A New Method for Validating Mobile Laser Scanning (MLS) Corridor Surveys

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ABSTRACT

The introduction of Mobile Laser Scanning (MLS) in 2009 changed the approach to corridor surveys. The method has become popular as the data is collected quickly, accurately and safely. In addition, a huge swath of data is collected, enabling the whole corridor to be measured including the complete road surface. The nature of MLS lends itself to a range of road survey applications, including engineering survey for widenings, asset capture, road subsidence monitoring and clash detection. Since the introduction of MLS to the survey market, a couple of different approaches for data collection and processing have emerged. The Multi-Target (MT) approach was developed by scanner manufacturers and has been adopted by many road agencies around the world. In 2009, McMullen Nolan Group (MNG) introduced the Multi-Pass (MP) approach, which is based on survey principles and addresses some of the inherent disadvantages of Multi-Target. This paper uses two recent project examples to demonstrate some advantages of using Multi-Pass MLS. The data presented demonstrate the ability for MP MLS to be used to identify any issues with the target control coordinates, validate MLS road corridor models and detect small changes in a road corridor for the purpose of identifying areas of subsidence or change. The paper then discusses the implications of these findings for both MLS corridor model validation surveys and subsidence monitoring surveys.

KEYWORDS: *Survey model validation, multi-pass MLS, laser scanning.*

1 INTRODUCTION

Mobile Laser Scanning (MLS) was first introduced in Australia in 2009. All aspects of the technology (field collection, scanners, data processing) continue to develop and improve rapidly. Scanning is now applied to many corridor surveys and is leading the way into areas such as high-accuracy asset management and Building Information Modelling (BIM).

Over the years, two different approaches have been developed in the market for processing of MLS data along corridors:

- The Multi-Target (MT) approach was developed by many of the scanner manufacturers, which required the scanned data to be 'draped' over a rigorous survey control network. This method has become the standard for MLS surveys and has been adopted by many road authorities around the world (Caltrans, 2011; Olsen et al., 2013).

- The Multi-Pass (MP) approach was developed by McMullen Nolan Group (MNG). This approach consists of a data collection methodology as well as a processing strategy. It relies on the inherent strength of collecting redundant data to both identify outliers and improve the accuracy of the survey. The MP approach incorporates a 'self-checking accuracy system' that identifies any weaknesses in any of the survey components, whether they arise from the control coordinates and targets locations or from the scan itself (Eckels and Nolan, 2013).

MNG has been promoting the use of the MP approach for many years. We have talked about the 'theoretical' advantages of the approach – without being able to demonstrate using field data. Recently, MNG has been involved in two surveys that have enabled us to compare the MT approach to the MP approach based on real data.

This paper discusses the datasets and demonstrates how:

- MP MLS can identify errors in a control survey (that incorporates survey control and targets).
- MP MLS can find errors the original scanning survey (that were not identified using current model validation approaches).

The paper provides a summary overview of the MT and MP approaches to MLS field methodology and processing. It then investigates the two different datasets and discusses the results that were achieved. The implications of these findings on MLS road corridor surveys are then discussed in regards to:

- Control requirements – checking existing control.
- Target separation.
- Subsidence or monitoring surveys.
- MLS validation surveys.

2 REVIEW OF MLS APPROACHES

MLS is a complicated measurement process that involves a combination of scanning and imagery sensors that are mounted on a moving platform. The orientation and relative position of all the measurement sensors must be known, and the trajectory of the moving platform has to be determined to 'survey' accuracy (i.e. ±15 mm).

Many of the error sources can be minimised, measured or eliminated through an equipment calibration process (Glennie, 2007). After calibration is complete, the largest error sources that affect the accuracy of the point cloud are the positioning errors of the moving platform. The moving platform (whether it be a car, hi-rail vehicle, aircraft or boat) is positioned using both Global Navigation Satellite System (GNSS) observations and an Inertial Measurement Unit (IMU). GNSS positioning takes the form of a kinematic solution based on dual-frequency carrier phase measurements. GNSS base stations are established along the route to enable a carrier phase solution (resolved ambiguities) to be calculated each second (1 Hz). The attitude of the platform (pitch, roll and yaw) as well as its trajectory is provided by the IMU at 200 Hz, which directly measures bumps in the road and the platform position when satellite blockages occur (e.g. caused by bridges).

