Automatic Road Clearance Surveying with Sensor Fusion

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Abstract

This paper introduces an automatic road clearance surveying (ARCS) method based on sensor fusion. Equipped with laser measurement system (LMS), camera and proprioceptive sensors (IMU and Odometer), this system is very efficient with improved personal safety. The LMS sensors measure surroundings by collecting range and remission data. Range data is processed to build up 3D model of surveyed objectives with position and attitude information from the proprioceptive sensors. Remission data is used for extracting traffic lanes. The lowest points detected within each lane are considered to be the lanes' clearance, and marked on the 3D model. Experimental results of a vehicle mounted prototype demonstrate its performance for automatic road clearance surveying.

1 Introduction

With the development of transportation system, bridges and tunnels become the critical components of modern transportation infrastructure. They improve transportation capability, but make road conditions more complex. Over height vehicles are often involved in bridge strike accidents with serious consequence [Leader, 2011]. Bridges and tunnels have a certain clearance and it is critical to accurately measure and to mark the clearance in order to avoid this kind of accidents. Moreover, during the services life, bridges and tunnels' deformation and road re-pavement could lower the clearance. It is highly demanded to survey road clearance accurately and efficiently.

Traditionally, bridge and tunnel clearance is surveyed manually with rods and other surveying tools. During the process, surveying personnel need to hold rods to measure the height of suspected lowest points, which is inefficient and may introduce human errors to impact the accuracy. This method is not only labour and time consuming but also creates traffic disruption and safety hazard for workers [Waheed and Caya, 2006]. Therefore, a safe and efficient method to survey bridge and tunnel clearance is required, which is the motivation of the proposed research.

The novel ARCS method has been developed with sensor fusion and 3D modelling. Compared to traditional clearance surveying method, which needs a team of about ten members and two hours to survey a single clearance [BDI, 2005], it only requires driving the ARCS system under bridges or tunnels at road speed with little time to deliver accurate results. In addition to measuring the distance from a bridge, tunnel or advance protective barrier (APB) to the road surface, 3D model of surroundings is also produced by the system, which can be used for road condition assessment and asset management.

1.1 Related Work

Laser is one of the most popular sensors for distance measurement because of its accuracy and robustness [Wang et al., 2009]. A couple of approaches for bridge clearance data collection involve using one or two high-frequency point laser sensors at the rear of a vehicle at the upward and downward direction to acquire clearance along a single plumb line [Waheed and Caya, 2006; Kodagoda and Balasuriya; Lauzon, 2000]. Combine laser sensors with ultra-sound sensors is another interesting approach that was proposed by BDI [BDI, 2005]. The sensors take one-point scan and the system is able to perform at high-speed (70mile-per-hour). These approaches exhibit a number of limitations: (i) Bridges, tunnels and APBs may be sloped or have striped structure. Single laser point has little chance to detect the lowest point. (ii) The road surface may also be sloped. (iii) It can only survey a single traffic lane in each run.

2D Laser sensors have been applied for obstacle detection and road-boundary detection etc. [Dunlay, 1998; Cramer, 2002; Wijesoma, 2004]. Laser sensors with remission data acquired can perform road border detection. Saitoh and Kuroda proposed an interesting method of road boundary detection and road curb-tracking. They place a 2D LMS in front of a vehicle scanning forward and use the LMS' range and remission data to extract road surface features [Saitoh and Kuroda, 2010]. However, the speed of the vehicle must be limited to the maximum speed of a LMS (e.g. 10 m/s typical for SICK lasers); otherwise the measure accuracy will be severely degraded [SICK, 2011].

1.2 System Features Highlight

The proposed ARCS system is consist of LMS sensors, camera and IMU, and is able to scan the cross section of bridge and road surface even when vehicle is driving at 70 km/h. A 3D model of bridge or tunnel marked with the lowest point of each lane can be produced soon after surveying. The features of ARCS are listed as below:

- Scan bridge/tunnel cross-section at road speed
- Extract traffic-lanes
- 3D structure modelling

- Automatic determine the minimum height for each traffic lane
- Intense scan on low-height area
- File report with clearance surveying results
- Potential for road condition assessment and asset management.

2 System Design

2.1 System Framework

In order to achieve efficient and robust road clearance surveying, an ARCS system is designed with structure illustrated in Figure 1.

