ROAD ENVIRONMENT MAPPING SYSTEM OF THE FINNISH GEODETIC INSTITUTE - FGI ROAMER -

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ABSTRACT:

The Finnish Geodetic Institute has been developing a mobile road environment mapping system, named as ROAMER, since 2003. The vehicle-borne ROAMER system consists of a carrying platform, positioning and navigation systems, and a 3D data acquisition system. The system employed a 3D laser scanner operated in a profiling mode. The laser scanner can be mounted in several different positions to meet the special needs of some planned applications of the mobile mapping system. In order to be able to accomplish the high automation in 3D modeling, a laser scanner capable to provide dense point clouds was set as the requirement for the system. Additionally, the system is aimed to be a flexible moving laboratory for various road environment applications. The wide field of view and a high point measurement frequency of 120 kHz provided by the laser scanner in use, makes the ROAMER unique. This paper describes the hardware and the navigation solution of the FGI ROAMER. We also discuss the applicability of mobile mapping system in the field of traffic engineering as data source. There is a wide range of laser sensors applicable, as the MMS presented in this paper, but also static laser profilers could be used for real-time traffic flow measurements. This data could be used as input to the MMS based 3D virtual models of the different traffic places to help traffic planners to increase the traffic safety. The detailed 3D models of the transport systems can be used for traffic modeling and traffic simulation systems. In 3D models the interactions between vehicles, pedestrians and bicycles can be examined in high detail. Also the interaction with traffic environment can be studied.

1. INTRODUCTION

Modern transportation planning is becoming an increasingly interactive process between planners, authorities, road users, and private companies requiring more communication between various parties. On the other hand, the traffic systems are becoming more and more complex and difficult to understand as a whole. Thus, more complex modeling techniques are needed, which makes it more difficult to maintain the dialog between involved parties. In many other technology fields, virtual reality and 3D modeling techniques have made it possible to describe complicated systems. However, in the field of transportation engineering, the use of virtual reality and 3D modeling has so far developed slowly. The 3D modeling of a whole city or its transportation system is a time-consuming and expensive process, and road environments are not modelled with accuracy that would provide solutions to transportation engineering. These bottlenecks slow down the use of 3D in road environments and, thus, new solutions are needed for fast and automatic data collection.

The detailed 3D models of the transport systems can be used for traffic modeling and traffic simulation systems. In 3D models the interactions between cars, pedestrians and bicycles can be examined in high detail. Also the interaction with traffic environment can be studied. As an example, the number of vehicle-train accidents in Finland is four times larger than that in other Scandinavian countries. Poor visibility due to vegetation and low density of gates (appr. 20%) are the main reason for these accidents. Virtual reality information in 3D of these interchanges could help in reducing future accidents.

There is also a growing need to improve of the efficiency of urban traffic. It is now recognized that this objective requires not only the improvement of traffic monitoring and management schemes in traffic control centres but also the provision of information services for ordinary road users. New ICT technologies can provide a new source of up-to-date, real-

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time traffic information (time as the fourth dimension). Especially, when the dynamic traffic data is combined with the static model of the city, it is possible to produce new services for drivers and improve the traffic management. Also if computational methods, such as simulation or neural networks are integrated, it is possible to produce short-time predictions of the traffic situation and derive indicators about traffic fluency, safety, economy and environmental aspects.

In transportation engineering, the transport telematics is the most rapidly developing area. Transport telematics is used for collecting traffic data, for processing it and creating new services for driver and authorities (Kulmala, 1995; Kosonen, 1999). Land vehicle navigation has advanced significantly over the past 20 years (El-Sheimy, 1996). First this was largely due to the advancement of navigation and computer related technologies (Krakiwsky, 1991). During that period, land vehicle navigation was known as, or associated with, Automatic Vehicle Location and Navigation (AVLN), Intelligent Vehicle Highway Systems (IVHS), Intelligent Transportation Systems (ITS), and Mobile Mapping Systems (MMS) (El-Sheimy, 1996). The integration of navigation sensors with sighting devices, e.g. digital cameras and laser imaging, extends the application of AVLN systems to inventory and mobile mapping (MMS), some of which are capable of collecting 3D information of the surroundings (El-Sheimy, 1996).

