Building urban databases for smart city applications using crowdsensing techniques by additional evaluation of vision based driver assistance systems

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***Abstract*—**Smart city solutions – especially autonomous driving in cities – need detailed model of the environment.

The spread of the driver assistance systems, and the growing importance of their vision component, open new possibilities for constructing such database, which describe the environment in deep details online. The onboard vision system of a state of the art vehicle delivers much more information than we need for its basic tasks. By use of additional evaluation of the visual information, and with the installation of extension elements and communication tools we achieve a cheap data source for new applications.

By use of a dead reckoning trajectory tracking based motion stereo solution, we can extend the onboard vision system towards a 3D modelling sensor. Although the accuracy of such a solution is strongly limited, the huge amount of the information delivered by the individual agents makes the reduction of noises and the artificial generation of higher resolution possible. Additional illumination (i.e. IR laser strip) makes the calculation of 3D information more effective. The development of the 3D model needs sophisticated picture processing algorithms for separation of the change in the sensed image caused by the movement of the camera from those produced by the perspective transformation.

As an example we will introduce our crowdsourcing based solution for the continuous update of road surface quality database. . The windshield mounted video camera of the vehicle extended by a cheap laser light strip illuminator and robust software solution produces detailed description of the road surface profile along the movement's track. The type of the deviation of the surface from the needed value together with the GPS position of the failure's location will be transmitted to the central database. Based on this information the maintenance works logistic can be optimized, which reduces the cost of the road repair enormously.

***Keywords*—**driver assistance systems, crowdsensing, machine vision, road surface testing, road surface survey

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I. Introduction

In present days the constant rise in road utilization and load cause the anomalies on the pavement – e.g. potholes, ruts – to deteriorate road safety both directly and indirectly. This safety factor is what allows the continuous inspection of road surfaces – especially in highly congested cities – to be considered essential.

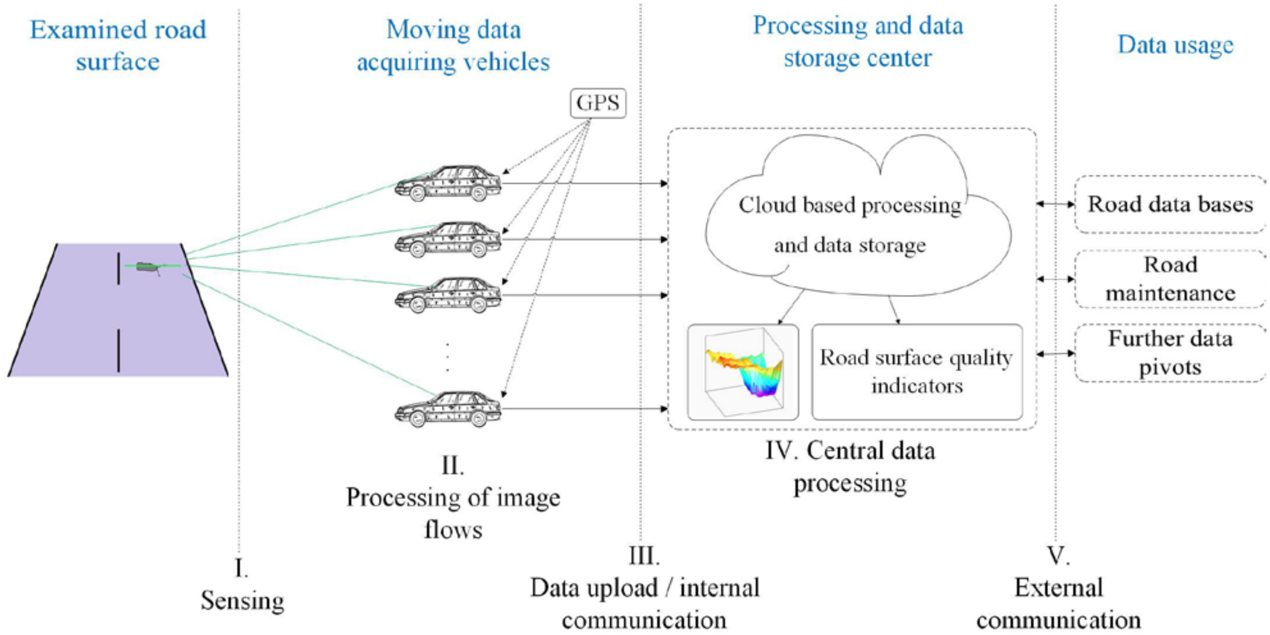
The system proposed in this paper is able to survey the quality and state of road surfaces, using a crowdsensing approach, then to create a database that can be updated in real time. The structure of the introduced system is shown in Fig. 1.

