PHOTOGRAMMETRIC PAVEMENT DETECTION SYSTEM

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ABSTRACT:

This paper introduces a complex, low-cost road pavement measurement system designed primarily for pothole and crack detection. The onboard system is composed of a GPS/INS navigation unit, an image acquisition module, and a photogrammetric and image-processing subsystem. Due to the use of structured light and the availability of accurate navigation data, the 3D coordinates of the road points, in the form of cross profiles, as well as the size and location of the potholes, can be derived from the images at cm-level relative accuracy. For the road classification the International Roughness Index (IRI) can be derived. This paper also discusses the potential future developments of the system; it reports on the initial investigations of applying single camera with laser line projection which can significantly simplify the overall procedure.

1. INRODUCTION AND CONCEPT

In the well-motorized countries the transportation authorities spend significant amounts of money to road constructions and road pavement maintenance. The roads are aging; the maintenance works have to keep pace with the new constructions. The traffic delays are mostly caused by road closures, this topic is always highlighted in the news. Therefore, the optimized scheduling became extremely important, the authorities tend to turn to new technologies in order to map the actual condition of the road pavement and decide upon the priorities of the scheduled maintenance works.

Since road engineering is one of the most extended engineering field, many "traditional" road surveying methods used for construction and maintenance planning. As most of the maintenance works are scheduled based on experiences, the road conditions are often classified by visual observations. The number of potholes, the length and type of the cracks, and lane grooves are clear indicators of the overall road condition.

However, there are a few autonomous (or at least semi-autonomous) systems in use, e.g. the Swedish RST (http://www.opq.se) or the Mandli Roadview (http://www.mandli.com): both systems are able to measure the cross- and longitudinal profiles of the roads; moreover, Mandli is collecting digital images about the road surface.

This paper discusses the structure and results of the original system, the potential of the entry-level IMUs (inertial measurement unit) in mobile mapping and introduces the latest concept with the initial test results.

2. SYSTEM COMPONENTS

Our basic idea was to create a road pavement detection system, which uses optical sensors for measuring the longitudinal and cross sections of the roads and the pavement anomalies (potholes, wide cracks). Figure 1 shows how the system components are linked to each other. The sensor component consists of two cameras (Sony XCD-SX910) synchronized by external trigger and laser projectors, the location component contains an integrated GPS/INS (Global Positioning System / Inertial Navigation System) unit (Crossbow NAV420CA).

The cameras are capturing downward images about the pavement at a rate of 5 fps. 20 individual laser projectors provide the equally spaced marker points located perpendicular to the travelling direction on the surface. Therefore, the 3D coordinates of the points can be computed by evaluating equations of geometric constraints.

The georeferenced position and orientation of the camera pair are provided by the integrated GPS/INS system. The NAV420CA system consists of a navigation grade GPS receiver, an entry-level IMU (Inertial Measurement Unit), and a built-in Kalman-filter. The accuracy of the positioning by the GPS module is about 3 m CEP, whereas the random walk of the IMU is about $4.5°/hr1/2$ (Barsi et al. 2005).

The cameras have 1280 by 960 pixel resolution which results in 3 mm ground pixel size, which enable not only the detailed surface description but the scar and crack detection from the images, too. The camera location assures the full lane-width visibility, covering 3.5 m wide area. The cameras are linked by FireWire to the laptop mounted in the cab (Figure 2).