A modern MMS can be today considered as a multi-sensor system that integrates various navigation and data acquisition sensors on a rigid, moving platform (van, car) for determining the positions of the surrounding objects remotely. The navigation sensors typically include GPS (Global Positioning System) receiver and IMU (Inertial Measurement Unit), while in the data acquisition sensors some of the most sophisticated systems use both terrestrial laser scanners and digital cameras or videos. Other possible data acquisition sensors include film cameras, multi-spectral linear scanners, CCD cameras, imaging laser, laser profilers, laser scanners, impulse radar, and ultra sonic sensors depending on the needed information (see e.g. El-Sheimy, 2005 for more details).

Typical requirements for a MMS are that visible objects should be measured with accuracy of few decimetres with a maximum speed of 50-60 km/h and desired objects should be collected at distance of several tens of meters from the sensor. Because of the high costs of the MMS, mainly due to navigation-grade IMU used, the systems are one-off systems that are operated by the companies or institutions that build them. (El-Sheimy, 2005).

Mobile mapping systems have become an independent field of research and a short summary of state-of-the-art of systems can be found in El-Sheimy (2005). He concluded his overview in mobile mapping systems by stating "Considerable work is needed in the areas of real-time and post-mission quality control, automation of GPS/INS integration in case of frequent lock of loss, automatic feature extraction in post mission processing, and the efficient and user-oriented manipulation of extremely large databases."

Recent papers in the MMS field includes El-Sheimy (2005), Clarke (2004), Grejner-Brzezinska and Toth (2003), Habib et al. (2001), Joo et al. (2005), Karimi et al. (2000), Manandhar and Shikbasaki (2001,2002,2003), Reulke and Wehr (2004), Talaya et al (2004), Tao (2001), Tao et al. (2001), Zhang and Xiao (2003), Zhao and Shibasaki (2003ab, 2005).

Finnish Geodetic Institute initiated a MMS development in 2003 with an aim to develop a system that would maximize the automation of feature extraction at the post processing phase. Additionally, the MMS system should be a moving MMS laboratory flexible for various road environment applications. To accomplish the high automation, a laser scanner capable of providing dense point clouds was set as the requirement for the system. This paper describes the hardware of the FGI ROAMER equipment for the first time.

2. MOBILE MAPPING UNIT/PLATFORM

The MMS platform is manufactured of hardened aluminium plates and profile tubes. The base plate is approximately 63 cm in length and width. The height of the scanner origin/mirror is approximately 97.5 cm above the base plate in the normal position, where the scanner is in upright position, and between 36-57 cm when some of the tilted (fixed) positions are used. The tilt angles are 60º, 45º, 30º, and 15º below the horizon of the platform. The design of the MMS/ROAMER integration platform is presented in Figure 1. The total weight of the intended instrumentation and the platform sums up to approximately 40 kg.

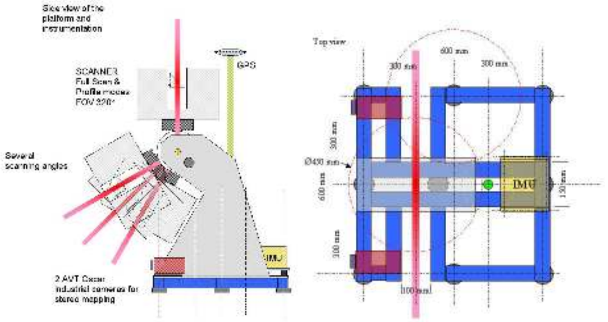

Figure 1. Side and top views of the platform design and instrumentation.

The integration platform is mounted on three standard off-the-self racks designed for the railings on top of the vehicle. Between the rack and the platform there is a suspension layer of nine shock absorption dampers to attenuate vibrations. The idea is to provide a compact and robust platform, isolated from the carrier vehicle, for the instrumentation to be mounted on, as seen in Figure 2.

The GPS antenna is attached on top of a mast in front of the scanner socket/holder. The height of the antenna can be adjusted using mast pieces with known length to avoid unnecessary wobble of the antenna. The root of the antenna mast is made of 30 mm square aluminum profile. The additional antenna mast pieces are at 10, 20 and 30 cm in length and made of 20 mm round aluminum bar.

Figure 2. The ROAMER instrumentation on its first field run. The scanner is tilted to the backward direction.