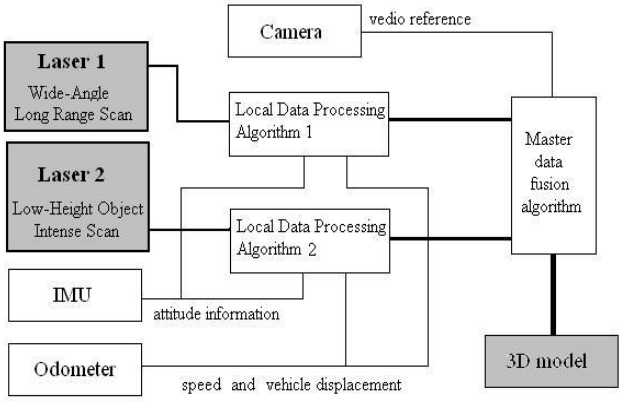

Figure 1, ARCS System Structure

The basic structure of the system was designed in a fashion that laser range measurements are combined with the attitude and position information to construct the 3D model of surveyed objects (bridge/tunnel). Data needed for the surveying includes laser range and remission measurement, IMU and vehicle odometer data. The cross section of surveyed object can be produced by processing the laser range data and IMU data; then the overall 3D model is built by adding information from the vehicle odometer, which gives the travelling distance and the speed.

2.2 Sensors Selection

Laser Measurement System sensors: Two SICK LMS sensors are selected, which are LMS-111 (Laser 1) and LMS-400 (Laser 2). The LMS-111 scanner has a scan angle of 270° with maximum scan frequency of 50Hz. Its scan range is 20m, which is adequate for scanning the cross section of bridges and tunnels. The LMS-400 has a maximum scan frequency of 500Hz with a scan angle of 70° and scan range up to 3m. Its scan frequency was set to 370Hz during the testing in order to achieve a balance of measurement resolution and accuracy.

Both laser sensors are mounted on an aluminium integrated sensors frame (ISF), which is then installed at the back of a vehicle at proper height (2300 mm), for scanning perpendicular to the vehicle moving direction. Due to its wider scan angle, the LMS-111 is on the right side of the frame, which allows it to scan from the left-lane to right-lane for both the ground and overhead objects as driving along the left-lane. Its remission data is also collected for lane detection. The LMS-400 is mounted on the front of the ISF, which takes the full advantages of its fast scan frequency and accurate range measurement to detect smaller objects (such as APBs) whilst the vehicle is travelling at high speed (60-80km/h). Laser sensors geometric configuration is shown in Figure 2. The blue area is the scan area of LMS-111, which is overlapping the scan area of LMS-400 (brown triangle). The relative position of the two LMS sensors is calibrated after they are mounted on the frame.

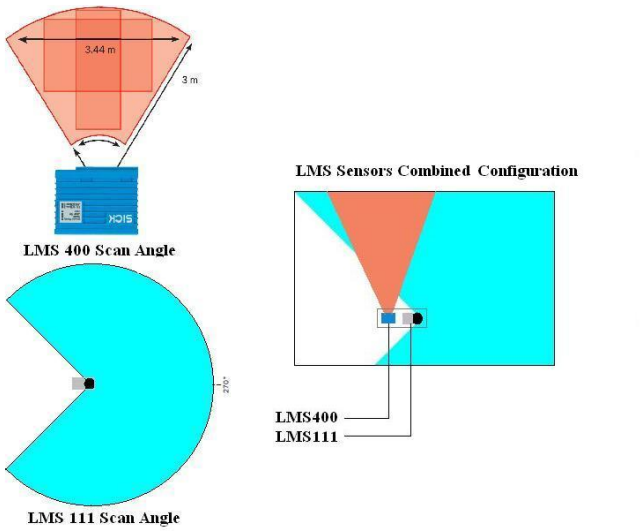

Figure 2, Laser sensors configuration

It is necessary to analysis laser beam diameter expansion against distance. Based on the need of road clearance surveying, the typical range is 2.0-3.0m for LMS-400 and 2.0-7.0m for LMS-111. The expansion of beam means the diameter of individual measured point is expanding with the measuring distance [SICK 2009]. From the LMS-111 manual, the beam expands with distance is given by:

Beam diameter = (distance (mm)*0.015rad) +8mm (1)

The diameter at each distance is given in Table 1.

Table 1, LMS-111 laser beam expansion

Distance(mm)	2000	3000	4000	5000	6000	7000
B-Diameter(mm)	38	53	68	83	98	113

At designed platform height and speed (65km/h), the distance between LMS-111 scans at 50Hz is 361.1mm. Meanwhile, with 0.5 degree interval, it ensures that there is no gap between the scan points; thus the surveying covers whole cross section of the scan angle.