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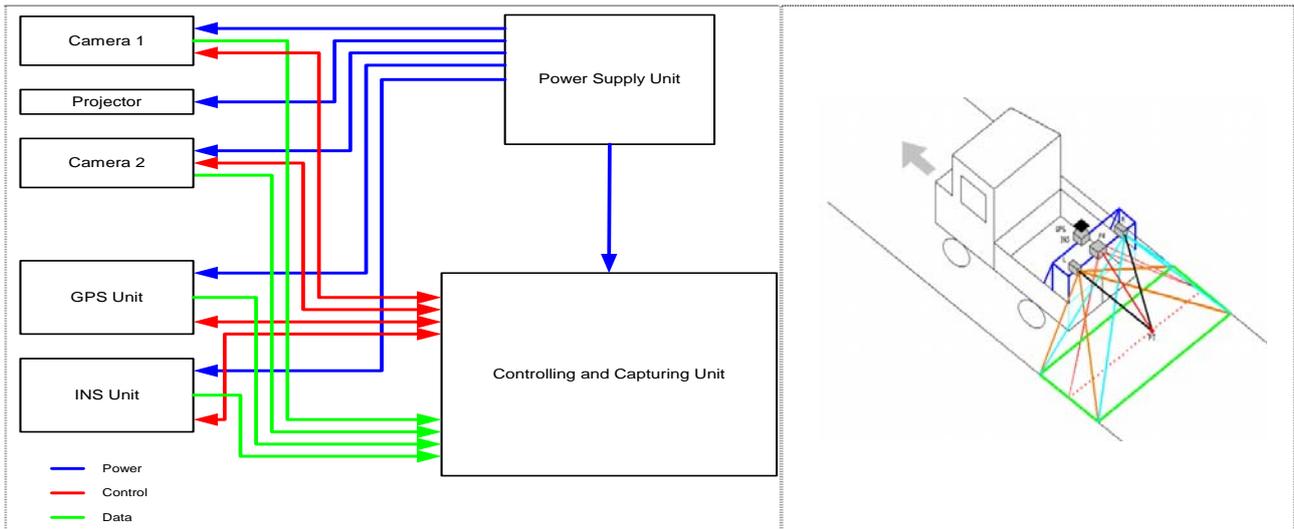
Figure 1. The main components of the system
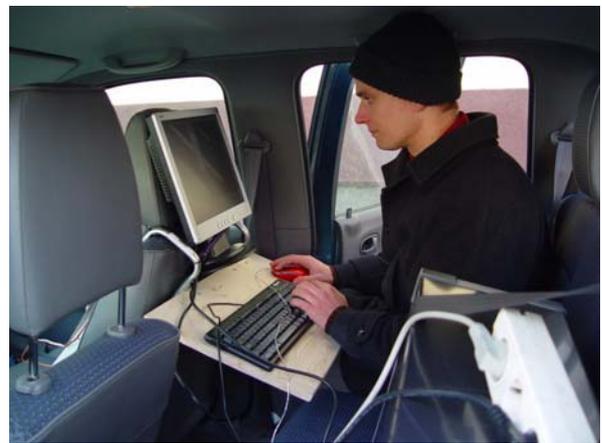
Figure 2. The instrument platform mounted on the pickup and the controlling environment

3. INITIAL RESULTS

The system will be used by the transportation authorities and intended to replace the existing road measurement technologies. There are several types of end products obtained by the developed system. The two main categories are: elevation information of the road surface and images about the pavement. From the elevation data of the projected points the cross and longitudinal sections of the road surface can be computed. If the point arrays are linked together, the digital surface model of the road can be created and enhanced on demand with the gradient values (Figure 3). Using the optical images for crack detection is considered as a completely separate category. Applying well-known image processing algorithms, the length of the cracks can be computed.
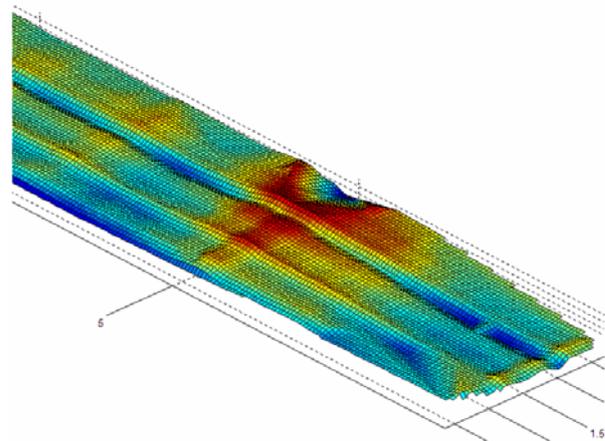
Figure 3. Pavement surface model

4. V2 – BASIC CONCEPT

The idea behind the second version is measuring height in a single image by profile detection. If a straight line is projected on a smooth surface and an image is taken from oblique camera position, the line appears straight on the image (Figure 4).
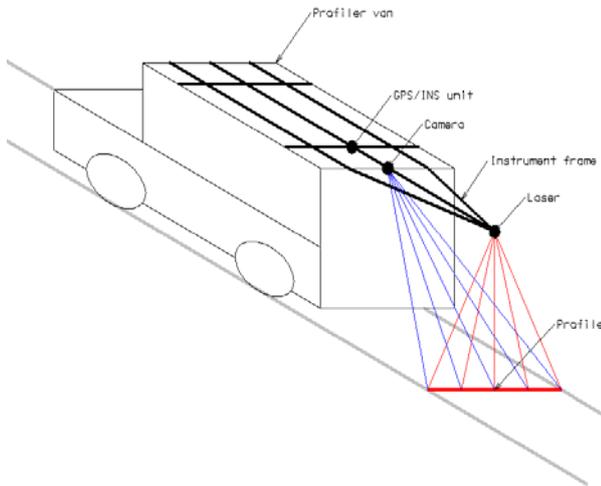
Figure 4. The concept of the second version