For the attitude determination of the MMS an inertial measurement unit (IMU) is applied. The IMU unit is mounted on its own rack at the front end of the platform base plate, with a suspension of four additional rubber absorbers. The unit is centered by tight fittings designed for the openings found in its feet. Two aluminium brackets are used to fasten the IMU-unit into its position.

The laser scanner is mounted on a steel socket/holder at the upper end of the instrument arm. The scanner socket can easily be tilted to acquire full scene and profile scans at different scanning angles. Both scanning modes can be utilized, which makes the versatility of the platform unique.

The normal scanner position can be used when structures lying above the lanes, i.e. bridges and traffic signs, have to be included in the model. The normal position is also good for measurements for the building facades and other similar structures, though many of them can be captured also at any of the tilted positions.

The tilted scanner positions are used in the extraction of the road surface. Tilted scanning plane also produces multiple hits even from narrow pole structures usually present on the both sides of the road. This is due to the high profile repetition frequency (scan rate), high point density along the profile, and especially due to the fact that the wide FOV makes it possible to acquire multiple hits from several sequential profiles from an object as the mapping unit passes by, as illustrated in Figure 3. The speed of the vehicle determines the number of profiles sweeping the object in the end.

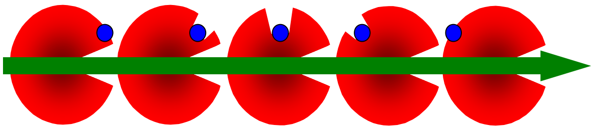

Figure 3. Wide FOV and tilted laser plane produces multiple hits from sequential profiles even from narrow vertical objects (blue circle presents a pole) lying on the side of the road. The height of the hits in each profile gets lower, though, giving a good estimation for the location of the pole.

3. LASER SCANNER SYSTEM

The mobile mapping system utilizes the FARO LS 880HE80 (FARO LS) terrestrial laser scanner for 3D measurements. FARO LS is based on phase difference technique providing high-speed data acquisition. The disadvantage for this is the relatively modest measurement distances ranging in practice up to 30-40 meters. Wide field of view (FOV) and good angular resolution however compensate this. Some of the technical properties of the scanner are summed up in the Table 1. In Figure 4 the modular construction of the FARO LS is presented.

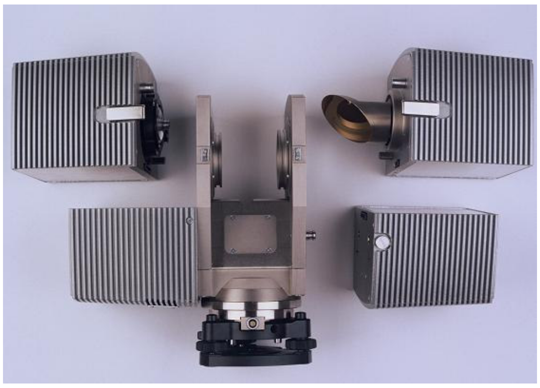

Figure 4. FARO LS 880HE80 terrestrial laser scanner. Top left: the laser ranging unit. Top right: Deflection unit. Bottom right: The data storage unit. Bottom left and center: The scanner electronics and base structure.

Table 1. Technical properties of the FARO LS 880HE80.

Maximum range	~76 m
Measurement rate	120 kHz
Field of view	320°x360°
Beam divergence	0.2 mrad, 3 mm at aperture
Maximum angular resolutions	
Vertical	0.009°
Horizontal	0.00076°
Ranging error	±3 mm, linearity e.
Mirror frequencies	3,6,12,15,24,30 Hz
Temp. limit > 0°C, dry conditions	

With slightly modified hardware, the FARO LS provides a so-called tunnel mode, or profile measurements, with synchronization to be used with external positioning and data logging systems. The deflection unit sends a synchronization pulse for every profile to the navigation hardware to be logged. This information is needed to derive the position and attitude information for each 3D-point produced by the laser scanner.

The mirror rotation frequency, or scan rate of the FARO LS can be set between 3 and 30 Hz, thus giving the vertical angular resolution of 0.0096-0.096 degrees (0.17-1,7 mrad), respectively. The corresponding point spacing at a typical scanning range of 15 meters in road mapping is thus 2.5-25 mm in the scanning plane. More general illustration of the point spacing at a given range and resolution level are summarized in Figure 5. It is seen that the point density is reasonable at any resolution level within the scan profile.