The LMS-400 was configured to choose between two frequencies, 370Hz (default) and 500Hz (maximum). At each frequency, the vehicle moving speed shapes the gap between individual scan, as in Table 2.

Table 2, LMS-400 gap between scans

Speed (km/hr)	45	50	55	60	65	70	75	80
370Hz gap (mm)	33	37	41	45	59	52	56	60
500Hz gap (mm)	25	27	30	33	36	38	41	44

Optimising the vehicle speed is also important for the performance of the surveying system. Although driving

along the left (slow) lane, the vehicle should travel at a reasonable speed that does not interrupt the traffic, while maintain the gap between each LMS scan small. We kept the testing vehicle at 70km/hr in an 80km/hr zone and the gap between each scan is 52 mm. The system is able to detect structure details and obtain accurate measurement at this speed.

Camera: A camera serves as a visual reference guide in the system. The camera will be turned on when surveying object is insight. Any sign with clearance indication will be recorded and compared to the automatic detected road clearance after surveying. Moreover, video recording assists the construction of 3D model, and identifies the ambient interference sources that distort the LMS data.

IMU: An Xsens Mti IMU is mounted on the ISF and used for two purposes. Firstly, it is used for measuring the maximum vibration and shock generated on the ISF while the vehicle driving on the road. This allows monitoring the vibration on sensors as LMS sensors subject to a vibration and shock limit. Secondly, the Euler-angle of the ISF on the testing vehicle during actual surveying is measured by the IMU. This information is critical for transforming 2D laser range measurement into local coordinate system for 3D model construction.

Odometer: Four-wheel vehicle odometer is integrated into the ARCS system to get the vehicle's displacement and speed information. This is used for 3D model construction and clearance point localization. GPS is not used in the system as its performance will degrade under bridges or in tunnels due to satellite signal blockage.

2.3 System Accuracy Analysis

Accuracy is vital to any surveying method, including ARCS, Therefore, accuracy is analysed in detail for the method.

A two-stage accuracy analysis is utilised for the measurement rectification [Weingarten, 2006]. The first stage is the error analysis for the principle of laser range measurement, as shown in Figure 3.

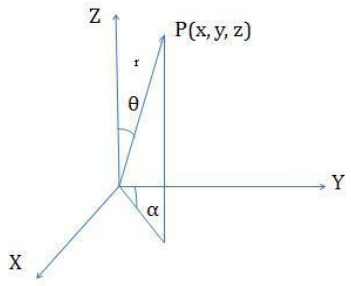

Figure 3, LMS sensors range measurement.

Range (r) is given by the laser sensors, and two angles, α and θ are the horizontal and vertical angles measured by the IMU. Based on this information, the coordinate of P(x, y, z) is given by:

$$\begin{aligned} x &= r\times\sin\theta\times\sin\alpha \\ y &= r\times\sin\theta\times\cos\alpha \\ z &= r\times\cos\theta \end{aligned} \quad (2)$$

The error of range r is decided by the LMS sensor's performance. LMS-111 has a systematic error of ±30mm, and statistical error of 12mm [SICK, 2009]. LMS-400 has a systematic error of ±4mm and statistical error of ±3mm [SICK, 2011]. The error functions are

$$\Delta h = \left(\frac{\partial h}{\partial s}\right)\Delta s + \left(\frac{\partial h}{\partial \vartheta}\right)\Delta\vartheta \quad (3)$$

$$m_h^2 = \left(\frac{\partial h}{\partial s}\right)^2 m_s^2 + \left(\frac{\partial h}{\partial \vartheta}\right)^2 \left(\frac{m_\vartheta}{\rho}\right)^2 \quad (4)$$

Where ρ is a constant of 206265, and $m_s = \pm 3/2 = \pm 1.5$. The accuracy of the coordinate is at ±33mm.

The second stage is the measurement error analysis of the two LMS-sensors installed on ISF. The LMS-400 and LMS-111 are mounted 460mm apart in horizontal direction and 30mm in vertical. Even with much attention during the ISF's manufacture, error is still inevitable. The error affecting the combined surveying accuracy is given by Yu et al. [2002]:

$$\Delta = \sum_{i=1}^{r}\Delta_i \pm \sqrt{\sum_{i=1}^{s} e_i^2 + \sum_{i=1}^{q}\delta_i^2} \quad (5)$$

$$\Delta^2 = \sum_{i=1}^{q}\delta_i^2 \quad (6)$$

Where Δ_i is the known systemic error, e_i is unknown system error and δ_i is random error; r, s, q are the number of errors. The total error based on the calculation is ±29.056mm.

