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ROAD MAINTENANCE USING IMAGE ACQUISITION PROTOTYPE FOR NON-SPECIALIZED VEHICLE

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Abstract

The presented prototype for image acquisitions and processing (IPA) aims to create a maintenance road system with minimal cost, mounted on *non-specialized vehicle*, enabling image acquisition in various conditions. IPA has an important role in the proposed platform designed by PAV3M for intelligent management, monitoring and maintenance of pavements and roads. We have developed new image processing solutions, analysis methods and enhanced (more robust, efficient, dedicated) solutions for solving the specific problems related to pavement analysis using PCI standards for road crack detection and classification.

Key words: image analysis, image processing, road distress, road network surveillance

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1. Introduction

Within pavement engineering a central role is held by pavement crack detection and classification starting with pavement construction and followed by the evaluation, performance measurement, maintenance, rehabilitation, and reconstruction of the road pavement (Al-Mistarehi, 2016; Benta et al., 2017; Shi and Fu, 2018). Especially in maintenance and rehabilitation, but not only, evaluation of cracks, distress and any other type of pavement deterioration using automatic road inspection and image processing is a current practice nowadays.

For instance, the surface area unit (length and width) is an indicator for crack detection, patching and binder enrichment. For outbreaks (potholes) the area unit (diameter) is a suitable indicator for detection while the sum of lengths is an indicator for the detection of open work seams. Unfortunately, nowadays there are no standard specifications and no standard methods for controlling the severity level, *i.e.* several countries implement their own standards for severity levels. In USA all cases and indicators for severity levels are based on the classification of being either low, medium, or high, unrelated to depth and using the PAVER System Manual (Barrette, 2011; Shanin, 2002). German standards are based on the state value-*ZG* and normalized state value determination -*ZW* (FGSV, 2006), Nordic states have their own standards based on climatic conditions and type of cracks.

We mention several common international standards among which the Pavement Condition Index (PCI) and the Long-Term Pavement Performance Program (LTPP). PCI is used by the American Society for Testing and Materials (ASTM) standards in order to promote health and safety as well as for the reliability of products, materials, and systems. LTPP is a more accurate solution by descriptions and methods for measuring all types of distress: cracks, potholes, rutting, and spalling, both in flexible and rigid pavements (Dumitrescu et al., 2014; McPherson

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and Bennett, 2005; Miller and Bellinger, 2003). Another popular solution is offered by the American Association of State Highway Officials in AASHTO Provisional Standards (AASHTO, 2007). PCI is a simple, convenient and inexpensive solution for maintenance and rehabilitation, monitoring the condition of the surface of roads, identifying rehabilitation needs and to ensure road maintenance in budgets limits (Karim et al., 2016). PCI method was used in several automatic solution for automatic road inspection in maintenance and rehabilitation process (ARAN, 2018; Karim et al., 2016; Wu, 2015).

Automatic road inspection has become a constant concern for researchers and specialists since 1990. The first well known solution was offered by a group of researchers from the University of Arkansas which developed a specialized vehicle called Digital Highway Data Vehicle (DHDV). This real time visual inspection of the pavement system has geo-positioning features by coupling with a GPS receiver a distance measuring instrument for cracks and other distress types, a gyro sensor and a power source (ARAN, 2018).

Another high-speed vehicle was the Roadware's Automatic Road Analyzer (*ARAN*) which has the capability to offer wide range of information related to: images of pavement and identifying traits and flaws, images immediately adjacent to roadway profiles or roughness, longitudinal profile or roughness transverse inclination angle intersection etc. Another specialized system called Fugro ADVantage is installed and transported by a vehicle as the ARAN system. It is produced by Fugro Consultants LP and can be classified as one of the first digital systems for automatic inspection of the pavement (Ametech, 2015). Major impediment for using these systems is insufficient fund for acquisition in several points of local roads.

The main objective of this paper is to offer a low-cost solution for image acquisition and processing in road maintenance management systems, using non-specialized vehicle. After a short introduction to specific objectives, the second section outlines the existing solutions while the third section details the proposed solution developed using a non-specialized vehicle. We offer a detailed description of the implementation features and experimental results. In the last section we conclude and outline future work.