A. Smart Cities

The response of information and communication technology to the constantly escalating degree of urbanization and the ongoing rise of cities' population is smart cities. The demand for the so-called smart city applications in the technology-rich big cities arose in past years not only from research and development problems and the solutions given to them but also from everyday activities, such as traffic monitoring or weather forecasts. These technology rich cities are called the smart cities.

The concept of a smart city can-not be defined as unambiguously, because there are several approaches for labeling cities 'smart' [1].

- The *technocratic approach* is the concept where a city is considered 'smart' if the fix-installed sensors, the cameras and other data sources are constantly connected, and the data supplied are collected most importantly in order to optimize operation and maintenance works.



g.1. The structure of a crowdsensing based road surface quality database supporting system.

- The complex approach is the concept in which a city can be labeled smart if besides the existence of the necessary information and communication technologies, there are other attributes overlaid them, such as flexibility, formability, ability for cooperation and strategic behavior.
- The ranking based approach is the notion where the labeling is performed using an evaluation process, that is based on a complex indicator-structure. These surveys take into account the parts of the city-in-question's infrastructure that are essential for smart city development.

Regardless of the approach we take to discuss smart cities, the presence of the applications used in them and for their operation is interlocked with another commonly used ICT concept, namely the Internet of Things (IoT) paradigm. This structure is based on the cooperation, data acquisition and storing of network connected (in most cases internet connected, hence the name Internet of Things) devices. The strong reduction of all electric devices caused an extraordinary growth of smart technology (i.e. smartphones, tablets) accessibility: According to a forecast described in [2] until 2020 each person will possess more than 6 devices on average.

This process indirectly causes the expansion of IoT solutions and caused the appearance of the so-called Collaborative IoT (C-IoT) paradigm. C-IoT systems are those which are used mainly in cities for environmental monitoring and which enable communication and cooperation between humans, enterprises and governmental entities.

One form of C-IoT systems that is used increasingly often in present days is called Mobile Crowdsensing (MCS). This is the collective name for those applications whose data sources are the individuals that possess smart devices, and the used sensors are the ones built in their equipment [3].

Numerous functioning smart city applications are being used nowadays, most of which are well documented in technical literature such as [3]. These applications include: Cumulocity, AllJoyn, Xively, ThingWorx, however these are only some examples of the services existing for environmental monitoring of cities.

When constructing databases using the data provided by environment monitoring collaborators of a MCS system, it is crucial to know the position of the data acquisition as precisely as possible. There are several techniques used for positioning a moving vehicle or device [4]:

- GPS (Global Positioning System) which is a satellite-based navigation system. The performance of such positioning systems is limited by atmospheric disturbances, signal masking and multipath phenomenon. The latter often occurs in cities with tall buildings.
- DGPS (Differential Global Positioning System) which is used for eliminating some of the errors by using the signals of one stationary GPS receiver besides the one located on the vehicle or device in question.
- The combinations of GPS and INS (Inertial Navigation Systems) is also able to eliminate some of the inaccuracies mentioned above by using the gyroscopes and accelerometers of the INS.
- Another commonly used solution for the precise positioning of a moving device inside city limits is dead reckoning trajectory tracking. Using the data provided by sensors implemented for other driver assistance systems, such as the anti-lock braking system (ABS), the current position of the vehicle is calculated from a known previous position, the movement speed of the

vehicle and the steering direction in the time following the instant when the position was known.