2.4 Surveying Data Acquisition Software

SOPAS is the original software to connect to LMS sensors [SICK, 2009]. However, it is limited functionality for scan data plotting and recording [SICK, 2011]. Based on tests results, SOPAS takes 67 milliseconds to record each scan data, which is roughly 15 Hz. Compared to the 50 Hz scan frequency of LMS-111 and 370 Hz of LMS-400, SOPAS's recording rate is very limited. Therefore, we developed a graphic user interface (GUI) for the sensors control and data acquisition. It has multi functions, such as configuring LMS scan frequency, scan resolution, recording scan data, LMS-111 and LMS-400 calibration and exporting recorded data into MATLAB .mat file.

The function of real-time scan plotting allows us to monitor the scan of complex structure and make sure that small objects are not missed. Moreover, the travelling speed of testing vehicle can be optimised by judging from the plot result.

This data acquisition software is constructed based on the Java Socket Communication. Ethernet other than RS-232 connections were used to prevent data losses. The GUI utilises the LMS COLA-B protocol to transmit binary coded messages, and maximises the communication speed [SICK, 2011]. The binary messages are then converted into decimal and stored into .mat files. The .mat files can be processed directly in the following Data Processing Algorithm (DPA) developed with MARLAB.

3 Data Processing Algorithm

Recorded scan data, IMU data, together with sensors' configuration parameters, such as scan resolution and frequency, are processed in the DPA. A 3D model of the scanned objects will be constructed with the lowest points marked for each lane. The calculated height of lowest

point that ARCS detected is then compared to the height which displayed on the clearance sign captured by the camera. The flowchart of the 3D model extraction is shown in Figure 4.

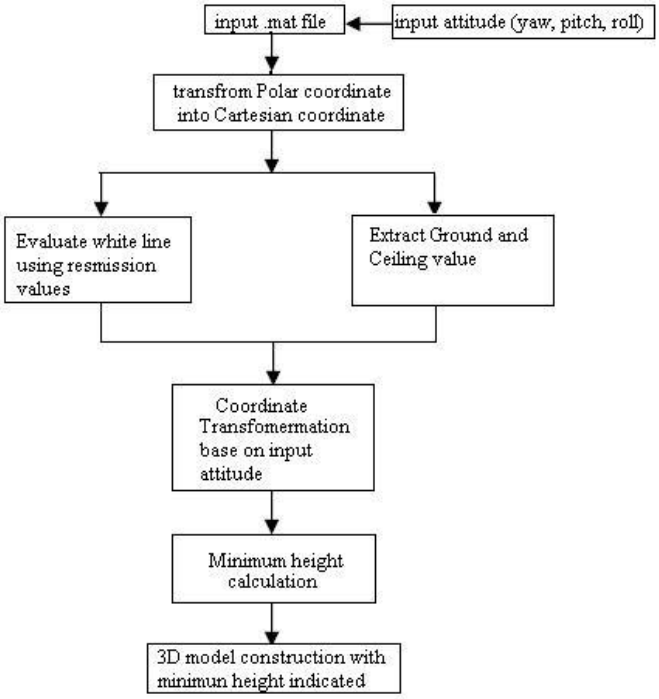

Figure 4, DPA flow-chart

Sensors Data Association: LMS data and IMU data are acquired from different sensors at different frequencies. In our case, LMS-111 is set at scan frequency of 50Hz, LMS-400 is at 370Hz and Mti IMU is at 250Hz. Data synchronisation can be achieved by real-time hardware approach or software post processing with the recorded data [Wang et al., 2009]. For simpler algorithm and cost-efficiency of the system, our data synchronisation is performed after surveying. Mti IMU sensor data is processed by taking every five data, which is used for LMS-111 scan data coordinates transformation.

Scan data coordinates transformation: Scan data was recorded in .mat format and each scan with a timestamp. The scan data includes the scan angle (α), range (r) and remission measurements. The x and y value of the corresponding point in Cartesian coordinate is transferred as follows:

Algorithm 1: Individual Laser Measurement

1. Work out LMS111 scan angle: starts from -135 to +135 degree (Figure 2), with 0.5 degree interval. It can be expressed as follow:

   $\alpha = -0.75\pi : \pi / (180\times 2) : 0.75\pi$;

2. Transform the polar coordinate into Cartesian coordinate:

   $x = r\times\cos(\alpha)$; $y = r\times\sin(\alpha)$;

During on-road surveying, the sensors' attitude changes time to time. This will affect the accuracy of road clearance surveying if the changes were not counted. Therefore, measurement from the IMU is integrated into the data processing algorithm for attitude calculation.