In case of height change (an object or pothole, for example), the image of the line seems straight only from top view, but it's broken from any oblique view point (Figure 5).
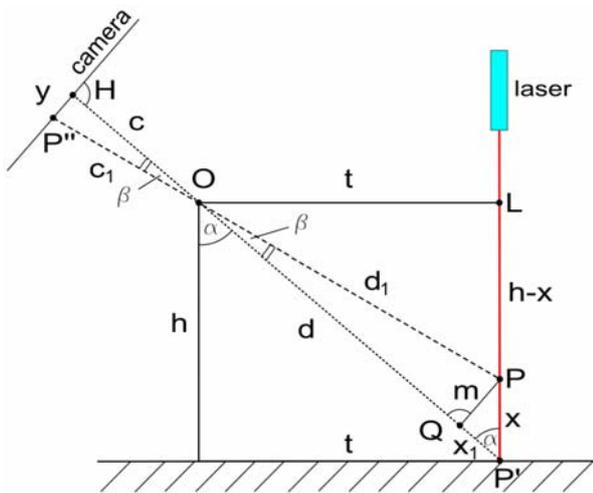
Figure 5. The basic concept of measuring height (x) in a single image taken from oblique viewpoint.

Based on similar triangles clear correspondence can be defined between y and x, which is a quadratic equation. For x the function is the following:

$$x = f(h, t, c, y) \tag{1}$$

During the calibration, the camera focal length is considered as constant. So the only inputs of calibration are the h and t values.

This system can be considered much robust compared to the previous version, since it avoids stereo imagery. Moreover, in this concept every single points of the projected line can be evaluated and measured (note, that previously separated points have been projected); therefore it enables much higher resolution for the road surface model. The surface resolution depends on the camera cross-directional resolution. Initially only a single line is projected onto the surface, later, if higher measurement speed is needed, more lines can be projected simultaneously.

5. FIRST TESTS WITH V2: CONCEPT PROOF

In the first phase the image processing module has been developed. For the concept proof an industrial laser line projector and an industrial digital camera were used, the same equipments are intended to apply in the final version. The laser projector is a 5 mW, 660 nm Lasiris laser diode, with special optic for the structured light. The imaging unit is a TheImagingSource DFK 41F02 color camera with 1280 × 960 resolution and 7.5 fps image acquisition speed.

The laser projector was mounted vertically (perpendicularly to the surface); the projected line was captured by the camera from the oblique position of about 45 degrees.

In all cases the objects have been moved towards the camera, perpendicularly to the projected line. Sequences of camera images were the inputs of the overall object reconstruction procedure. In all images the red laser stripe was extracted by filtering and binary image morphology, and then the y image coordinates of the laserline were computed.

The accuracy of the reconstructed object depends on the capturing resolution (number of images per object) and the calibration parameters (camera height, object distance). In the following the computed cross sections and the reconstructed object are shown (Figure 6).

As it can be seen in Figure 6, the detected object is nicely reconstructed. The accuracy of the height measurement ensures adequate solution for road condition detection, since the final purpose is measuring the height differences on the road surface and deriving the IRI number (roughness index) for dedicated road segments.
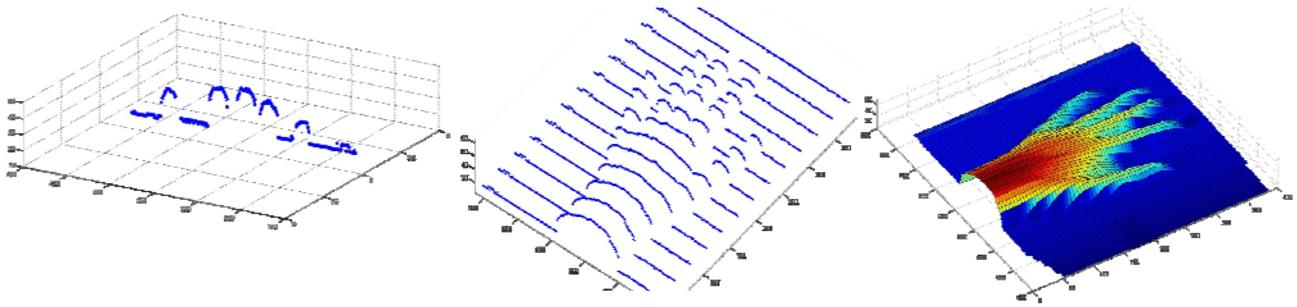
Figure 6.Computed cross sections and the reconstructed model of a hand