The errors that affect the position of the platform are related to standard GNSS measurements and comprise multipath effects and errors associated with changes in satellite configuration (satellites rising and setting). The magnitude of the errors from satellite sources can easily be ±3 cm (Figure 1), which is higher than required for engineering surveys (Schön and Dilßner, 2007).

Figure 1: Satellite errors affecting kinematic GNSS.

A key challenge for all MLS users is to minimise or eliminate these positioning errors. To this end, two different approaches have been developed. These are known as the Multi-Target (MT) approach and the Multi-Pass (MP) approach.

2.1 Multi-Target Approach

The Multi-Target (MT) approach assumes that the trajectory of the platform cannot be determined accurately from the kinematic GNSS measurements and therefore needs to be monitored (Caltrans, 2011). Using MT, multiple targets are established along the corridor. Comparing the 'surveyed' coordinates of these targets with the measured coordinates (from the scan) enables the operator to monitor the drift and position of the scanner at regular intervals. The scan data can then be corrected and adjusted by 'pinning' it to the established control. The scan data is completely dependent on the control survey and can be imagined to be 'draped' over it.

MT requires that multiple targets be established along the corridor. These targets need to be incorporated in a survey control network that is connected to the surrounding, previously established control (Figure 2). It is recognised that the closer the target spacing, the more accurate the expected result (Soininen, 2012).

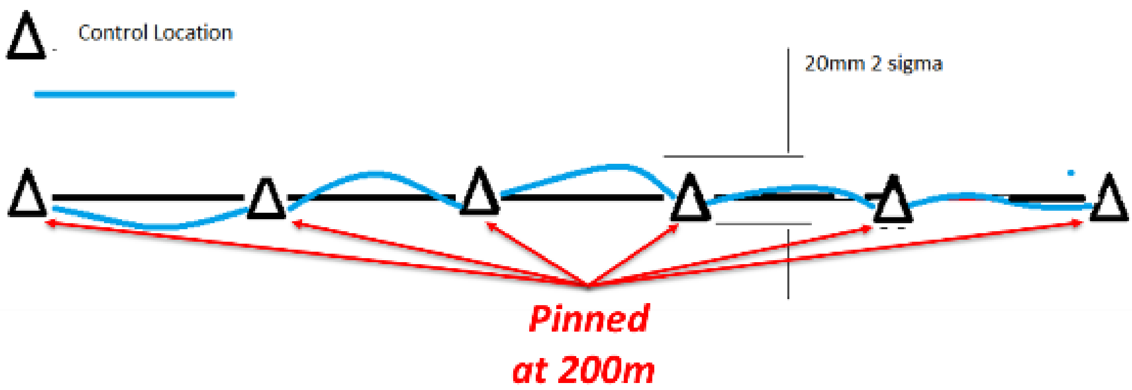

Figure 2: Multi-target approach to MLS.

One disadvantage of the MT approach is that surveyors are required to work along the corridor shoulder to establish the targets. This process often requires night work and closed lanes to ensure the safety of the survey party. Establishing targets can be time-consuming and significantly add to the cost of the job.

However, there are also some inherent dangers in the MT approach that can be very difficult to eliminate:

- Any errors in the control survey target coordinates will translate directly into the final scan surface.
- Satellite positioning errors can still occur between the targets.

2.2 Multi-Pass Approach

The Multi-Pass (MP) approach to MLS scanning creates a survey-accurate trajectory from independent measurements along a corridor. This trajectory is used to create the scan model of the corridor. Target points are required to monitor the accuracy of the scanned model and to transform the data into the local reference system.