After combining the pitch-roll-yaw motions matrix together, a rotation matrix is produced which gives the transformation of scan data based on the IMU measurement [Steven, 2006]:

$$R(\alpha,\beta,\gamma) = Rz(\alpha)Ry(\beta)Rx(\gamma) \quad (8)$$

Traffic lane feature extraction: The significance of traffic lane extraction is to indicate the minimum height of each traffic lane on the road. Road surfaces are not perfectly level and the clearance of each lane may vary. Extracting traffic lane could improve road safety by instructing high vehicles (trucks, double deck buses) to use lanes with higher clearance. Furthermore, extracted traffic lanes define the road boundary, which is used to filter out unwanted structure measurements outside the road. Generally, traffic lines are painted in white, which has higher remission value than the road surface [Lakshmanan and Hero, 2000]. From the scan results, white lines with higher-remission value are distinctive from road surface, shown in Figure 5, which is used to extract traffic lanes.

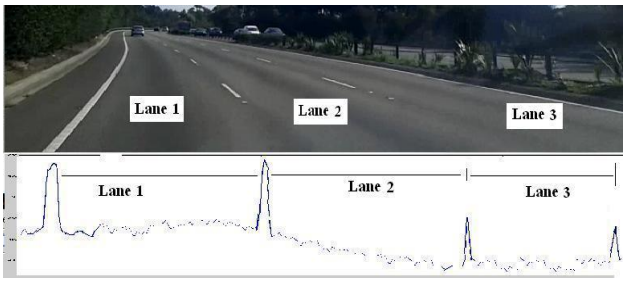

Figure 5, Remission values of traffic lines

Road surface conditions could be complex and noisy. Water, oil, pieces of debris that have high remission values make the process of traffic lanes extraction much more challenging than that in ideal case. Therefore, we designed two stage mechanisms for robust and reliable traffic lane extraction. Based on the analysis of recorded scan data, the remission value of white lines is associated with distance of the LMS. Farther white lines appears to have lower remission value, but still distinctive from its surrounding road surface.

Stage one involves searching for the peak remission points by taking Remission Value Ratio (RVR):

$$\mathrm{RVR} = \frac{Rem(i+1)-Rem(i)}{Rem(i+1)};\ 1 \le i \le 541 \quad (9)$$

Each LMS-111 scan contains 541 remission values, and i in (9) is the number of scan points. The RVR is positive when the remission value is increasing, and negative when decreasing. Rapid changing of RVR is a sign of white line. Threshold value of RVR is defined at $\pm R_{th}$. The candidates of white lines must satisfy the condition below:

$$\begin{cases} RVR \ge +R_{th};\ left\ edge\ of\ white\ line \\ RVR \le -R_{th};\ right\ edge\ of\ white\ line \end{cases} \quad (10)$$

The stage two involves filtering out the interference objects and plots the real white lines. The width of potential white line can be calculated with the number of scan between the left edge and right edge. Traffic lanes width is designed to be 3.5m in urban environment [AUSTROADS, 2003]. Therefore, unwanted objects that have high remission value can be filtered out by fitting a distance selector. Only the objects with distance within a boundary are considered to be white lines, where n is the number of traffic lanes:

$$3.450m \times n \leq Dist \leq 3.650m \times n; \quad (11)$$

Minimum clearance extraction: LMS-111 scans both the over head structure and the ground. Combined with the IMU data, a cross-section plot is built perpendicular to the ground. Both LMS-111 and LMS-400 data are plotted in the same coordinate system and interpolation of the data is performed if necessary. LMS-111 data is processed for the cross-section build-up and 3D modelling, whilst LMS-400's more intense scans are used for a detailed surveying of the minimum height and lower height structure inspection. Then the clearance of each lane in a single cross-section is detected by finding the minimum distance between the points of road surface and the corresponding ones of over head structure. The final road clearance of each lane is the minimum one of the values of all the cross-sections scaned. To make the clearance surveying reliable and effective, only the minimum height presented within the boundary of traffic lanes is extracted.

Most tunnels in NSW are between 4.4m to 4.6m, and bridges are slightly higher, at 5.1m to 5.3m [RTA, 2011a, b]. LMS-400 has a maximum range measurement of 3.0m; it was designed to scan upward (see Figure 2). As the ISF was mounted at the height of about 2.3m, LMS-400 is able to scan objects in details with height up to 5.3m.

