

MEASUREMENT OF ROAD ROUGHNESS BY LOW-COST PHOTOGRAMMETRIC SYSTEM

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ABSTRACT:

This paper discusses the continuation of the research work started in 2004. The previous results have been published both in ASPRS and ISPRS conferences. Now we intend to emphasize the latest developments and extended application areas of the system.

Due to the increasing demand of the transportation authorities for rapid, accurate data acquisition about the road pavement, a mobile mapping system has been developed primarily for road surface detection. Our system involves a data archiving and system control unit (notebook), an imaging unit (two industrial cameras), a positioning unit (combined GPS/IMU system with built-in Kalman filtering), a marker unit (point-projection by laser diode array) and the mobile platform (pickup with special carrier frame and specified power supply). The first reported results were about creating the digital road surface model and detecting the cracks on the pavement. The system is now in test-phase at the road maintenance company of Budapest city (Municipal Public Service); during the practical tests several new demands have been raised.

For the complex transportation management (scheduling road construction works, reconstruction etc.) the roads have to be classified into coarse categories. Therefore the resulted digital surface model has to be transformed into basic numeric form. Internationally, the so-called IRI (International Roughness Index) is used to represent the road condition.

Besides the digital surface model of the road pavement, the INS measurements can be used without the images to derive data that indicate the pavement condition. Our experiments showed that vertical acceleration and the roll/pitch values are strongly correlated with the road roughness and waviness. Based on the single INS measurements, the roads can be classified into categories, our tests and initial results are also discussed in the paper.

1. INTRODUCTION

The status of the national road network has been significantly changed in Hungary in the last decades. These changes are caused mainly by two reasons: people easier get loans to buy cars, which increased the number of vehicles. The second reason was the lower budget of road maintenance. These effects "produced" visible cracks, potholes and other injuries of the road surface.

The road maintenance company of Budapest has decided to develop an own system to survey the road status, which can be the base of scheduling road works. Recently trained employees monitor the network and report the size and place of any anomalies based on visual observation. Since this human evaluation is not objectively comparable and many difficulties were arisen, the decision makers have chosen a human independent, i.e. automatic solution. This demand initiated the development of the road surface inspection system, called PHORMS.

2. MEASUREMENT SYSTEM

PHORMS stands for Photogrammetry Based Road Measurement System. The main components of the system are the camera subsystem, which contains two industrial Sony XCD SX910 CCD-cameras with a 1280×960 pixel resolution. The cameras have wide angle lenses (Pentax Cosmocar 4.8 mm); therefore the whole traffic lane can be covered. The 8 bit black-and-white cameras are synchronized by an external trigger generating capture frame rate of 5 fps, which ensures the precise timing of exposures. The cameras are calibrated; besides the

focus distance and the principal points, the lens distortions have also been derived. The light sensitivity of the cameras (about 4 lux) enables to perform the measurements even in twilight or dark circumstances. The cameras were connected to the laptop by Firewire (IEEE 1394) ports.

The system applies a laser point array perpendicular to the road axis for marking the surface points. The 20 laser sources (5 mW energy) having 660 nm wavelength are installed onto a stable and rigid instrument frame. The projected laser points are located on the surface in equal distance (17 cm) from each other.

The third component on the instrument frame is the inertial measurement unit (IMU), which registers all the frame movements: three angles and three accelerations along the local coordinate axes.

The control of the system is a laptop, which serves as data storage unit, too. All the GPS/INS measurements, as well as the camera images are stored in project folders, which are later archived on DVDs.

The power supply is an aggregator in the design phase, which will be replaced in the next phases by an inverter module connected to the vehicle's electric system.

The concept, as well as the first experiments of the PHORMS system has been reported in Barsi et al. 2005, and Barsi et al. 2006. The system budget was about 74.000 EUR for nearly 2 years development, including the system design, hardware and vehicle installation, software development and tests, as well as project administration and institutional overhead costs.

The measurement system contains a post processing package, which detects the laser marker points in the registered images and stores the coordinates in a list, then calculates the marker coordinates by photogrammetric intersection for each marker

profile. The visualization of the results is threefold: the trajectory of the vehicle, longitudinal and cross sections of the investigated road segment, 3D perspective (Fig. 1) and isoline visualizations.

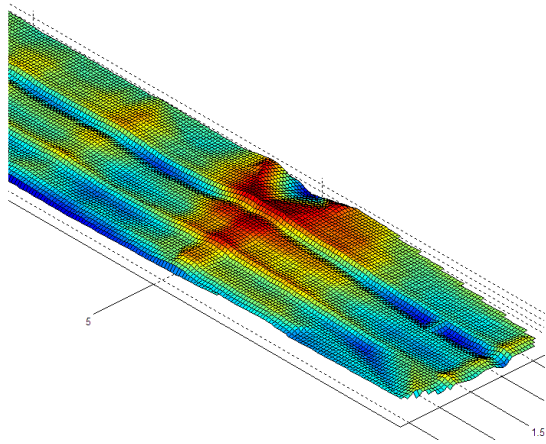


Figure 1. Perspective visualization of a road segment (with enlarged anomalies)

3. INERTIAL MEASUREMENTS

The evaluation of the overall system requires testing of the components. The first experiments focused on the inertial measurements. The built-in GPS/INS unit is a Crossbow NAV420-CA100 type 100 Hz MEMS instrument. Before the installation the unit was compared to a Crossbow AHRS400-CB, which is a 56 Hz IMU without GPS feature. These previous tests have proven the need of the NAV420. It is an integrated GPS/INS module with a relative simple Kalman-filter, thus it can output WGS84 positions and altitude values. The system belongs to the entry level instrument category.