The key to this approach is the determination of an 'averaged' trajectory (Figure 3). Each measurement epoch consists of both the GNSS trajectory (subject to satellite errors) and the scan data itself. When one measurement is compared to another, it is assumed that any differences in the results are due to satellite errors – as the road surface itself would not have moved (Eckels and Nolan, 2013).

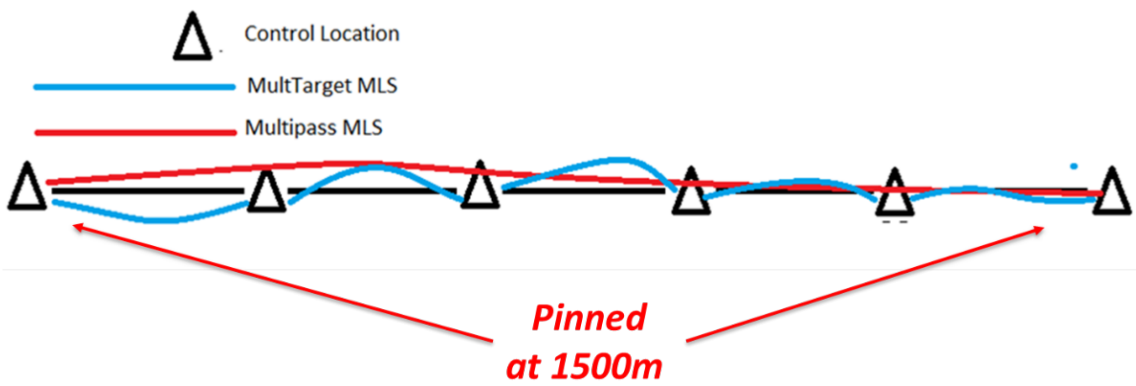

Figure 3: Multi-pass approach compared to multi-target approach.

Using MP, each corridor is measured multiple times. Each of these measurements is subject to a different set of satellite errors. The individual measurements can be plotted on a graph, which provides immediate feedback as to the quality of the data:

- If all trajectory lines are smooth and close together, the data quality is good (open road – few obstructions).
- If the trajectory lines vary greatly and separate, the data quality may be poor (when GNSS coverage is bad – GNSS obstructed corridors, tunnels, etc.).

Inspection of the plotted graph allows easy identification of outliers (bad GNSS runs), which can be omitted from further processing. The strength of MP results from combining and averaging all the runs, as the accuracy of the combined measurements is increased. The 'internal' accuracy (without considering control) can be determined, and has been found to be ±15 mm, which is an excellent result for data derived from kinematic GNSS.

The advantages of this approach are:

- It provides a 'survey-grade' measurement of the trajectory of the averaged scan. This can be compared to the coordinates of the targets (to identify targets).
- Large positioning errors caused by multipath and changes in satellite configuration are minimised as they are averaged out over multiple independent measurements.

MNG developed MP when it entered the market in 2009 and has been promoting its advantages since. From our own internal data, we have seen the errors that may occur from using single MLS runs. Recently, however, we have had an opportunity to compare some MP data to previously collected MT data and inspect the differences. We have found some interesting results, which are described in the following section.

3 DATASETS FOR REVIEW

In 2015, MNG participated in MLS surveys where MT MLS data was available. This was the first opportunity to compare the results of a MT and MP MLS survey. This section outlines the review of two such surveys performed in Australia and the United States.

3.1 Australian Dataset

The Australian dataset involved a test to monitor possible subsidence in a motorway around Sydney. The aim of the survey was to show how MP can be used to provide regular, ongoing monitoring of a road corridor to identify and quantify any movement in the road surface. This application highlights one powerful application of MLS technology.

The first dataset was collected using MT:

- A control survey was undertaken to validate the survey control coordinates around the motorway.
- Targets were placed every 150 m on both sides of the carriageway. Every second target was used to 'pin' the MLS data to the control, while the alternative targets were used in the validation survey.
- MLS data was collected and processed – this formed 'epoch 0' of the subsidence survey.