As shown in Figure 6, both LMS-111 and LMS-400 scaned a section of a structure. The minimum clearance LMS-111 gives is 4.53m at 19.93m inwards and 1.20m to the left boundary (inside the traffic lane). The LMS-400 gives detailed plot of low-height structure, and locates the minimum height is 4.53m at 19.91m inwards and 1.21m to the left boundary. Considering the system requirement and noise involved in the surveying practice, above results are acceptable as the clearance of the structure surveyed.

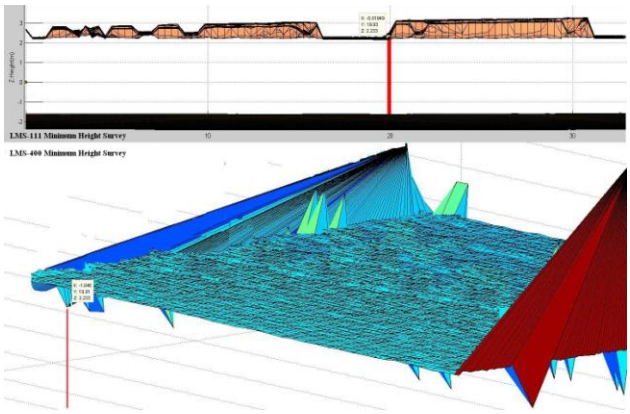

Figure 6, Compare minimum clearance surveying between LMS-111 (up), and LMS-400 (below)

3D model construction: After successfully achieved sensors data association and coordinates transformation, traffic lanes extraction and minimum clearance extraction, 3D model is constructed based on the processing results. The lowest clearance point of each lane is indicated in the 3D model and presented in the DPA GUI. The 3D model delivers the most intuitional profile of surveyed objects, and includes lines on the road surface and the location of clearance points. The 3D model could also provide valuable information for the asset (bridge/tunnel) maintenance.

4. ISF Calibration

The ISF was designed in such way that the centres of LMS-111 and LMS-400 460mm are apart horizontally and 30mm vertically, and their scan planes are parallel, as shown in Figure 7. Calibration is necessary for correcting the machine and human error during the ISF fabrication and sensors installation.

Two calibrations were conducted for the assembled ISF, the scan-centre alignment and the parallel scan plane calibration. The first calibration is to determinate exactly how far the centres are apart from each other. During the process of calibration, both LMS sensors are pointing at an object that has uniform surface at a given distance. The scan data are plotted by the data acquisition GUI software mentioned earlier. The initial plots suggests that even with the offset (640mm, 30mm) added to the system, the plot gap between LMS-111 and LMS-400 is still at (8mm, 3.5mm). Therefore, the calibration result shows that displacement between LMS-111 and LMS-400 centres is to (648mm, 33.5mm), which will be used in the scan data transformation.

Figure 7, Front and rear view of ISF

The calibration of the two scan planes' parallel was conducted after the centre alignment. With both LMS sensors mounted on the ISF, LMS-400 is kept to scan vertically by adjusting the base according to its visible laser. Then the calibration is to adjust the LMS-111 scan plane free of lean and at the same orientation as LMS-400 scan plane.

Let the sensors scan a structure overhead with a straight edge at a range of 3m. LMS-111 is scanning along the edge to ensure that its scan plane is aligned with the edge. Minor adjustment was conducted to keep the distance between the edge and the visible line of LMS-400's laser projection consistent. The same process was repeated when the range was changed to 1.5m. The distance measured at the two ranges should be same; otherwise adjustment is needed to achieve this. All these processes can ensure that both LMS sensors' scan planes are parallel. After the ISF calibration, on-road test was conducted for measuring its shock and vibration.

5. Shock and Vibration Test

Weighted more than 5 kilograms and mounted 2.3m above the ground on a moving vehicle, the ISF on a beam may have serious shock and vibration that is potential to exceed the LMS sensors' limitation and cause hazard consequence.

Figure 8 shows the ISF and the testing vehicle. The ISF is mounted a vertical steel beam fixed to the tow-bar of a pick-up track, a horizontal triangle supporting frame is added to strengthen the mounting structure as well as minimise vibration. Based on the LMS-111 and LMS-400 manual, the maximum single shock to the sensors is 15g, and vibration is 5g over a frequency range of 50Hz to 150Hz [SICK, 2009; SICK, 2011]. Shock and vibration not only affect the accuracy of the measurement, but also may damage the LMS sensors.