6. DERIVING THE INTERNATIONAL ROUGHNESS INDEX (IRI)

The IRI measurement has m/km (sometimes mm/m) or in/mi units. The determination of IRI can be easily done from the intersected surface points; only the longitudinal profile has to be used. The most relevant place of road roughness is exactly under the tires, therefore the four (2 left and 2 right) markers in line with the tires have been selected for IRI calculations. The IRI values are calculated for all four points, samples taken in every 80 cm (at a speed of 4 m/s [15 km/h]) along the road, then their average are ordered to the analyzed road segment.

A further software module has been developed, which produces IRI files (reports) and IRI maps. In Figure 7 the effect of the recently finished road reconstruction on the bridge and the lack of it on the east (Pest) side can be clearly seen.

Figure 9 shows the results of a 56 km long surveying campaign produced by the latest version of the measurement system in April 2008. Figure 10 is an enlargement to visualize some details of the survey.

There were registrations in three different days, where the measurement repeatability and accuracy can be analyzed. The system classifies the road segments into six categories depending from their IRI values: Cat. 1 is the best and Cat 5 the worst. The special sixth category is used for non-measured segment, where the GPS-positioning was failed (e.g. because of urban canyon effect, under bridges) or the IRI-measurement had any other problem. The following table shows the quality distribution of the surveyed roads for the five longest sections:

	S1	S2	S3	S4	S5
Cat. 1	2606	1340	1475	518	979
Cat. 2	4456	1797	1968	978	842
Cat. 3	2408	1269	707	753	402
Cat. 4	1228	737	362	466	223
Cat. 5	1785	1143	401	773	342
Cat. 6	2266	1615	336	820	946
Length	14752	7904	5251	4312	3737
Mean IRI	9.32	10.00	7.70	11.54	8.28
IRI SD	7.28	7.51	6.72	8.52	7.19

Table 1. Basic statistics for the five longest sections measured in the last campaign. The categories and length are given in m, IRI in m/km

The IRI calculation is done at the highest resolution, but of course the values can be aggregated arbitrary.

An additional experiment was also performed: the potential of vertical acceleration directly in IRI calculation i.e. how can IRI be derived from the single vertical acceleration measurements. To test this hypothesis, regular gridded vertical acceleration values were interpolated, then they were integrated into vertical movements, and at the end the IRI-calculations were performed as (Sayers & Karamihas 1998) refers. The IRI-values are calculated for 2 m long segments. Since only a single IMU was applied in the vehicle, no smoothing (e.g. averaging) was needed (compared to the previously mentioned "optical" IRI method).
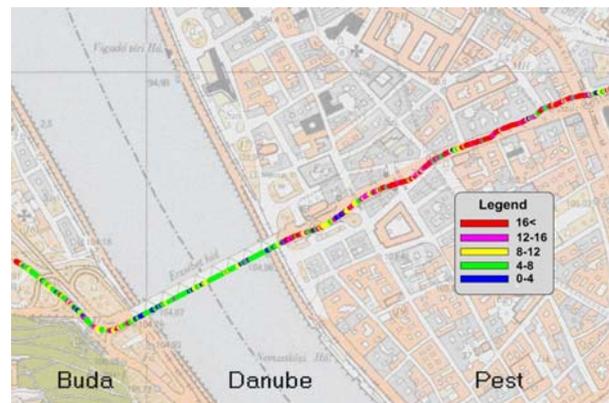
Figure 7. IRI map derived from laser markers below the tires. (light is for good, dark for bad status.)
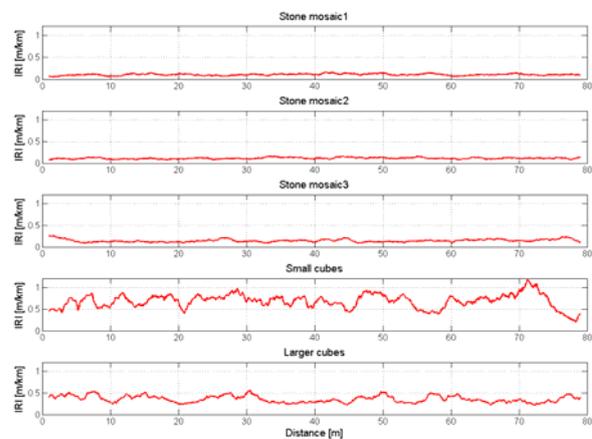
Figure 8. IRI-values calculated directly from vertical acceleration measurements on different pavement types

Considering different pavement types the IRI-diagrams can be compared (Figure 8).