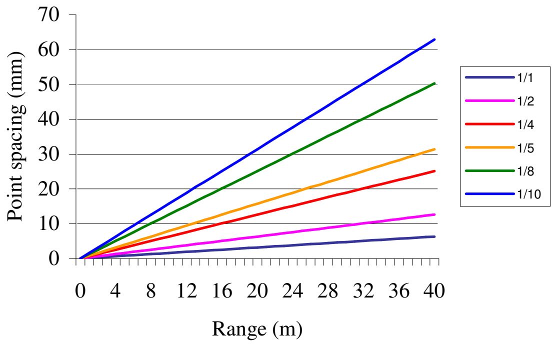

Figure 5. Point spacing at ranges from 0 to 40 meters for different scanning resolutions.

In Figure 6 the achievable along-track distances between two sequential profiles are shown as a function of platform velocity at different scan frequencies. Along-track profile spacing is less than one meter even for the speeds up to 70-80 km/h when high mirror speeds are used. For the platform speeds of 50-60 km/h the profile spacing around one meter is achieved also for the mid-frequencies for the mirror. The resulting point pattern cast on the scene depends on whether the scanner is in the normal or in the tilted position.

In the profile measurement mode the operator can determine the number of profiles to be measured. The number of profiles can be calculated by estimating the time needed for driving the planned route, and according to the selected mirror frequency. The operator can choose to automatically split the accumulating data into separate files of selected size, i.e. the number of profiles.

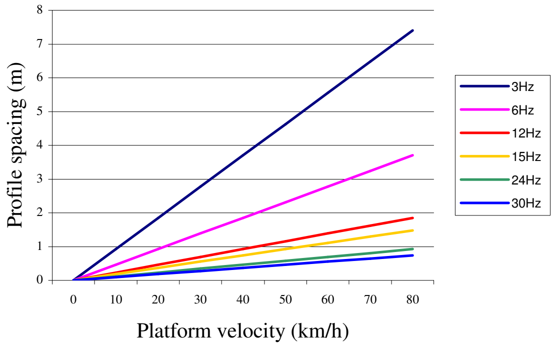

Figure 6. Movement of the scanner origin between two sequential profiles at different scan frequencies and platform velocities.

The operator controls the data recording with an external device. Using this device the operator can pause the data recording, and synchronization signal output, without stopping the scanner mirror rotation. This is useful in situations where the measurement vehicle has to stop due to other traffic, or for example in traffic lights.

Full scans can be used in the so called stop-and-go procedure, where the mapping unit stops to one position to acquire a full scene scan, and then proceeds. Full scene scans are also used for the calibration of the MMS sub-systems to a common coordinate frame. Full scans can be acquired in both normal and tilted positions of the scanner. One full FOV scan at ¼ of the full resolution produces approximately 40 million 3D-points, and an external calibrated digital camera (Nikon D70s) with fisheye lens can be used to produce RGB values for the scan points.

4. NAVIGATION SYSTEM

For orientation of the data acquisition sensors in to the external coordinate system, the instantaneous rotations and the position of the MMS platform is determined by the navigation system. Navigation solution for the MMS is produced by a NovAtel's SPAN (Synchronized Position Attitude Navigation) Technology that integrates GPS and inertial data for applications requiring greater functionality and reliability than traditional stand-alone GPS can offer. The SPAN system also operates in RTK (Real-Time Kinematic) mode with an Internet-based application, named vDiff, developed by the Finnish Geodetic Institute.

Table 2. SPAN's IMU (HG1700 AG11) specifications.

Gyro Input Range	±1000 deg/s
Gyro Rate Bias	1.0 deg/s
Gyro Rate Scale Factor	150 ppm
Angular Random Walk	0.125 deg/hr
Accelerometer Range	±50 g
Accelerometer Linearity	500 ppm
Accelerometer Scale Factor	300 ppm
Accelerometer Bias	1.0 mg

The GPS receiver is a NovAtel DL-4plus, containing the OEM-G2 engine. Additionally, A GPS-702 antenna that offers access to the GPS L1 and L2 frequencies is included. The inertial measurement unit is a tactical-grade, ring laser gyro (RLG)-based IMU manufactured by Honeywell, and its specifications are given in the table 2.

