CONVERGENCE OF MMS AND PAVEMENT INSPECTION SENSORS FOR COMPLETE ROAD ASSESSMENT

C. Larouche, C. Laflamme, E. McCuaig

a Trimble Navigation Ltd., Ignace St., Suite L, Brossard (QC), J4Y 2P3, Canada clarouche@geo-3d.com, claflamme@geo-3d.com

b Trimble Navigation Ltd., Via de las Dos Castillas, 33, Edificio 7 - 1 Planta, 28224 Pozuelo de Alarcon, Madrid, Spain – eric_mccuaig@trimble.com

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ABSTRACT:
In order to save on road network survey costs, DOT managers and service providers increasingly require that MMS technology and pavement inspection technologies be combined on a single vehicle. These supervans are able to map road side assets, measure road geometry and inspect pavement for roughness and distress characterizations. As most of these functions become automated or semi-automated, the supervan is becoming more of a commodity. Geo-3D Inc., a Trimble Company, develops and commercializes a Mobile Mapping System (MMS) that produces georeferenced sequences of digital images and LIDAR based dense point clouds along road corridors. The addition of pavement inspection sub-systems to its MMS base is now part of its standard product line. This paper focuses on the integration of MMS and pavement inspection sub-systems and discusses the variety of deliverables that can be automatically produced from data acquired with this supervan. Several examples are presented and accuracy considerations are discussed.

1. INTRODUCTION
In order to save on road network survey costs, Department of Transportation (DOT) managers and service providers increasingly require that MMS technology and pavement inspection technologies be combined on a single vehicle. Geo-3D Inc., a Trimble Company, develops and commercializes a Mobile Mapping System (MMS) that produces georeferenced sequences of digital images and LIDAR based dense point clouds along road corridors. This paper focuses on the addition of pavement inspection sensors to regular MMS Sensors to form a complete road assessment system. By collecting the most possible data in a single pass, such systems improve efficiency. The collected data are relevant for asset, pavement and geospatial applications and a wider variety of deliverables can be automatically produced such as:

- Roadside assets inventory
- Pavement markings inventory
- road cross-sections with cross-slope and longitudinal-slope measurements
- mosaics of the road surface either from Line Scan images or rectified frame images
- pavement IRI, rut measurements and distress reporting.

These deliverables are useful for pavement management systems, asset management systems, road safety audits and road rehabilitation projects. Several examples are presented and accuracy considerations are discussed.

2. BASE MOBILE MAPPING SYSTEM
The basic components of the T3D MMS integrate several sensors: navigation sensors (GNSS, INS, DMI), high resolution digital CCD cameras and laser sensors. The system is completed by camera and laser capture software that controls and synchronizes the geospatial data acquisition coming from different sensors (Kingston et al. 2007a, Laflamme et al. 2006). Figure 1 shows a MMS vehicle equipped with 2 digital cameras and 2 laser sensors. The navigation sensors are comprised of an Applanix POS LV, which consists of a GNSS receiver and antennas mounted on specific locations on the roof of the survey vehicle, an Inertial Measurement Unit (IMU) and a precise Distance Measuring Instrument (DMI). An optimal blended navigation solution of all GNSS, IMU and DMI data is obtained through an advanced Kalman Filter. This integration of the GNSS data with the IMU data provides a more robust solution to noise from multipath and GPS outages. The DMI is also used for triggering image captures at fixed distance intervals. Thus, at the end of the survey, images and laser-scanning shots are tagged with appropriate position and orientation information. After proper interior and exterior camera calibrations (Kingston et al. 2007a) and laser sensor alignment (Huber et al. 2008), manual and automatic extraction of road side assets (signs, poles, pavement markings, etc.) can be carried out with the T3D Analyst software. Some results are presented further in this article. Kingston et al. (2007b) have demonstrated the financial and operational benefits as well as an optimal return of investment (ROI) of such base MMS. The following sections explain the advantage of adding other sensors to the MMS and the resulting improved ROI.
3. ADDITION OF PAVEMENT INSPECTION SENSORS

The previous section described the basic components of a MMS that produce georeferenced sequences of digital images and LIDAR based dense point clouds along road corridors. In this section, the addition of pavement inspection sub-systems that produce pavement roughness and distress assessment data as well as rutting data is presented. Pavement roughness can be defined as the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage. Longitudinal profile, transverse profile, distress and IRI (International Roughness Index) are examples of roughness indicators.

The IRI is a filtered ratio of a standard vehicle’s accumulated suspension motion divided by the distance traveled by the vehicle during the measurement. Multiple devices exist to measure IRI but the one selected for the MMS vehicle described in this paper is a system composed of vertical accelerometers and precise 16 kHz point lasers. These devices are installed in a special enclosure called a rut-bar at the very bottom part of the vehicle as shown in Figure 2. A typical setup is to have two laser sensors, one in each wheel path of the vehicle. The accelerometers are used to measure the vertical movement of the rut-bar while the point laser measure the distance between the rut-bar and the pavement. By differentiating the two values, a true longitudinal profile of the pavement is obtained. From the 3D profile, IRI is computed.

Rutting data collection is a means of quantifying how much deviation from the pavement crown is in a vehicle wheel path due to constant traffic and loading on the pavement structure. Heavy rutting is caused by improper design and build of a road as it relates to vehicle travel. Rutting can impact road safety due to the issues with ponding and improper drainage of water. Rutting is measured in rut depth values and can also be used as a surface distress attribute in summarizing an overall pavement condition index. Precise measurements of rutting can be carried out with the sophisticated optical instrumentation installed at the back of the MMS vehicle, the middle sensors, as shown in Figure 2. This is a laser rut measurement system (LRMS) or a transverse profiling device that detects and characterizes pavement rutting (INO, 2008a). The LRMS can acquire full 4-meter wide profiles of a highway lane at normal traffic speeds, with two options for the maximum sampling rate: 30 or 150 Hz. The system uses two laser profilers that digitize transverse sections of the pavement. The system can operate in full daylight or in night-time conditions. Road transverse profile data can be collected and processed in real time on board the vehicle. Rut extraction algorithms have been developed to automatically measure rut depth at an accuracy of 1 mm and width at an accuracy of 3 mm. Figure 3 shows the output that can be produced with these sensors.
pixels. The lasers are used to insure regular illumination of the scene. Figure 4 shows the LRIS configuration and operation.