By combining the dead reckoning trajectory tracking technique for learning the precise position of the sensor carrying device (i.e. the data acquiring vehicle), the motion stereo sensor system proposed in this paper can also be used for other environmental monitoring purposes. Motion stereo processing allows the software to calculate the accurate position and orientation of the sensor (i.e. the camera in this case). If a laser strip projector is added to the camera, as it is in the system shown in Fig. 1., it becomes possible to approximate the 3D models of the buildings' walls surrounding the track of movement of the data acquisition vehicle. This allows us to create another additional function to the proposed crowdsensing system, i.e. creating a realistic environmental model database by mapping the sensed texture onto a 3D model.

B. Proposal

In this paper the sensing (I.), the processing of image flows (II.) and the central data processing (IV.) steps of the system shown if Fig. 1. are introduced.

The operation of crowdsensing based applications strongly relies on the contribution of the individual members of the crowd, therefore, it is utterly important to make the involvement of the crowd as easy and as low-cost as possible. The increasing spread of camera based advanced driver assistance systems makes image acquisition from the road surfaces a progressively easier task for the members of traffic – e.g. cars, buses. The operation of such systems can be modified to allow data processing, using a spatial image mapping system. The introduced method enables the advanced driver assistance system to transmit spatial road surface images with such extremely high speeds that the system shown in Fig. 1. requires.

The moving agents in step I. of the above introduced system, the so-called data acquiring vehicles, are capable of recording image sets. It is necessary for the operation of the system to have the acquired images transferred to the processing and data storage center. In order not to raise the amount of mobile data used by the members of the contributing crowd significantly, the images have to be preprocessed on the level of the data acquiring vehicles. The method of preprocessing is also introduced in this paper.

The central processing step (IV. in Fig. 1.) has also been developed. Our algorithm combines the spatial image information transferred by the individual moving data acquisition agents and the position data supplied by modern mobile devices or cars (e.g. GPS) to create a database that contains up-to-date road-surface information about the roads on which the members of the contributing crowd have travelled. The results of the algorithm are spatial images of the examined road-surface segment as well as typical indicators of the pavement quality. The data acquired in such a way can be used to keep road databases up-to-date using an extremely low-cost method. Based on such real time updated road surface databases, logistics and cost effectivity of road maintenance works may be optimized.

II. Advanced Driver Assistance Systems

In the majority of medium or top class automobiles produced in the last decade and a half some type of driver assistance systems (DAS) is present. The great expansion and development potential of such systems is best shown by the predictions of market researches: the global market of DAS's is expected to grow by more than 22% in the next ten years - from $92 billion in 2016 to $112.69 billion by 2027 [5].

About 90% of road accidents occur because of the drivers' inattention: only in Germany in 2011 4000 fatalities and 390 000 minor or major injuries resulted from traffic accidents [6]. The number and seriousness of such accidents can be drastically reduced by the operation of the so-called Autonomous Emergency Braking (AEB) systems. Therefore the survey of these DAS's has become part of the European New Car Assessment Programme (Euro NCAP) [7].

Amongst other causes, the above mentioned reasons could very well be some of the most important motives for car manufacturers to include the development of driver assistance systems within their most important business goals. By a great margin, however, the focus in DAS development has always been on the possibilities to increase driver comfort as well as to reduce the number of cognitive tasks performed by the driver.

There are two different types of DAS's:

- The basic driver assistance systems, such as the Antilock Braking Systems (ABS), the Electronic Stability Program (ESP) and several other such systems that intervene on a low level thus not requiring any input from the driver.

- The advanced driver assistance systems (ADAS) such as the Lane Keeping Assistance (LKA), the Adaptive Cruise Control (ACC) and further systems alike which require compound sensing and intervention and/or actuation. The operation of ADAS's require driver supervision [8].

About 90% of the sequence of decisions made by an automobile driver depend on the information acquired by the driver through his/her vision. Therefore it is natural that the partial automation of driving largely depends on the determination of presence, position and speed of objects near the vehicle. The equipment responsible in earlier ADAS's for obtaining such data used to be almost exclusively radar, (LIDAR – light detection and ranging,) ultrasound or infrared-based sensors. Such technology can be found in numerous ADAS's including Adaptive Cruise Control (ACC) and Intelligent Parking Assist Systems (IPAS).