2. Existing solutions

We focus on several existing solutions for pavement survey and crack detection, which use modern technologies such as: Global Positioning System (GPS) or Differential Global Positioning System (DGPS) for location accuracy, GNSS (Global Navigational Satellite System) for positioning, laser solutions, digital camera or Digital Cinema Package (DCP) for image acquisition. DGPS improves GPS accuracy from 15-meter to 10 cm in professional implementations and calculates the difference between the GPS calculated position for the ground reference station and the actual position of the ground reference station (Esri, 2017). DCP is a collection of digital cinema and digital files (audio, image, and data streams) used for storing and communications.

SME's pavement experts from USA use manual and automated condition surveys for pavement sampling with coring, DCP and Geoprobe®, and nondestructive testing with falling weight deflectometer. This complex platform can be used for road, airfields and even technical driller in every maintenance and rehabilitation projects. The Geoprobe® Model 7822DT is a direct push machine with a narrow platform and high capacity for limited access areas and a sufficient stroke for added work space under the hammer (Geoprobe, 2017). Pavement evaluations consist of: examination of the current surface and subsurface conditions, analysis of in-situ pavement layer strengths, identification of distress causes and pavement design parameters. For airfields it can estimate pavement load carrying capacity and pavement classification numbers (PCN), can evaluate the impact of changing uses or establish functional and structural characteristics (GEO, 2017).

Laser Version System is a certified ISO 9001-2000 solution proposed by G.I.E. Technology, Canada, for managing road networks, airports and large surface parking lots. Using laser, camera, GNSS and DGPS provides a solution for evaluating the pavement condition, prioritizing and establishing maintenance and rehabilitation programs based on technical and economical solutions. G.I.E. offers an efficient Data Collection System and automated equipment's and vehicles for pavement evaluation. Measurement includes: longitudinal and transverse road profiles, road geometry, surface friction and deflection. All images are processed and analyzed in order to identify surface distress. This system is basing its data analysis on North America's standards for roughness (IRI), rutting, cracking and surface distresses, deflection measurement, friction testing, geometrics measurements (gradient, cross fall and curvature), thickness of pavement layers, road sign inventory and asset management. Several reports like network condition report, maintenance and rehabilitation plan and multi-year budget plan serve for prioritizing maintenance and rehabilitation projects. All evaluation and historical pavement data are consolidated and analyzed considering the needs, priorities and shared proper public funds (Evdorides, 2018; GIE, 2017).

GeoAutomation™ is an image-based mobile-mapping system, which was developed by GeoAutomation Company, Belgium. Using a set of cameras mounted on top of a vehicle or other platforms and GNSS; this system can capture efficient and accurate measurements, which are imported into GIS systems, using a recording system. Geoautomation innovation consolidated on pixel recognition, a new technology developed by the University of Leuven, and Belgian surveying company. The standard configuration involves 14 and 16 cameras oriented to customer's claims with each camera having 2 & 8 Megapixels. Image capturing and processing are realized with a pipeline and surveying has several steps: recording drive-through, 3D reconstruction of recorded images, with automatic processing, geo-referencing of the result, surveying and measuring based on the 360° view images into GIS system, surveying on the Web (GEO, 2017).

3D Mapping Solutions GmbH is a company which offers a solution for road and railway kinematic surveying. They integrated sensor and sensor fusion, calibration of multi-sensor systems and practical solutions for interpretation of kinematic surveying. We mention several opportunities in this field: a) accuracy in road and railway surveying from *sub-meter* in navigation applications, to *decimeter* for road and railway or *centimeter* for road surfaces when evaluated by digital elevation models, b) geo-referenced road information and digital image documentation of traffic corridors and high-resolution road surface DTM. 3D Mapping is a complete system for kinematic surveying with options for customization and integration of other modules in existing systems, technical support and training courses (3D Mapping, 2017).

Technology serves to different kinematic measuring applications based on modular hardware and software solutions: module Trajectory, module Multi Camera Photogrammetry, module Image Documentation and module Laser Scanner. Module Trajectory is composed of an inertial measurement unit (IMU), DGPS and a linear odometer and a multi-sensor system for 3D position and orientation. Module Multi Camera Photogrammetry includes facilities for calibration, determination and object definition attribute with a software module. Module Image Documentation use high-resolution multi camera system for kinematic surveying and documentation and Module Laser Scanner have one or more scanners for digital high definition surveying.