Figure 4. LRIS Configuration (from INO, 2008b)

4. CONVERGENCE OF BASE MMS AND PAVEMENT INSPECTION SENSORS

Convergence can be defined as the merging of distinct technologies, industries, or devices into a unified whole (Webster’s Dictionary, 2009). In a mobile mapping vehicle, the integration of basic MMS components with pavement inspection sensors allows the collection of converged road assets, pavement and geospatial data. All these data, collected in a single pass, can be processed with modular and automatic information extraction tools such as:

- Sign detection
- Pole detection
- Pavement marking detection
- Crack detection and mapping
- Road geometry calculations
- Corridor clearance calculation
- IRI reporting
- Rutting calculation
- Distress rating.

Figure 5 shows that most of the above applications have been integrated as plugins in the T3D Analyst software, which is powered by a strong photogrammetric engine for accurate georeferencing and measurement.

Figure 5. T3D Analyst Application Plugins

All the above information extraction tools are useful for road managers in their maintenance process of road side assets, pavement condition and other geospatial data, which are detailed in the following sections.

4.1 Roadside Asset Management Process

Roadside asset management is an important subset of an overall Road Asset Management Program, and can be defined as the process by which all assets other than the pavement itself are inventoried, valued and managed by the road owner. Examples of such assets are signs, poles, guiderails, security barriers, stop lights, pavement stripes, bridges, mileposts, etc. All these different asset types can manually be extracted from observations made on imagery through photogrammetric computations (Laflamme et al., 2004 and Kingston et al., 2007). The automatic extraction of some of these assets, such as signs, poles and pavement markings has been made possible with the use of laser sensors, which has been demonstrated in different papers (Kingston and Laflamme, 2007; Kingston et al., 2007 and Laflamme et al., 2006) and integrated in T3D Analyst software as application plugins as seen in Figure 5. Figure 6 shows the T3D Analyst user interface with results obtained with automatic sign detection and recognition tools.

Figure 6. Automatic Sign Detection and Recognition using laser data
4.2 Pavement Management Process

Pavement management, another important subset of an overall Road Asset Management Program, is the process by which maintenance works are planned and optimized through the accurate collection and analysis of pavement condition data. Examples of such data are International Roughness Index (IRI), rutting, cracking, potholes, other surface defects, etc. Figure 3 shows automatic rut extraction information results produced with LRMS sensors as explained in Section 3. It is also possible to automatically extract good pavement assessment information from laser sensor installed horizontally, which scans the surface of the road. Data acquired this way can be used to extract road cross-sections and compute transversal and longitudinal slopes (Huber et al., 2008). By comparing the slopes obtained from laser observations with the ones acquired from a traditional method, accuracy within half a percent (0.5%) was reached. It should be noted that the method in which the laser calculates the road cross section, using the average of a mass number of points, is much more comprehensive than a traditional approach and thus provides a more accurate portrayal of field conditions. As seen in Figure 7, a meaningful modeling of road geometry can be carried out from laser data of road surface and slope information derived from an automatic generation of road cross-sections. A rigorous algorithm for automatic centerline geometry extraction using MMS data is also described in Gikas et al. (2008) and Stratakos et al. (2009). Another interesting tool available in T3D Analyst software is the generation of georeferenced mosaics of line scan images of the road surface as shown in Figure 8. Finally, a plugin is also available to automatically create a report of pavement defects from an inventory of different types of cracks saved in polyline and polygon layers.

4.3 Geospatial Data Management Process

Geospatial data management is the process by which georeferenced vehicle based imagery and laser data is collected to provide data for diverse applications such as 3D city modeling, utilities surveys, DTM, road geometry, road safety, bridge management, 3D point clouds, and vegetation/landscape inventory. Examples of such geospatial applications are discussed in previous sections of the paper, such the automatic road sign detection in Section 4.1, and automatic road geometry reconstruction and mosaicing of road surface in Section 4.2.

Another example is the automatic measurement of bridge vertical clearance from laser data with one of the application plugins, as shown in Figure 9. By comparing vertical measurements obtained with this technique (laser data and T3D Analyst plugin) and those observed with a handheld laser range instrument, an average difference of 1.3 cm has been determined. Note that a sample of 19 manual measurements was observed with the handheld device while hundreds of automatic measurements can be done with the MMS laser dataset. Also, observing vertical measurements with the handheld device presents serious safety issues, especially under highway overpasses which is not the case when the data is collected from a MMS vehicle.
5. CONCLUSION

This paper has presented the integration of basic MMS technology with pavement inspection technologies on a single vehicle. The main advantage of such convergence is the return of investment (ROI) for road managers, users and contractors for the following reasons:

- savings on road network survey costs using an efficient data collection that allows asset, pavement and geospatial data to be acquired in a single pass;
- cost reductions through automated data extraction;
- capital investment amortized over multiple applications;
- optimized budget allocation and maintenance/management decisions; and
- better value for shareholders and taxpayers.

The Mobile Mapping System’s flexible technology and applications evolve and adapt to market requirements to increase productivity, provide users with timely and accurate enterprise data, minimize road crew exposure and create robust information products that serve multiple uses.

REFERENCES