However, in recent years most of the world's leading car manufacturers started producing cars with ADAS's that use cameras and/or camera systems – amongst other sensors – to obtain information about their environment, therefore their operation relies mostly on processing visual information i.e. images. Such systems include:

- *Adaptive lighting*: these systems modify specific parameters of the headlamps in order to achieve optimal illumination of the automobile's traffic environment. Optimal illumination means keeping the road and its surroundings as bright as possible while not blinding other members of traffic or the driver himself/herself [9].
- *Nighttime pedestrian detection*: it can be extremely hard for the driver to catch sight of unlit pedestrians walking beside the pavement on the open road. Nighttime pedestrian detection systems warn the driver of the potential dangers ahead [10].
- *Traffic sign recognition assistant*: Many times during driving the driver has to focus on so many traffic signs that he/she might miss some utterly important information such as the actual speed limit. The traffic sign recognition assistant systems reduce the risk of such events by displaying the currently relevant regulation on the dashboard [11].
- *Lane keeping system*: These systems warn the driver whenever the vehicle starts drifting out of a certain lane without signaling. The two most commonly used types of lane keeping systems are Lane Departure Warning (LDW) and Lane Keeping Assistance (LKA) systems [12].

Lane keeping systems are developed and produced by several manufacturers that use different sensors for obtaining visual (or pseudo-visual) information about the lanes marked on the road surface. These sensor types include: simple CCD or CMOS matrix camera, stereo CCD or CMOS matrix camera-pair, image-recognition device with infrared sensor. In most cases the utilized cameras are placed at the base of the rear-view mirror mounted onto the windshield as shown in Fig. 2.

The camera's exact position and field of view must be precisely known for the proper operation of the system. The housing and the mounting base of the sensors generally determines these values, however, because of the manufacturing and assembly inaccuracies, prior to the operation some fine positioning is required as well as a calibration procedure.

The above mentioned CCD or CMOS cameras that are used for obtaining information about the surroundings of the automobile transmit images at such high frame rate and resolution (usually 1024*768 pixels @ 30 fps [13]) that the amount of the gathered data satisfy the needs of the ADAS's. may fulfill that of an additional application: the new application proposed in this paper will be able to utilize the images, which are captured by these windshield-mounted cameras, for the purpose of an extensive road surface survey network.

Fig. 2. Placement of sensor-module in cars. Sensors of module (from top to bottom): lane keeping system camera, rain and light sensor, adaptive lighting system camera [12].

III. Modified Advanced Driver Assistance System

One of the most important considerations when designing the sensor for the above explained crowdsensing based system was that it should be feasible with the slightest possible modification of an already existing ADAS, and therefore easily accessible for as many drivers as possible. This design property increases the size of the potential participating crowd. As a starting point for the design, therefore, we used the lane keeping assistant, since the placement of the environment sensor for this system – i.e. the windscreen mounted camera – is scanning the road surface ahead of the vehicle as per its original function as well. Because the resolution and the frame grabbing rate of such a camera is sufficient for the real time processability of spatial images, usieng the lane keeping assist as the take-off for the image acquiring agents' sensor is ideal for the crowdsensing approach.

By extending the system with a cheap laser-strip projector, its functionality may be widened so that it can be used as a spatial image processing system that utilizes the advances of laser triangulation. The original operation is not affected by this additional functionality. The requirement for road surface scanning in the movement direction of the vehicles for comfort purposes has already appeared in the automotive industry, so it can be anticipated that this technology will start to appear at several car manufacturers [14]. Since laser triangulation is one of the most commonly used profilometry methods, some road surface scanning algorithms can be expected to use this method in the future as well. Beyond these reasons, the use of laser illumination technologies also appeared in the automotive industry in recent years. With the help of laser light sources the vehicles utilizing this technology are able to project certain illumination patterns in front of the vehicle, meaning the problem of structured light (e.g. laser strip) projection on the pavement surfaces has been solved in some high-end cars [15].

For the realization of the data acquisition vehicle's sensor we used the following elements:

- the vehicle onto which the sensor's parts were mounted (Volvo 440),
- ConCorde HD30 dashcam (1080p resolution, 30 fps),
- laser source: laser strip projector (P=2mW, green, 120° projection angle).