All these solutions represent each a dedicated vehicle for road network surveillance, navigation and driver assistance or for surveillance of road object data and/or determination of road conditions based on derivation from sensor-based measurements or visual determination and subsequent image storing and processing. It used automatic evaluation and classification solution for evaluating the pavement condition, prioritizing and establishing maintenance and rehabilitation by identification of distress causes and pavement design parameters. Unfortunately, common features are linked on specialized vehicle, which involve serious budget efforts based on public found, a major difficulty to implement in our country.

3. Proposed solution

3.1. System architecture

The proposed prototype aims to analyze and process acquired images and solve the following important issues that require solving by developing and implementing appropriate algorithms:

a) eliminating the artifacts introduced by the acquisition of images at high speeds;

b) identifying and removing shadows;

c) identifying and removing all category of objects from the pavement: stones, papers, stains, spikes, intruders, etc.

d) extremely efficient algorithms / postprocessing methods

e) defining the defects and determining a PCI on the analyzed portion of the road.

System architecture for processing and acquisition of an image is represented in Fig. 1 and consists of a system comprising: digital camera, mobile workstation (laptop or robust embedded system), GPS receiver, image processing and analysis modules (IPA). Its major advantage of it is overall cost, based on non-specialized vehicle and other components mounted on it, which not claim very expensive amount. The IPA modules perform image acquisition, image preprocessing, detection of pavement distress, and image post processing. Storage and post processing are required both high computing power and significant storage space which are ensured by a dedicated High-Performance Computing (HPC) unit. HPC provides high-performance computing facilities used for developing and running scalable methods of analysis (parallelized). Parallel image processing algorithms, both in pre-processing and post-processing, ensure high speed image processing (Fig. 1).

The GPS receiver offers road coordinates like GPS parameters (longitudes and latitudes) to provide accurate position of detected pavement defects. Differential GPS (DGPS) offers increasing resolution and this choice depends on additional information: ground-based reference stations or satellite-based augmentation systems. DGPS provides improved location accuracy, from the 15-meter nominal GPS accuracy to about 10 cm in case of the best implementations.

The DGPS system calculates the difference between the GPS calculated position for the ground reference station and the actual position of the ground reference station. DGPS requires that a GPS receiver be set up on a precisely known location. This GPS receiver is the base or reference station. The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the second GPS receiver, which is known as the roving receiver. The corrected information can be applied to data from the roving receiver in real time in the field using radio signals or through post processing after data capture using special processing software (Esri, 2017).

The prototype offers an application integral for flagship in road maintenance and monitoring solution, using GPS and DGPS devices and geo-coding and reverse coding features of MultiMap Database (Fig.1).

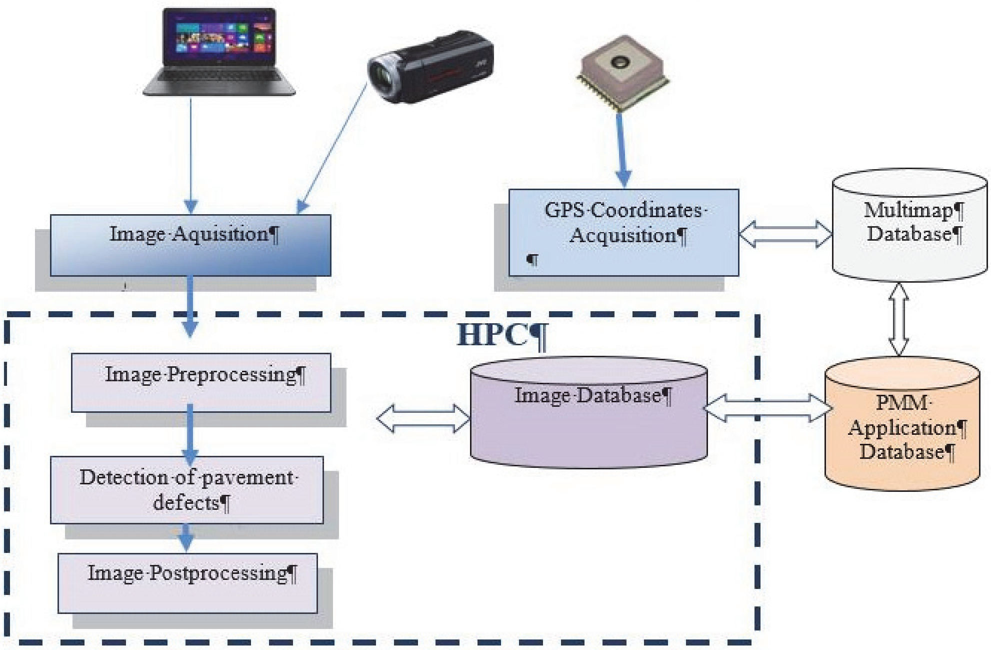

Fig. 1. Image processing and analyzing prototype –PAV3M

In the prototype performance specifications, we are mentioning a few important features:

1. The speed of the vehicle is 120 km / h. This constraint leads to the necessity of using fast cameras, devices that raise the price of the equipment end, or the need to develop methods of analysis of images powerful enough so as to allow retrieval features in / defects, paving images even if these images have a lower quality possible.
2. Positioning inspection system is based on the GPS independent navigation information available internally of a carrier vehicle.
3. Data transmission protocols, including data compression in real time, were studied based on a collaboration with the University of Nantes / Ircynn.
4. Integrating images / video with positioning information (GIS) requires specialized expertise in the field of GIS (Geographical Information Systems. The image acquisition module is delivering image files as jpeg, gif or another image format (GISCE, 2010).

Image preprocessing used image acquisition and consist on restoration (removal of artifacts introduced by the acquisition process), supper resolution, identification and removal of non-pavement details (shadows, stones, papers, oil spots, etc.), image correction due to variations in illumination.

Detection of pavement defects aim is to determine correct measures of distress and classification type of distress and finally whole road, based on image filtering (e.g. directional filters), texture analysis, image segmentation, post segmentation processing.

Image post-processing has role of characterization of defects, clustering and classification, data fusion, defect statistics for whole road segments etc.

3.2. Image processing and analysis

Ideally, a fully automated system should be able to automatically and objectively determine, based on predefined criteria, the condition, state and quality of roads and pavements: PCI, PAVER, aso. Road pavement data are collected by a running vehicle at more than 50 km/h. Due to the speed of the vehicle, a fast camera must be used. This constraint increases in principle the cost of the equipment. A major objective of our research is to investigate the possible use of low-cost cameras instead of high-end cameras with high resolution, high sensitivity and very high frame rates (Vision, 2017). Because of the vehicles' high speed, the image acquired by a standard camera is blurred. For the blurred image, each pixel represents the average on a local neighborhood along the motion direction. The inversion of the degraded image in order to recover the original when the degradation model is known is the classical restoration problem. Image restoration can be performed either in frequency or in spatial domain. In PAV3M, the major difficulties are due to the high-speed of the vehicle and the mathematical complexity of the constraints. It should be mentioned that in our case by assuming that the motion is translation uniform motion we can simplify the restoration problem setting and use an efficient recursive solution.

In image processing, *super-resolution* is the procedure to obtain a high-resolution image from a sequence of low-resolution, displaced and generally degraded copies. Since the low-resolution images are noisy, blurred, down-sampled copies of the same image, super-resolution is a complex restoration problem (Fig.1). The success of the super-resolution greatly depends on the accuracy of the degradation model. While the first setting of the super-resolution was in the frequency domain, now all the approaches published in the literature operate considers the spatial domain. Various methods are used: algebraic regularization, conjugated gradient, projection onto convex sets (Santhosh et al., 2019; Mendre et al. 2017). In the frame of PAV3M, the average distance between the camera and the road surface is constant but the disturbance induced by the moving car increases with speed. However, its effect can be significantly reduced by using the *accelerometer data* and an appropriate *filtering technique (Kalman)*, in order to associate to each image frame the actual position of the cameras during capture. Furthermore, the camera has a translation motion at constant speed. The complexity constraints imposed by PAV3M are severe.

Fast super-resolution algorithms have been reported as well (Reddy et al., 2017; Sujatha et al., 2017). It should be mentioned that almost all the papers published on this topic consider simulated examples, where the degraded low-resolution copies were obtained by sub-sampling, low-pass filtering, and so on. We estimate that it will be possible to improve 4-16 times the resolution for the true data acquired by our system.

The segmentation algorithms developed in previous Matlab languages were rewritten into C language and tested on the available image sequences at VASC (2019) and NAV (2019). The results obtained were compared with the results obtained in the previous step. For image sequences (resolution 480 x 640 pixels / frame, 10 frames per second), the processing consists of the following sequence of operations: color-> monochrome transformation with asphalt surface accentuation, contour detection (Prewitt operator), and straight-line Hough transformation.