Shock and vibration test was conducted with the LMS sensors unpowered, to see if any countermeasure is required to protect the LMS sensors. By doing so, all sensors were mounted to the ISF as shown in Figure 7, but only the IMU sensor is powered during the test. The IMU measured the ISF's shock and vibration over various road surface conditions. The vehicle was driven on the road at 60km/h for about 45 minutes.

IMU data was analysed and the conclusion was that the maximum shock/vibration on either X, Y, Z direction is under 2g, which is well under the specified maximum value.

6. Surveying and Analysis

Confirmed satisfying the requirement of LMS sensors working condition, the vehicle mounted ARCS system went for a trial surveying in urban environment. Onboard computer records the LMS sensors data and IMU data, a camera is attached to the windscreen. We selected the routes along the Southern Cross Drive/Eastern Distributor Motorway, Sydney. There are several bridges and tunnels with marked clearance.

Figure 8, ISF and testing vehicle assembly

Tunnel Surveying: The first on-road surveying trial was conducted on 22 August, 2011. The tunnel on the Eastern Distributor Motorway was surveyed. There is an APB before the entrance of the tunnel with marked clearance 4.4m, as shown in Figure 9. We surveyed both the APB and the tunnel. The reason to survey the APB is to check if the clearance of the protective barrier is as the sign indicated, and then to compare it to the actual tunnel clearance.

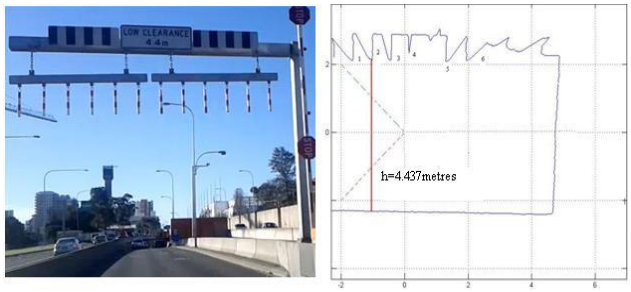

Figure 9, APB cross-section

The cross-section plot in Figure 9 shows that the surveyed minimum height of the APB is 4.43m, which matches the marked clearance, and this result was consistent between the two LMS sensors. Also note that in the actual APB has twelve hanging poles, however, only six poles are clearly plotted in the cross section scan. The reason is that some poles block the others from the vision of LMS sensors, and not all of them are in the same plane that parallels to the scan plane. This phenomenon should not impact on the accuracy of APB surveying, as lower poles are accurately surveyed. It is noticed that although the width of the road is for two lanes, there is no lane separation marks on the road. Therefor the DPA GUI treats this road as a single lane.

The tunnel surveying result is shown in Figure 10. The tunnel entrance starts at right side in Figure 10a. According to the IMU measurements, the tunnel is descending and then ascending. The measured length of the tunnel is 465.23m. There are two lanes in the tunnel, and two individual clearances are extracted from the surveying data. The thin white line in Figure 10a represents the actual white line in the middle of road that separates the two traffic lanes.

Two cross-section plots in the DPA GUI present the two sections that minimum clearance is measured for each lane. Figure 10b shows the details of cross section plot at the clearance point of the right lane on the right, and a photo of the tunnel on the left. A red line in the figure points out the bulge that causes the minimum clearance and its relative position on the ground.

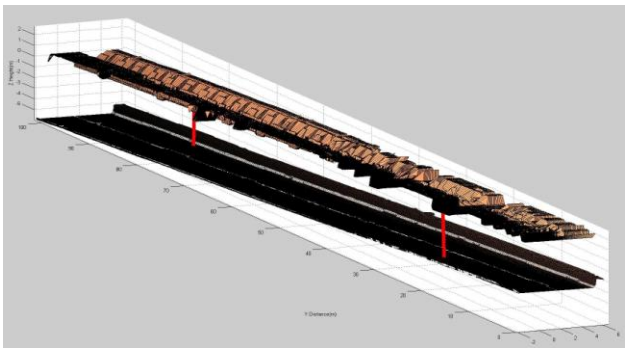

Figure 10a, Clearance marked on both lanes

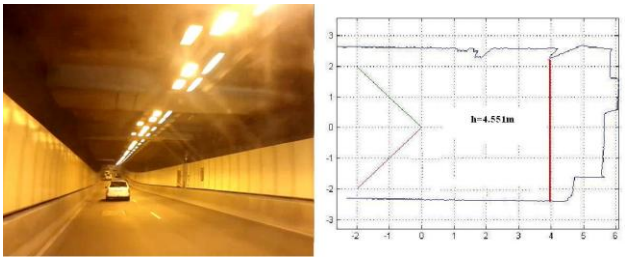

Figure 10b, Tunnel cross section photo and plot

The surveying results show that the minimum clearance of left lane is 4.54m. It is located at the point 19.93m from the entrance and 1.81m from the road left border. The minimum clearance of right lane is 4.55m, and located at the point 82.60m from the entrance and 6.23m from the road left border.