The operation of laser triangulation sensors are strongly affected by the size of the triangulation angle, i.e. the angle between the projection axis of the laser projector and the optical axis of the detector camera. For the actualization of the sensor we tested several geometric layouts as seen in Fig. 3.

In Fig. 3. green dots mark the position of the laser strip projector, green lines mark the projection axes, blue dots mark the position of the cameras and blue lines mark the cameras' ptical axes. All three layouts were tested. We concluded that the layout with the biggest triangulation angle yielded the best results – that is layout 2. in the above figure.

IV. Software

The algorithm performing the image processing tasks has been developed using National Instruments LabVIEW environment. The software uses the technique of differential triangulation for computing the depth images: this method combines the advantages of both the laser triangulation approach and the method of difference images to calculate the depth images of the pavement in the moving direction of the sensor – i.e. the data acquisition vehicle.

The most important steps of the image processing algorithm are:

- *Loading the images into the software:* The dashcam stores the recorded video(s) and image(s) on a microSD memory card, which can be loaded into the software after connecting the card to the computer running the processing software.
- *Calibration:* The constant structure of the realized sensor could not have been guaranteed, therefore prior to the evaluation of each image set or video the re-calibration of the system was necessary. For this, reference images – depicting reference objects – were used, which were the first ones in each image set. Such a reference image can be seen in Fig. 4.

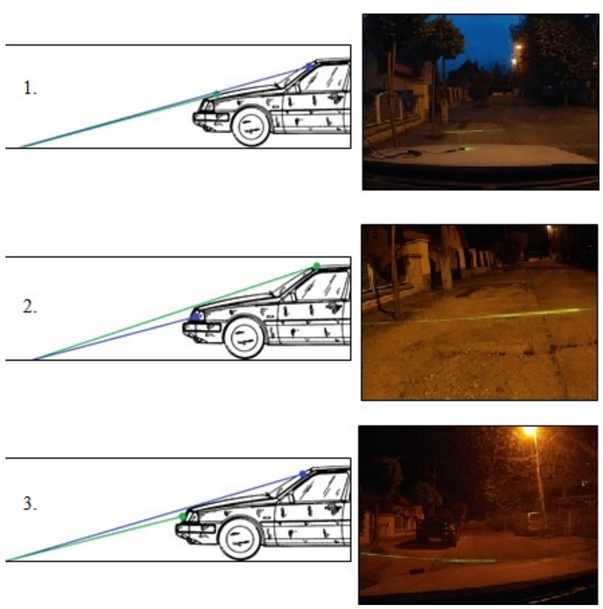


Fig. 3. Road surface surveying spatial mapping system's tested layouts (left) and test images taken with the given layout (right).

Fig. 4. Reference image on which the processing algorithm was able to calculate the calibration values of the sensor.

- *Calculating difference images:* The differences between the examined strip of pavement and a reference surface – i.e. a perfectly flat road – are identifiable in the individual images as the detected laser line's deviations from straight. Such calculation yields an array of depth values across the image i.e. the pavement profile that is illuminated by the laser strip. Such a calculated profile can be seen in Fig. 5.

- *Generating depth images:* Concatenating the right consequent profiles – i.e. depth-arrays – from a given image set produces a two dimensional array, whose elements are the pavement height values from a reference height at the given point of the pavement strip. The processing algorithm links the consequent profiles using different interpolation techniques: bilinear, bicubic, bicubic spline or nearest data point method. Such a depth image can be seen in Fig. 6.

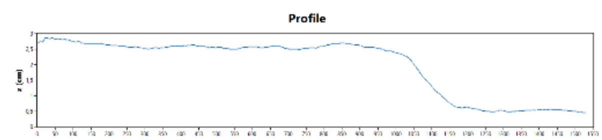


Fig. 5. Example of a calculated pavement profile (z (cm) – x (pixels)).