Texture analysis and classification is one of the domains of major interest in image processing. A central place in our research is image classification, namely surface degradation detection. We consider that when there is no degradation and at adequate resolution, we should deal with uniform textures. In the frame of PAv3M project, we developed novel methods for surface classification based on texture analysis. Implementation of fast algorithms will allow us to resolve the case of no degradation surface in real-time.

Fast algorithms PAV3M project deals with a huge amount of data to be processed and/or stored. The need of high-speed or real-time methods and algorithms has been already stressed. Fast algorithms are needed both in the mobile acquisition unit for the real-time processing and for the processing of the stored images on the cluster held by CITST (Fig. 1). Consequently, we will concentrate on developing fast algorithms and on parallelization of existing ones. For the latter there is expertise on at CITST which was involved in the parallelization of segmentation algorithms. We also have developed novel high-speed nonlinear and linear filtering algorithms. Regarding the importance of such filters, it is enough to mention that all the mathematical morphology operators are based on max/min filters.

We have investigated extension and adaptation of *segmentation methods* to the particularities of road data. Foreseen methods are Clustering Based Region Growing (CBRG) improved to handle general vectorial images as input (textural features). Additionally, new clustering kernels for the CBRG were studied. Also, different approaches to the clustering based segmentation like for example the mean-shift clustering will be considered. We have studded different methods to post-process the segmentation results using Region Adjacency Graph (RAG) in order to enhance the meaningfulness of the produced objects.

Semantic knowledge can further be extracted and used like as it is currently done in the context of Multimedia Content Based Retrieval and Browsing Systems like MUVIS (Fig. 1). Initial tests for developed methods can be made on images captured by Navigation Laboratories (NAV, 2019), and some of them are accessible to VASC (2019).

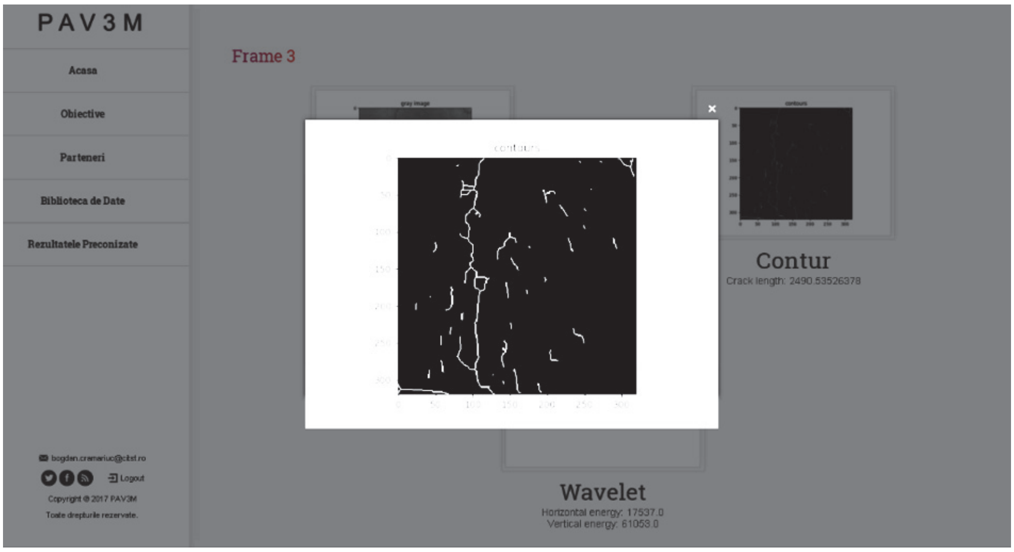

Fig. 2. Image border

The crack detection algorithm begins with a preprocessing stage of the video frames and extracting a border that covers as much as possible only a portion of the road, chosen by observing the road layout as seen by the camera. Frame excerpts are resized to calculate future efficiency. For starters, images are resized at 320 x 320 pixels. The resized RGB images are transformed into grayscale images. Next, log-transform will be applied to grayscale images. This algorithm allows defects, for example cracks, to be better distinguished from the usual pavement shades, defects appearing on video capture as color irregularities.