The standardized IRI values for airport runways and superhighways are 0.5-2.0, 1.5-3.5 for new pavement, 2.5-5.5 for older pavement, 4.0-11.0 for damaged pavement and 8.0-20.0 m/km for rough unpaved roads. Comparing the IRI values of Figure 7, relative good fitting can be noticed: the renewed pavement on the bridge has an average IRI value of 4 m/km, whilst the older road segment on the east river side has about 16 m/km. Especially this latter value points out that our system requires a calibration run to get the mathematical formula to assign the IRI observations to the standardized evaluation.

Figure 8 illustrates the IRI diagrams for the investigated pavement types, calculated from the raw vertical acceleration measurements.

The first three pavement types are the smooth surfaces; they have an average IRI value of about 0.1 with a relatively small (< 0.05) standard deviation. Compared to this, the last two pavements are worse as the observed higher IRI values (0.3 and 0.6) with larger standard deviation (> 0.05) clearly indicate it.

Although there are numerically greater differences between our mean IRI values and the standardized ones, the tendency is obvious: the worse road gets higher IRI measures. This solution also cannot avoid the calibration procedure.

Figure 9. IRI road status in Budapest derived by the last measurement campaign

The most important statistics of the IRI-values are the following:

Pavement type	Mean	Std deviation
Stone mosaic 1	0.1041	0.0195
Stone mosaic 2	0.1095	0.0164
Stone mosaic 3	0.1416	0.0317
Small cubes	0.6795	0.1586
Large cubes	0.3543	0.0775

Table 2. Basic statistics of IRI on different pavement types (derived from Figure 8 diagrams)

7. CONCLUSIONS

In this paper we presented a concept study and our initial results of the developed pavement detection system. Digital cameras capture the images of the road pavement which is lit by structured light. The exterior orientation parameters of the images are provided by a GPS/INS navigation system, which enables the pavement surface generation at good accuracy. Applying a special diffuse illumination, the small anomalies of the pavement, such as scars and potholes, can also be detected. In the context of this effort we developed a road profile and surface generation module which input the profiles formed from

the marker points. This CAD-based module not only computes the profiles from the given points, but generates a road surface model that represents the pavement condition and can be used for maintenance assessment, scheduling, and planning.

The investigations and tests described in this paper proved that the proposed single-camera detection method assures robust solution for road surface generation. Applying a single imaging unit simplifies the georeferencing and avoids the complicated calculation and calibration of two cameras which have to be synchronized. Using line projection instead of laser point array enables measuring all point heights along the profile, therefore the surface model resolution depends only on the horizontal resolution of the camera. This concept also has further potential in development, e.g. applying multiple projected lines in order to allow higher measurement speed, and also leaves open the possibility of using the camera images for additional purposes, such as crack detection, which is a critical issue regarding road condition detection.

The described mobile mapping system and the provided surface data can be used for deriving the IRI for the particular road segments, which is used by the transportation authorities for road pavement classification.

The next step in development is creating the engineering prototype of the road detection system; the camera, the laser projector, the control unit, and the navigation system are to be

mounted on a vehicle and the next tests are to be carried out in the environment of the final system, i.e. on the roads.
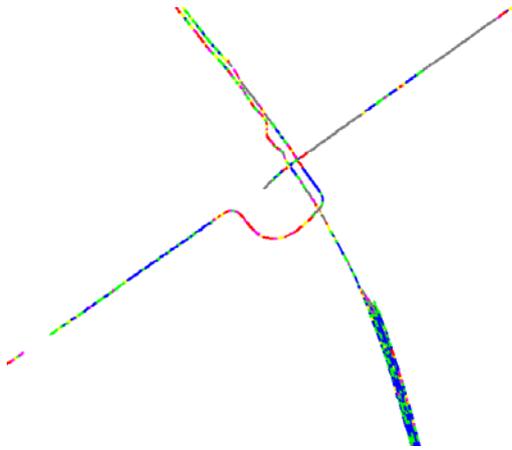
Figure 10. IRI map detail at a bridge and a river-side road

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