THE POTENTIAL OF LOW-END IMUS FOR MOBILE MAPPING SYSTEMS

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ABSTRACT:

Due to the decreasing prices of the sensors and equipments, mobile mapping technologies are widely used even in the commercial area (e.g. transportation) in the 21st century. The road networks often cannot cope with the increased traffic load; moreover, the roads in bad condition reduce the overall capacity of a network. Pavement condition is a central aspect of road transportation infrastructure management, and is particularly highlighted in Hungary; the loss in travel time, the damage in vehicles results in significant indignation in society and gives an everyday topic for the actual political life.
Scheduling road construction works requires effective monitoring of road conditions and the various components of a particular network have to be classified by quality. This paper introduces a complex road pavement measurement system designed primarily for pothole and crack detection.
The system, installed in a vehicle is composed of a navigation unit, image acquisition module and a photogrammetric image-processing subsystem. The navigation unit consists of an integrated GPS/INS system; the trajectory and attitude of the vehicle at the required accuracy is provided by a Kalman filter. All the sensors and a high-speed computer are mounted on a pick-up.
The low-end inertial measurement units (IMUs) have continued to improve in the last years, which broadened their application fields. The paper discusses the experimental results of the IMUs. First we compared the performance of two low-end IMUs on various road surfaces (wavy pavement, potholes etc.); secondly we analyzed their impact on the application. The obtained results have proved the potential of these types of sensors for this kind of road engineering applications.

1. INTRODUCTION AND CONCEPT

In the well-motorized countries the transportation authorities spend significant amounts 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.

Figure 1. Potholes and cracks on the pavement

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 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 transverse and longitudinal profiles of the roads; moreover, Mandli is collecting digital images about the road surface.

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 2 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 unit (Crossbow NAV420CA).
The cameras are capturing downward images about the pavement at a rate of 5 fps. 21 individual laser projectors provide the equally spaced marker points located perpendicular to the traveling direction on the surface. Therefore, the 3D coordinates of the points can be computed with spatial intersection.

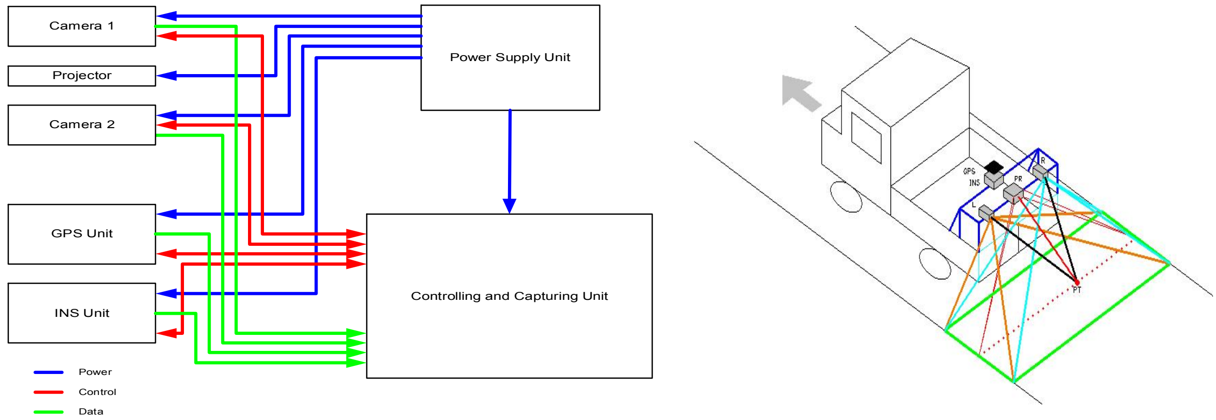


Figure 2. The main components of the system

The exterior orientation parameters of the camera pair are provided by the integrated GPS/INS system. The NAV420CA system consists of a navigation grade GPS receiver, a low-level IMU, 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°/hr$^{1/2}$ (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.

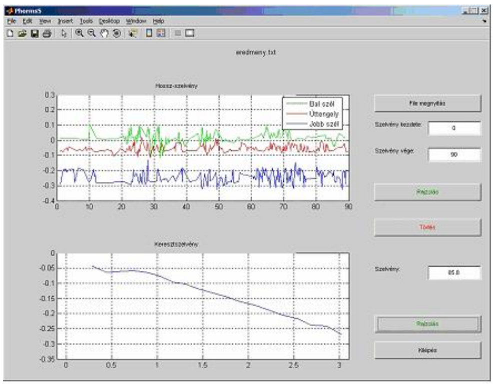
Figure 3. The instrument platform mounted on the pickup and the controlling environment