The algorithm uses the original frame and negative frame and updates each pixel by Eqs. (1-3):

Log_pixel[h][w] = 256 * (1 – e ^ Log_v[h][w]) (1)

Log_v[h][w] = B * Log_val[h][w] - (B - A) * Log_avg[h][w] (2)

where: Log_val - is the logarithm of the normalized value of a pixel (h, w) from the negative image; Log_avg[h][w] - is the average of the logarithms of the normalized values at the [0.1] range of the pixel values of the original image over a neighborhood around the pixel (h, w).

The parameters used are: A = 1.1, B = 0.9, neighborhood defined as a 7 x 7 pixel window (3 left, 3 right in each direction).

The result of applying log_t can be analyzed in Fig. 6, observing how the crack pixels appear more accentuated than the background in the image obtained from the log transform (right) application.

The tests were conducted on four road categories: a) asphalt road, smooth (without asperity); b) - asphalt road with slightly worn surface, but without cracks, pits, etc.; c) asphalted, with wear characterized by a multitude of cracks, without pits d) asphalted, with wear characterized by a multitude of cracks with different dimensions, corresponding to the PCI values (Eq. 3).

$$PCI_f = \frac{(N-A)}{N} PCI_1 + \frac{A}{N} PCI_2 \qquad (3)$$

where: PCI_f = PCI of pavement section, PCI_1 = average PCI of random samples, PCI_2 = average PCI of additional samples, N = total number of samples in the section, and A = number of additional samples inspected (Santhosh et all, 2019; Karim et all, 2016).

After we processed images in *Detection of pavement distress* (Fig. 1) we obtain a classification according to type of defects: cracking, potholes, raveling, patching, rutting, and edge failure. Based on defects parameters (width, height, deep) we classified road conditions using risk analysis by type of distress (R_D - Risk of distress) and give a PCI_t considering all kinds of images of any road (Eq. 3).

By identifying every PCI of random samples, we obtain finally PCI_f of road pavement section (Eq. 3). It serves both in management, maintenance and rehabilitation and risk management modules which use it in Monte Carlo simulation or kNN algorithm for prediction. For the risk identification and classification, based on the type of pavement distress, we followed the PCI (ASTM, 2017) standards and the Long-Term Pavement Performance Program (LTPP).

4. Experimental Results

Our acquisition prototype allows to store images in a local database on the on-board computer, or in a remote database located in the PAV3M platform. Sample images are presented in Fig. 4.

All images were pre-processed and post-processed on HPC using proper algorithms and loaded in the PAV3M database. During the analysis and processing of the acquired images, the following important issues were identified that required development and implementation of appropriate algorithms.

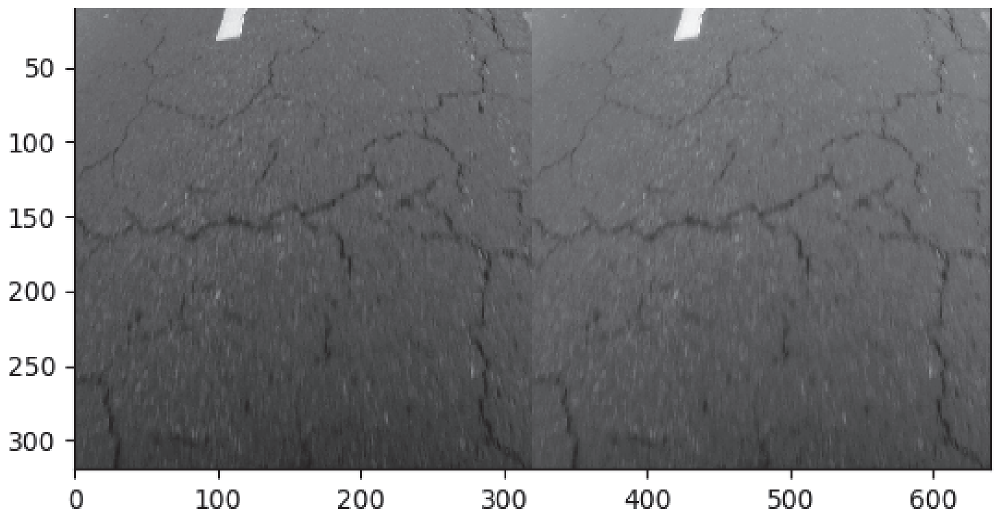

Fig. 3. Image pre-processing

(a) (b) (c) (d)

Fig. 4. Image acquisition with non-specialized vehicle

Solution for texture analysis and classification was given by CITST team (partner in the PAV3M project), which has solid experience in texture analysis being previously involved in developing a novel framework for textural feature extraction based on ordinal co-occurrence.