The surveying results show that the marked clearance of APB with 4.4m is consistent with the surveyed result. The tunnel's clearance is 4.54m on the left lane and 4.55m on the right lane. Although the surveyed clearance of tunnel is slightly higher than the sign marked 4.4m, it is safe for vehicle under 4.4m to pass.

Bridge Surveying: Several bridges were surveyed during the test. This is a pedestrian bridge over the Southern Cross Drive, Sydney, with a marked height of 5.1m, as shown in Figure 11 on the left. This section of road has three lanes, and each lane has a slightly different clearance. The 3D model of the surveying result is shown in Figure 12.

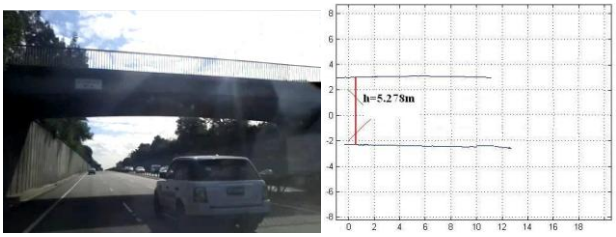

Figure 11, Pedestrian bridge cross-section

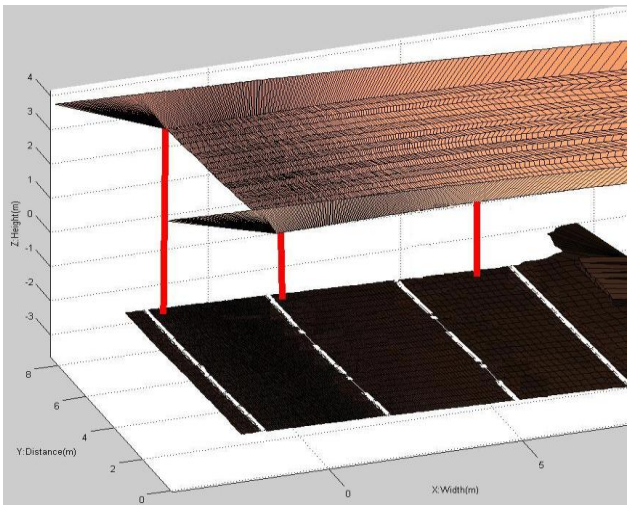

Figure12, Pedestrian Bridge surveying result

The measured clearance of left lane is 5.28m, at the point of 7.99m from the beginning of the bridge and 0.88m from the left border. For the middle lane, the clearance is 5.42m, at 7.99m from the beginning and 3.94m from the left border. The clearance of right lane is 5.35m, at 7.64m from the beginning and 7.04m from the left border.

Note that in the clearance cross-section plot (Figure 11 right), only half of the bridge can be plotted so as measurable by the LMA sensors. This is due to the fact that the LMS sensors could only pick up 10m range with 13% remission value [SICK, 2009].

Although the surveyed clearance is slightly over the marked one, it is considered to be reasonable. Considering the vehicle height changing moving, it is necessary to keep the actual road clearance higher than it is indicated, and to ensure vehicles up to the height-limit driving through safely.

7. Conclusion

This paper introduces a novel method for automatic road clearance surveying, and demonstrated the capability and robustness of a prototype ARCS system. It gives road maintainers the power to survey road clearance without tense labour and disrupting traffic. With sensors fusion technologies and data processing algorithms, 3D models of bridge and tunnel marked with the lowest point of each lane are constructed. Even under ambient interference, surveying data still can be processed to obtain road clearance result. Moreover, the ARCS is adapted with modular design, new components can be added into the system easily.

This research demonstrates that the proposed ARCS method is capable of surveying road clearance efficiently. It can supplant current traditional surveying method where large group of labours are involved.

As a novel surveying technology, however, the ARCS still has some limitations. For example, current system cannot function properly under extreme weather condition, changing lane or sudden acceleration/braking. Incorrect or inaccurate measurement may be acquired under such circumstances.

There are much potential that ARCS system could be improved. A GPS, IMU and Odometer integrated navigation system will provide much better position and attitude information to improve the system performance. Cooperation with roads and traffic authority is expected to test the system for robustness and feasibility evaluation.

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