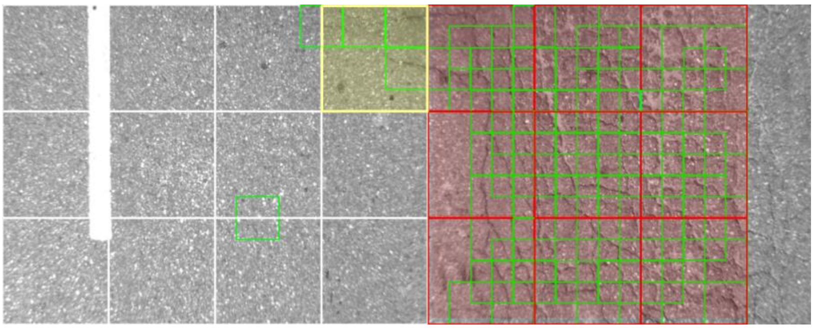


Fig. 5 – Detection of pavement cracks on road surface images by deep learning algorithm on a real dataset containing noise and artefacts such as: shadow, paint, water track.

The research results were reported to the Ministry of Transport in 2019 and highly evaluated by the scientific council based on the independent assessment of the Road Technical Center under DRVN who directly comparing the results of automatic crack detection and manual crack analysis results for a pavement image dataset collected in ten national roads [5].

3 Algorithm to automatically detects pavement segment crack on images taken from specialized road surface survey vehicle

3.1 Crack segmentation using deep learning

In the research mentioned above, the authors used deep learning to detect the crack on pavement images with the focus on automatic detection of crack squares on pavement grid. As a following effort, this research challenges to develop a method to segment crack on these images. While the detection task aims to classify the crack at the sample level, the purpose of segmentation task is classifying the crack at the pixel level.

There are many researchers have done in the problem of the crack segmentation. Gabor filters bases on the Gabor functions [6] are used for image feature extraction [7, 8]. The Gabor filters are simply implemented. By applying many Gabor filters at different angles, a Gabor filter bank can segment all most of the crack pixels. However, the Gabor filter are sensitive with noise, so they also segment many background pixels where the intensity value changes significantly.

The machine learning approach are observed as many advantages compare with traditional methods such as using image filters. U-Net model [9] is an advanced model used for biology image segmentation. This model used an architecture with two parts as the "U" letter. The first part is for feature extraction, and the second part is for feature reconstruction. The U-Net method uses deep CNNs architecture, and needs a large amount of data for training.

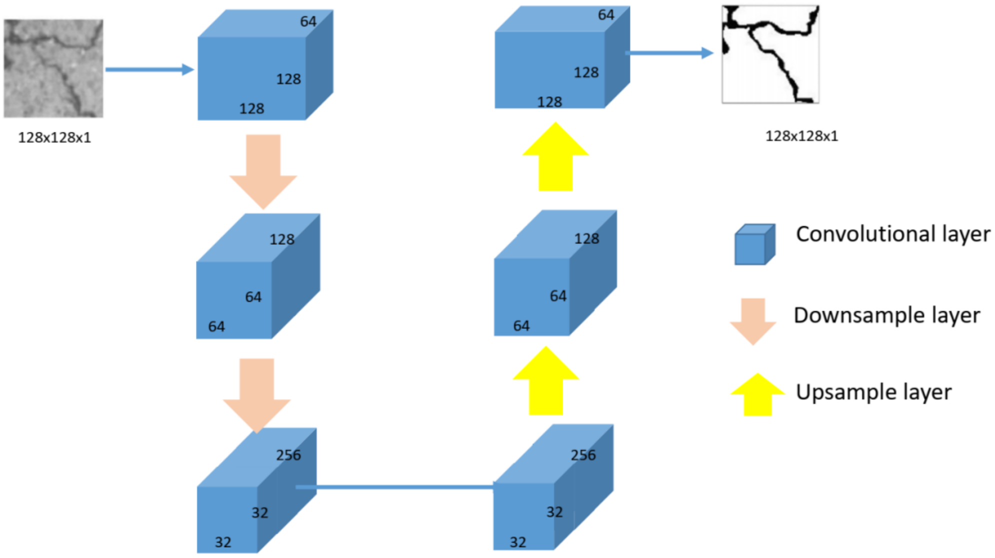


Fig. 6 – CNN architecture for crack segmentation.

3.2 Proposal method

Fig. 6 shows our proposal CNN architecture for crack segmentation. The original image captured from a real road survey system is cropped to obtain samples at a size of 128×128 pixels. The total samples used in this paper is about 2000 samples, then some argumentation methods such as shift, rotation to increase the number of samples have been used. The feature extraction part contains three convolutional layers with the increase of the number of kernels. Following each convolutional layer, a down sample layer to down sample the input feature of the convolutional layer has been conducted. The feature reconstruction part uses an inverse structure compare with the feature extraction part. The authors use up sample layers to rebuild the feature from the size of 32×32 pixel from the first layer to the final layer. The results image from the model is a binary image that contain crack pixels only and has a same size with the input image.

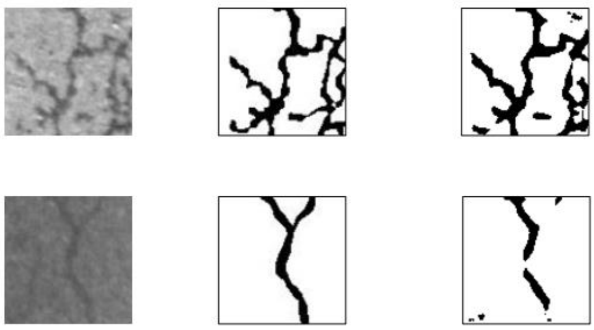


Fig. 7 – Some examples of the results

To create ground truth data for segmentation task, a tool in Matlab software has been applied. This software provides a free-hand tool of segmentation, so the authors can annotate the crack pixels manually. Fig. 7 shows some results of the research. Precision recall curve (PRC) metric was used to evaluate the method. Because the crack dataset contains many kind of noise, so a traditional method such as using a threshold of gray-scale can get about 60% of, our method got result Pr = 94%, Re = 74%, and F1 = 83% over all in segmentation task.

Notes: The first column shows the original image, the second column shows the ground truth image, and the third column illustrates the results.

4 Conclusions

The paper presents the research results of automatic segmentation of pavement crack feature on images taken from specialized road surface survey vehicle based on CNN architecture. The experiments also indicate that the method of using convolutional neural network performing crack segmentation better than traditional digital image processing methods such as the Gabor filter, using threshold. The trials show promising results that helps to upgrade our previous research in automatic detection of pavement crack squares and crack segmentation. The segmented results from the crack segmentation can be used to calculate crack characteristics such as crack width and crack length, and evaluate the crack road severity levels supporting for pavement management at both network level and project level.

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