In the test measurements a route including different types of pavements was selected: small size cubes, large size cubes, different size stone mosaics, and different types of asphalt pavements. Fig. 2 shows the remarkable differences in the vertical accelerations on different pavement types.

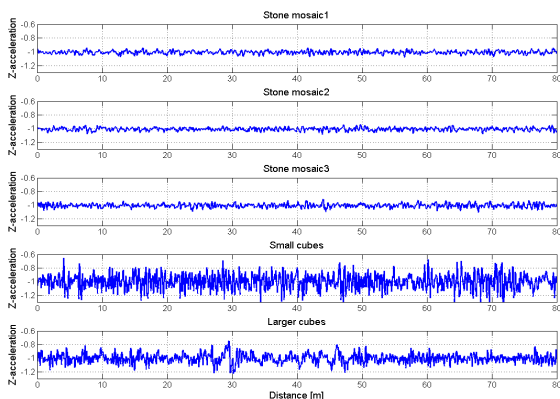


Figure 2. Vertical accelerations on different pavement types (stone mosaic 1, stone mosaic 2, stone mosaic 3, small cubes, large cubes, respectively)

Note that the x-coordinates in Fig. 2 are distances, which are derived from the GPS measurements.

The accelerations above can be transformed by Fast Fourier Transformation (FFT), so the main frequencies can be obtained. The same analyses can be performed on the angle measurements, too. Considering the roll values from a road segment, the waviness can easily be represented (Fig. 3).

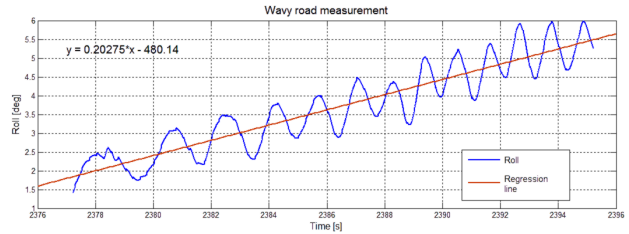


Figure 3. The registered roll values (angles around local x axis) on a newly paved road. The red line shows the linear trend, which was removed from the posterior computations

The FFT analysis determined the main wavelength of the road, which is about 19 meter. That fits to the distance measures of the storm drains.

Figure 4 shows more similarity between vertical acceleration, roll and pitch, as well as their Fourier-spectra on the same, newly paved road segment.

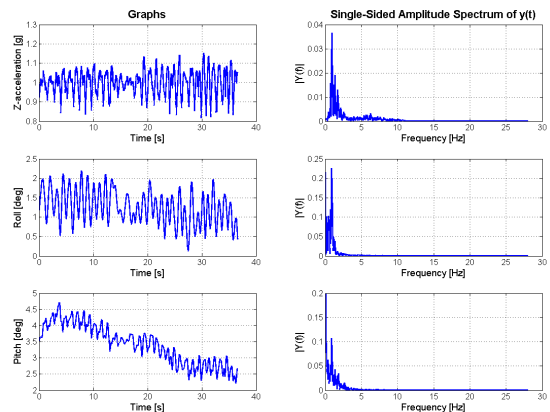


Figure 4. Vertical acceleration, roll, pitch, and their Fourier spectra

In fall 2006 and spring 2007 the acceleration measurements have been performed at different driving speeds. Both measurement campaigns were done by clear, dry nights, in low-traffic conditions.

Figure 5 shows the effect of the speed on the FFT diagram on the same pavement type: the diagram above is derived from a 20 km/h measurement, whilst the subplot below is of a 40 km/h sensing. Prior to the Fourier transformation the linear trend was removed (the mean was set to 0.0 g).

The tendency of the measurements are the same, therefore the speed alternation of the test vehicle can be eliminated.