When a standard camera is use, the images taken from the moving vehicle are blurred. Each pixel represents an average of the local brightness in the direction of the movement of the camera. Reversing image degradation in the situations where the degradation model is known is the object of *image restoration*. The problem of eliminating blur due to camera movement is a well-known issue. There are solutions in both the spatial and frequency domains. The difficulty with the PAV3M project is due to the high speed and constraints on mathematical complexity imposed by the situation in this application (IPA). A simplified translational hypothesis must also be used that can allow an efficient recursive resolution of the reversal of degradation. The algorithms were developed in Mathlab, then in C and Python.

The images in Fig. 5 illustrate an example of *pavement with shadows*. An important issue is the resemblance of tree shingle shadows and the image of pavement cracks. This problem appears to be addressed in specialized articles generally in the context of video security and control systems. In these cases, umbrellas are identified using different methods based on: statistical modeling, homo-morphic filtering, histograms, and shadow density. Eliminating shadows can also be done based on the similarity of the background texture in the areas affected by the shadow with adjacent areas.

The images in Fig. 6 illustrate a pavement frame with leaves and a pavement with stains. As with shadows, they are identified and removed from the acquired image.

The system must deal with a huge amount of data that needs to be processed and / or stored. In this context we intend to develop and continue to develop original research in order to develop fast and easily parallelizable algorithms. In the development and implementation of new algorithms and image post-processing methods, the following specific issues will be addressed: super-resolution, texture analysis and classification, segmentation and post-segmentation processing.

(a)

(b)

Fig. 5. Images with tree shadows (a) and cracks (b)

(a)

(b)

Fig.6. Pavement images with leaves (a) and stains (b)

5. Conclusions

Pavement crack detection and classification was a central concern of whole lifecycle, starting from pavement construction and continuing with then evaluation, performance measurement, maintenance, rehabilitation, and reconstruction of the road pavement.

There are several standards such as the German standards based on the state value-*ZG* and normalized state value determination - *ZW* (FGSV, 2006), or Nordic standards based on climatic conditions and type of cracks. USA used indicators for severity level, based on the observation either, low, medium, or high, unrelated to depth and using the PAVER System Manual (Shanin, 2002). Other international standards are: Pavement Condition Index (PCI), and the Long-Term Pavement Performance Program (LTPP). In our prototype we used PCI as a solution agreed by national transport authorities.

We presented several specialized solutions for pavement survey and crack detections, which use modern facilities like: GPS, DGPS for location accuracy, **GNSS** for positioning, laser solution, digital camera or Digital Cinema Package (DCP) for image storage and performing. SME's pavement uses manual and automated condition surveys for pavement sampling with coring, DCP and Geoprobe®, and nondestructive testing with falling weight deflectometer. LaserVersion System is a Canadian solution certified ISO 9001-2000 for managing road networks, airports and large surface parking lots, using laser, camera, GNSS and DGPS GIE offers an efficient Data Collection Systems and automated equipment's and vehicles for pavement evaluation. GeoAutomation™ is an image-based mobile-mapping system which used a set of cameras mounted on top of a vehicle or other platform and GNSS this system.

Our system architecture for processing and acquisition of images consists of a system of digital camera, mobile workstation (laptop or robust embedded system) and GPS receiver mounted on the vehicle, image processing and analysis modules (IPA) for: image acquisition, image preprocessing, detection of pavement distress, and image post processing, together with image database in HPC (High Performance Computer). The segmentation algorithms developed in previous Matlab languages were rewritten into C language. For image the processing consists of the following sequence of operations: color-> monochrome transformation with asphalt surface accentuation, contour detection (Prewitt operator), and straight-line Hough transformation.

Based on defects parameters (width, height, deep) we classified road conditions using risk analysis by type of distress (R_D - Risk of distress) and give a PCI considering all kinds of images of any road.

The main problems which solve our prototype are: Image preprocessing, Detection of pavement defects and Image post-processing. Experimental results offer sample for restoration, supper resolution, identification and removal of non-pavement details (shadows, stones, papers, oil spots, etc.), image correction due to variations in illumination. Also, we use filtering texture analysis, image segmentation, post-segmentation processing for detection of pavement defects.

The big advantage of the proposed prototype is that it can be mounted on non-specialized vehicles, which leads to efficient road maintenance solutions.

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