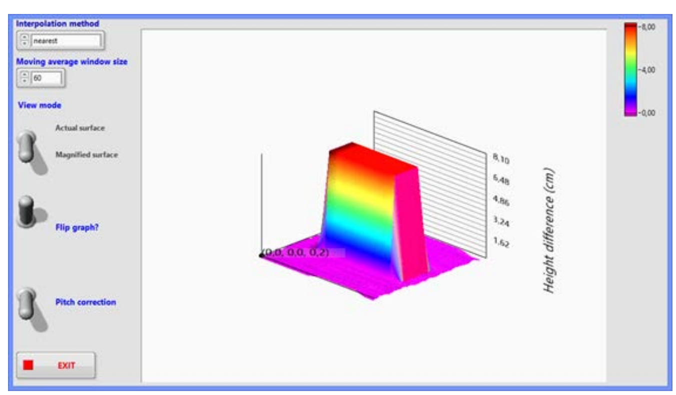


Fig. 6. Example of a calculated surface map shown in the graphical user interface of the image processing software developed in LabVIEW.

V. Results

As mentioned above, the realized sensor with the image processing software is able to calculate spatial surface maps from the pavement strips in the moving direction of the data acquisition vehicles. A generated surface map and one characteristic image taken out of the given image set based on which it is calculated is shown in Fig. 7.

With the pavement profiles calculated as described above, some typically used pavement quality indicators can be calculated, such as: mean profile depth (MPD), international roughness index (IRI) as described in ISO 13473 [16].

The software is able to correctly calculate the surface maps resembling the shape and dimensions of the pavement strip most of the time. However, some external effects may cause the detected profiles to have some incorrect height values, therefore causing the software to yield incorrect surface maps. The most common causes for error in the calculated surface maps are:

- intensity inconsistencies of the projected laser strip,
- pitch of data acquisition vehicle,
- external illumination conditions,
- road surface texture inconsistencies.

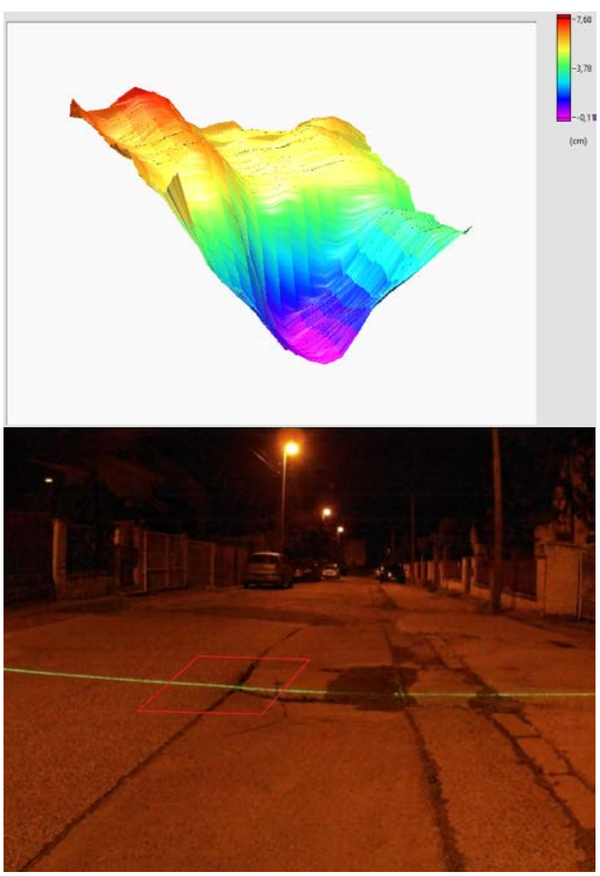


Fig. 7. Generated surface map (above) and characteristic instance of source image set (below) with mapped area marked (red).

VI. Conclusion

The crowdsensing based road pavement surveying system, introduced in this paper provides an alternative solution to the problem of creating and regular updating of road surface quality databases especially in smart cities. The crowdsensing based approach is beneficial as it is not only more cost-effective but it provides pavement quality data with update frequencies much higher than the systems used for the same purpose nowadays. Ultimately, using the above introduced system could result in keeping the road surface databases updated in real time. Based on up-to-date pavement quality databases the optimization of maintenance works and logistics can be performed, resulting in remarkably reduced road repair costs.

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