To establish correct navigation solution the offset between the IMU and the GPS antenna phase center should be measured as accurately as possible, preferably within millimeters especially for RTK operations. This is a task to be carried out in the MMS system calibration.

4.1 Results from driving test

To measure the performance of SPAN system in a more realistic setting, data were collected while driving a route of 18 km and the vehicle passed 4 bridges and areas covered by forest that offered possibility to test the solution under full outages. Figure 7 shows the trajectory travelled during the test as calculated for the GPS/INS filter, and for the RTK filter alone, without inertial aid. Table 3 shows the quantified position error during the test for both GPS and GPS/INS solutions.

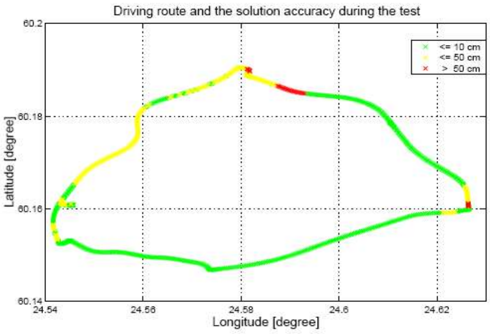

Figure 7. Driving route and solution accuracy during the test.

Table 3. Position Accuracy during the drive test.

Solution type	Positional Error (m)			
	Horizontal		Vertical	
	RMS	Max	RMS	Max
GPS-only	3.765	61.980	4.046	57.102
GPS/INS	0.232	1.043	0.124	0.650

Due to the shadowing of the forests and the passed bridges during the test drive and the instability of GPRS connection, the availability of a GPS-only solution was limited. Table 4 shows the solution availability for the GPS-only and GPS/INS filters, confirming that the addition of inertial data results in more reliable positioning solution.

Under the conditions of this test, the GPS-only solution could be computed for 82,6 percent of the time elapsed. The SPAN combined GPS/INS solution gave 100 percent availability, and from which 60,4 percent was RTK solution.

Table 4. Positioning solution availability during the drive test.

Solution type	Number of epochs	Percentage of solution
GPS-only	925	82,6%
RTK-fixed (GPS-only)	677	60,4%
GPS/INS	1120	100%

4.2 Results from a test with the entire MMS system in a static mode

The research team carried out a field test with all the major components/sensors in Otaniemi, Espoo. Also the SPAN system was involved together with the laser scanner. All the sensors were mounted on the common integration platform. The offset from the GPS antenna to IMU was measured within one-centimeter accuracy. All data were logged from the GPS receiver serial port to a laptop. A Thales ZX-Sensor GPS receiver was setup on the roof of FGI's office building as the reference station. The RTK baseline length was approximately 20 kilometers during the test and GPRS communication was stable.

Data were collected through two test runs in a static mode. When the laser scanner starts, it sends a pulse for each profile via the synchronization device connected to USB port to GPS receiver and a log called MARKPOS is generated and recorded.

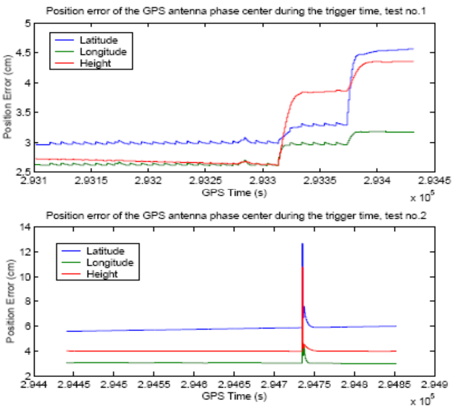

Figure 8. Position Error of the GPS/IMU solutions.

In Figure 8, the upper part shows the results of the first test, while the lower part shows that of the second test. In the second test, a larger error at the epoch between (294735.044 294736.026) occurred because the solution for this epoch was based on the wide-lane ambiguity. Table 5 summarizes the statistics of positioning solutions for the first test and the second test. It can be seen that a standard deviation is far below 2.0 cm.