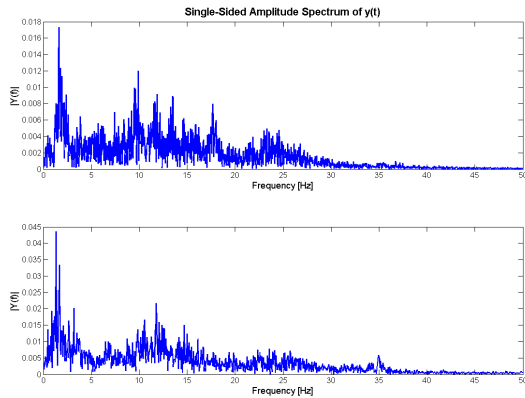


Figure 5. FFT diagrams of two measurements at different driving speeds on large cube pavement

4. DERIVING THE INTERNATIONAL ROUGHNESS INDEX

The International Road Roughness Index (IRI) is defined by the US National Cooperative Highway Research Program (NCHRP). IRI is essentially a computer based virtual response-type system. In order to calibrate it, an ideal system was defined for computer: the profile index was tailored to correlate well with the output. The filter is based on a mathematical model, called quarter-car. The NCHRP's special set of parameters for quartercar is called The Golden Car. IRI summarizes the roughness qualities, that impact vehicle response and is most appropriate when a roughness measure is desired that relates to overall vehicle operating cost, overall ride quality, dynamic wheel loads and overall surface condition. (Sayers-Karamihas 1998)

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 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 Fig. 6 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.

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 be IRI 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 averaging was needed (compared to the previously mentioned "optical" IRI method).

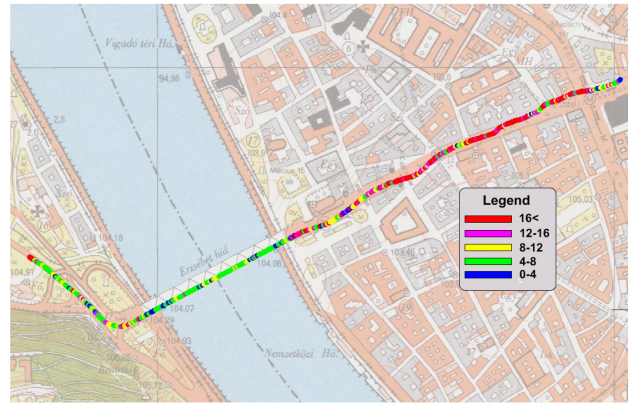


Figure 6. IRI map derived from laser markers below the tires. (Green is for good, red for bad status.)

Considering different pavement types the IRI-diagrams can be compared (Fig. 7).

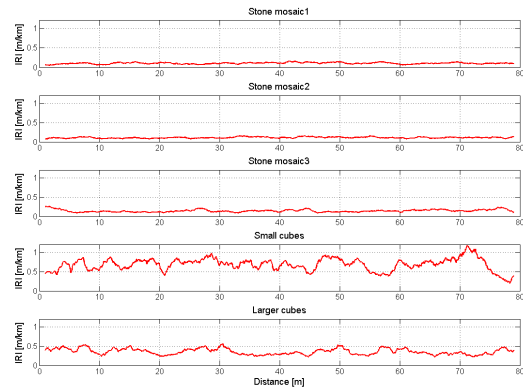


Figure 7. IRI-values calculated directly from vertical acceleration measurements on different pavement types

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 1. Basic statistics of IRI on different pavement types (derived from Figure 7 diagrams)

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 Fig. 6, 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 7 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 status gets higher IRI measures. This solution also cannot avoid the calibration procedure.

5. FUTURE DEVELOPMENT

In order to avoid several calibration works and make the whole process simpler, the system will be refined. The development work is in progress; the basic modifications are described as follows.

The measuring method has been completely redefined. Instead of using a camera pair, the images are captured by a single frame camera. A continuous laser line is projected onto the road and images are captured applying oblique camera.

The accumulated vertical movements of the image points of the projected line are the inputs for IRI calculations, therefore these movements are extracted by the image processing module. The oblique camera position and the vertical laser beam assure optimal positioning accuracy as well as have increased mechanical and numerical stability during the measurements. Similarly to the previous system, the best imaging reliability is guaranteed by time-to-time calibrations.

6. CONCLUSION

The paper presents a low-cost photogrammetry based road surface measurement system, which was designed and developed by the Department of Photogrammetry and Geoinformatics. The initial concept of the system was to create a measurement instrumentation, which have laser module to mark independent points that can be identified by image processing algorithms and therefore can be used for photogrammetric spatial intersection computations. The procedure requires known exterior orientation parameters, which are provided by a GPS/INS system component.

During the development phase two types of IMUs were tested and compared. These tests resulted interesting observations and influenced novel ideas concerning road evaluation. This paper reports on these efforts.

The measurements taken by IMUs can be evaluated also for road qualifying purposes. Roll and pitch angles, vertical acceleration show clear correlation with road quality; a wavy road segment can be identified by analyzing the mentioned measurements. By calculating FFT even the wavelength can be derived: some components equals to the distance of the storm drains.

Both the photogrammetric intersected surface points and the vertical accelerations are suitable to compute the International Roughness Index. The photogrammetric calculated IRI has been illustrated in form of a thematic map. The equidistance sampled or interpolated vertical accelerations can also be aggregated into the IRI calculations; our hypothesis has been proven on five different pavement types.

A complex road surface measurement system can provide several quality measures at the same time: the digital surface model (DSM) of the road pavement can be derived from the evaluation of the projected surface points, camera images can be used for visual evaluation of the pavement condition, and cracks can be automatically extracted by digital image processing. The

navigation observations deal with the input to the surface point determination module, but also as a standalone measurement they have the potential to directly derive roughness values in real time.

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