3. RESULTS

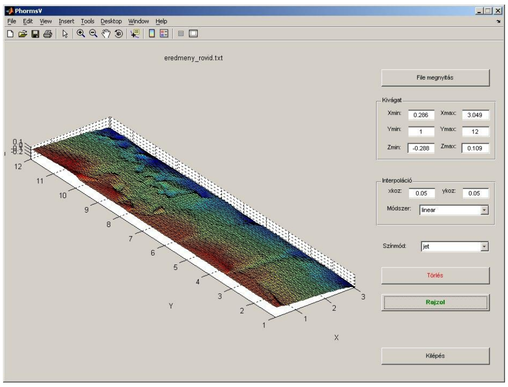
The system will be used by the transportation authorities and intended to replace the existing road measurement technologies. There are several types of end products obtained by the developed system. The two main categories are: elevation information of the road surface and images about the pavement. From the elevation data of the projected points the cross and longitudinal sections of the road surface can be computed (Fig. 4a). 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 (Fig 4b and c). 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 (Fig. 4d).
These data can be used for deriving the International Roughness Index (IRI). The 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 (that is, damage to the road from heavy trucks and braking and cornering safety limits available to passenger cars), and overall surface condition (Sayers and Karamihas, 1998).

4. LOW-END IMUS FOR MOBILE MAPPING SYSTEMS

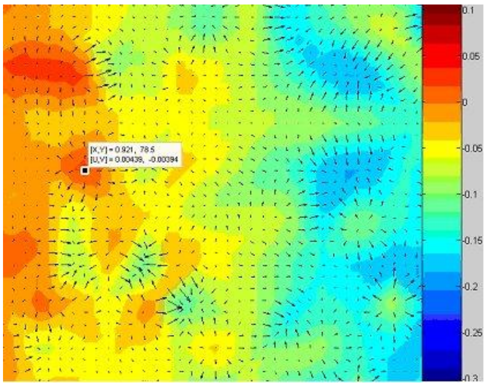
Our investigations and the initial results proved that the low-end IMUs can provide sufficient location and orientation data for such mobile mapping system. The Crossbow NAV420CA uses a 3-axis accelerometer and a 3-axis rate sensor to make a complete measurement of the dynamics of the system. The addition of a 3-axis magnetometer inside the NAV420CA allows it to make a true measurement of magnetic heading without an external flux valve. With the built-in GPS receiver, the combined system becomes a low-cost INS that can output location, velocity and acceleration. The Crossbow NAV420CA is a solid-state equivalent of a vertical gyro/artificial horizon display combined with a directional gyro, flux valve and Global Positioning System (GPS) (Crossbow, 2005).
We have investigated the potential of the NAV420CA integrated navigation system along with a Crossbow AHRS400CB strap-down IMU.



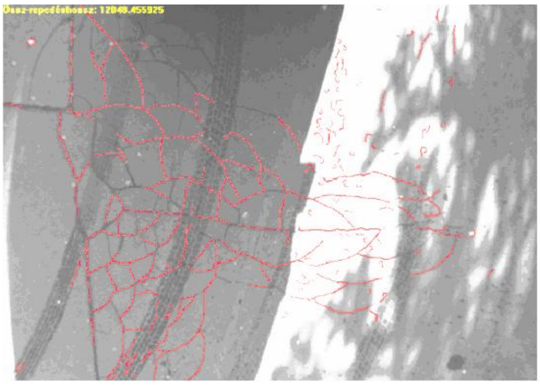
a) sections



b) surface model; perspective plot



c) gradient map



d) crack detection

Figure 4. Products derived by the system

Figure 5. The investigated IMUs (left NAV420CA, right AHRS400CB) and (bottom) the common mount platform

For the investigations, the units were mounted tightly together onto a wood platform (Fig. 5) and hardware synchronization was applied ensuring the same capture start for both units. GPS antenna was connected to the NAV420CA, this unit provided the absolute point coordinates. However, the shape of the trajectory can be derived from the acceleration and angle measurements. In Figure 6a the trajectory from the AHRS400CB and that of the NAV420CA (Fig. 6b) can be seen. Note, how the multiple circles in the roundabout are depicted by the AHRS data, whilst the NAV420 provided the accuracy of its GPS unit.