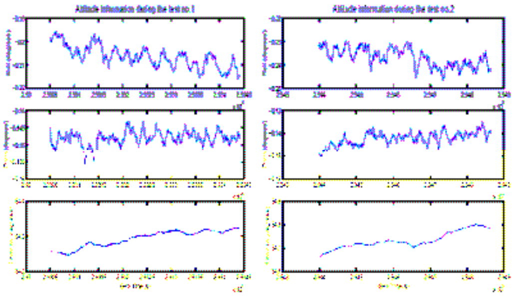

Figure 9. Attitude information of test no. 1 (left column) and test no. 2 (right column).

The INS solution was also initialized before the test start. The attitude information was logged with 1 Hz frequency. During the tests, as it is presented in Figure 9, the variations around the X-axis (roll) and Y-axis (pitch) were quite small within the interval of 0.03 degrees and 0.02 degrees, respectively. Moreover, the azimuth (heading) during the tests is almost constant, the small variation being determined by the Earth rotation around its own axis that are sensed by the IMU.

Table 5. Position of the antenna phase-center during the test.

Stats.	Cartesian coordinates in WGS 84		
	X	Y	Z
	Test no.1		
MIN	2885684.477	1333906.568	5510884.178
MAX	2885684.550	1333906.605	5510884.244
MEAN	2885684.528	1333906.586	5510884.205
STD	0.0150	0.0074	0.0157
	Test no.2		
MIN	2885684.478	1333906.547	5510884.194
MAX	2885684.543	1333906.599	5510884.247
MEAN	2885684.513	1333906.574	5510884.221
STD	0.0117	0.0107	0.0090

5. APPLICABILITY OF MOBILE MAPPING SYSTEM FOR TRAFFIC ENGINEERING, FUTURE ADD-ON'S AND DISCUSSION

In the following, some of the potential applications are delineated.

Industry - The Mobile Mapping System under development can be applied to various applications such as map and GIS database updating, 3-D mapping, virtual reality modeling and highway feature inventory acquisition.

Safety - In Finland there is four times higher number of vehicle-train accidents than in other Scandinavian countries. Poor visibility due to vegetation and low density of gates (appr. 20%) are the main reasons for accidents. Virtual reality information of these interchanges could help in reducing future accidents by showing the danger of these environments to decision makers.

Modeling of the traffic system - The capability of using modern simulation and modeling techniques in transport planning is not so much limited by the models themselves, but due to the difficulties in obtaining the large amount of input data required. The benefits of high computing power and state of the art modeling systems are lost, because the collecting and organizing of the input data is mostly done manually. The need for automatically generated data models of transportation infrastructure is very urgent. The mobile mapping technology can provide a solid solution to the bottleneck of data input.

Traffic simulation - As detailed static models of the traffic system get available the extensive use of microscopic traffic simulation is much more simple and cost effective. This would be a very significant improvement in traffic and infrastructure planning since micro-simulation can provide large scale of traffic indicators regarding traffic fluency, safety, economy and environmental aspects.

Improvement of traffic efficiency - There is also a growing need for measuring of the efficiency of urban traffic. It is possible to measure the traffic efficiency by indicators provided by real-time traffic simulation. This way the present situation can be monitored and compared with past situations in order to figure out trends of effects of traffic improvement and control operations. It is possible to produce short-term prediction for improving the traffic management capabilities.

In real-time simulation, a static model of the traffic site is first needed. For dynamic modeling of the traffic situations, the simulation model is able to digest various sources of traffic information (data fusion). The basic input for real-time simulation are vehicle detectors. However, the problem of using detector data only is the cumulative error in the traffic situation model. Therefore additional sources and an on-line calibration facility are needed. The use of laser scanning in direct measurement of the traffic density and queue length could be a very important new data source. This would be of great advance in development of comprehensive system for real-time modeling of the traffic.

The future hardware development of the MMS will concentrate on the calibration of the sub-systems to a common reference frame. Also, a camera system is planned to be included to the MMS, and it may to consist of two or three AVT Oscar 5 Mpix color cameras. The frame rate at full image size is five frames per second. The synchronization of the camera system to the other instrumentation of the MMS uses TTL signals, and the image data transfer is done via FireWire (IEEE 1394) connection.

One of the cameras may point forward, and will be used to drape the labels captured from the traffic signs to the modeled road environment data. The two other cameras are planned to be used to capture backward looking stereo pairs along-track to provide complementary image measurement power, navigational aid and colour information to the road mapping system.

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