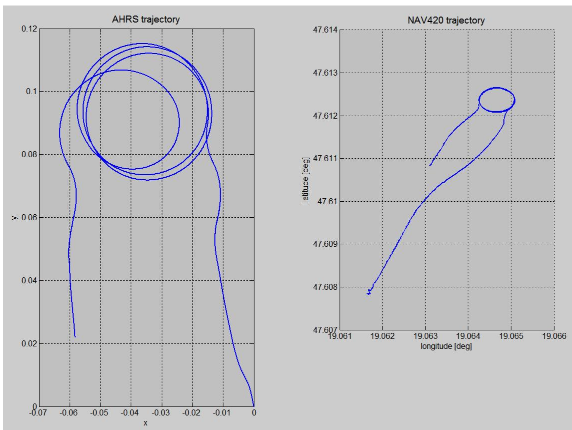


Figure 6. The trajectories of the IMUs about the same roundabout

Figure 7 is also representing the similarity of the yaw values (the shape of the trajectories), except the graph of the NAV420 has correct absolute location data since this unit is continuously initialized by its GPS receiver.

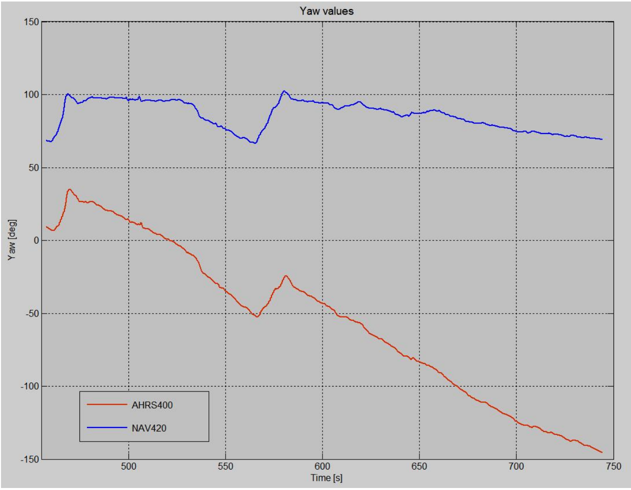


Figure 7. The trajectories (yaw values) of both IMUs

In order to investigate the capability of the IMUs, we've chosen a test path that contains a section where the drain holes (i.e. the catch basins) are built with equal gaps between them, making the road extremely wavy. Representing the roll values (Figure 8), the graph is wavy and strong correlation can be found between the gaps of the waves and the gaps of the drain holes. The bottom plot shows only the waves, where the height tendency has been removed.

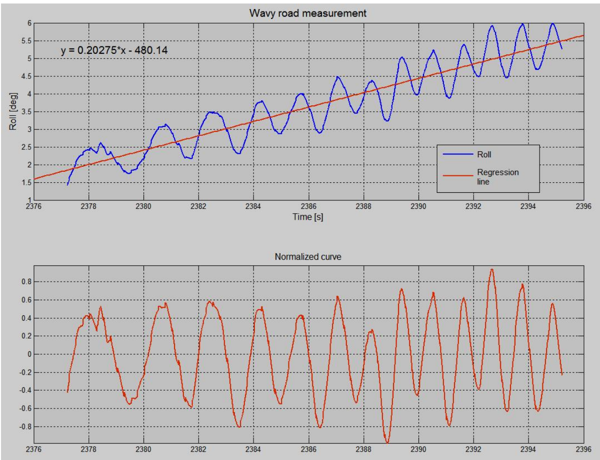


Figure 8. The roll values are in strong correlation with the waves of the pavement

5. CONCLUSIONS

Our investigations have proved that the low-end IMUs are capable of supporting mobile mapping applications. The provided accuracy of such IMU is sufficient for the exterior orientation of the imaging system. Since the NAV420 is equipped with GPS, it is capable of ensuring the absolute location as well, the computed trajectories fit well on the map (Fig 9).

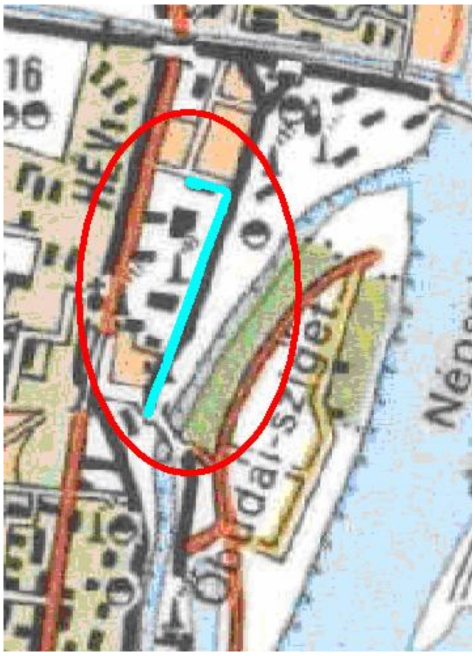


Figure 9. GPS/INS trajectory on map

The 10 meter overall absolute positioning accuracy enables the road section identification, whilst the acquisition rate of the IMUs seems sufficient for the orientation of the image pairs, compensating/tracking the movement of the cameras.
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.

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