Approximately 6 months later, MNG surveyed the same section using MP:

- 16 passes of data were collected.
- Every 10th target was used (every 1,500 m) to 'pin' the survey.
- Data was processed and compared to the original survey.

Data analysis comprised two tests, i.e. the analysis of target coordinates and the comparison of the point clouds.

3.1.1 Analysis of Target Coordinates

As already mentioned, we used every 10th target for the MP approach, spaced at approximately 1,500 m. The first task was to compare the coordinates of all the intermediate targets to the coordinates generated from the MP scan. The results are shown in Figure 4. The maximum difference was 12 mm and the standard deviation 5 mm. It should be noted that these differences include errors in both the original traditional 'control' survey and in the MP survey.

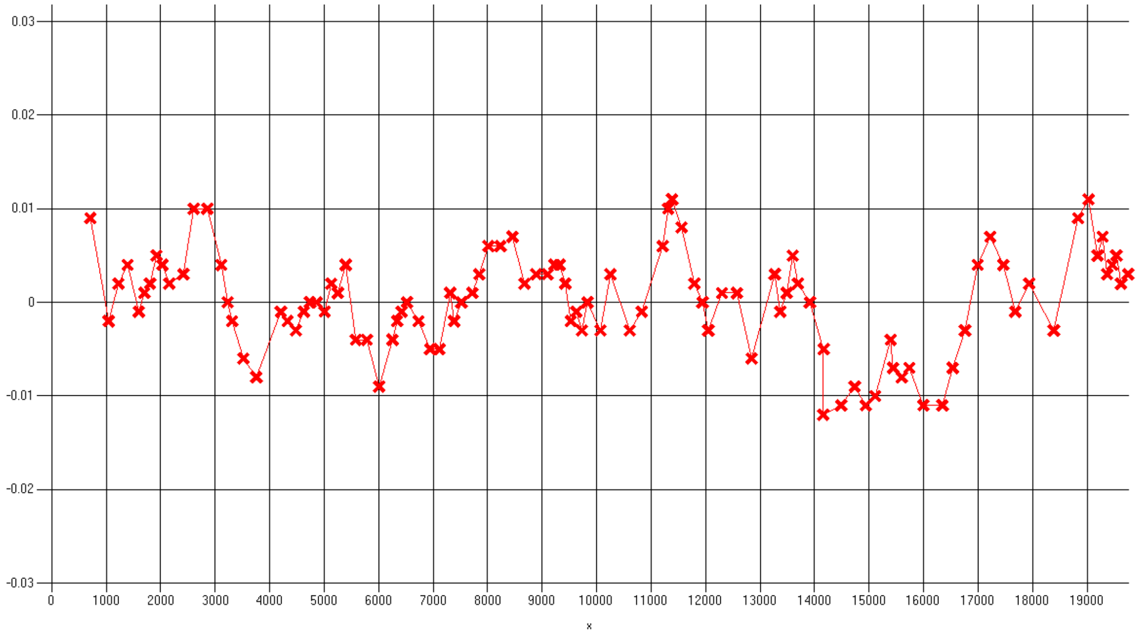

Figure 4: Target coordinates compared with MP values (values in metres).

These results indicate that the MP survey is equivalent to the accuracy of the survey control. Figure 4 also indicates that the control coordinates of all the targets were within expected tolerance.

3.1.2 Comparison of the Point Clouds

In order to compare the accuracy of the point clouds, surface points were extracted every 10 m along the centreline of each of the point clouds and compared. The maximum difference between these extracted points was 31 mm, with a standard deviation of 7 mm. This larger error appears to be due to some aberrations between some control points. Let us examine two of these aberrations.

Data Comparison 1

In this example, it appears that there is a significant deviation between the scanned surfaces (Figure 5). An image of this section is provided in Figure 6.

After some discussion, it was determined that this section of the motorway had been re-surfaced after the initial scan. The MP scan was able to measure the change in height of the road section and the extent of the re-surfacing.

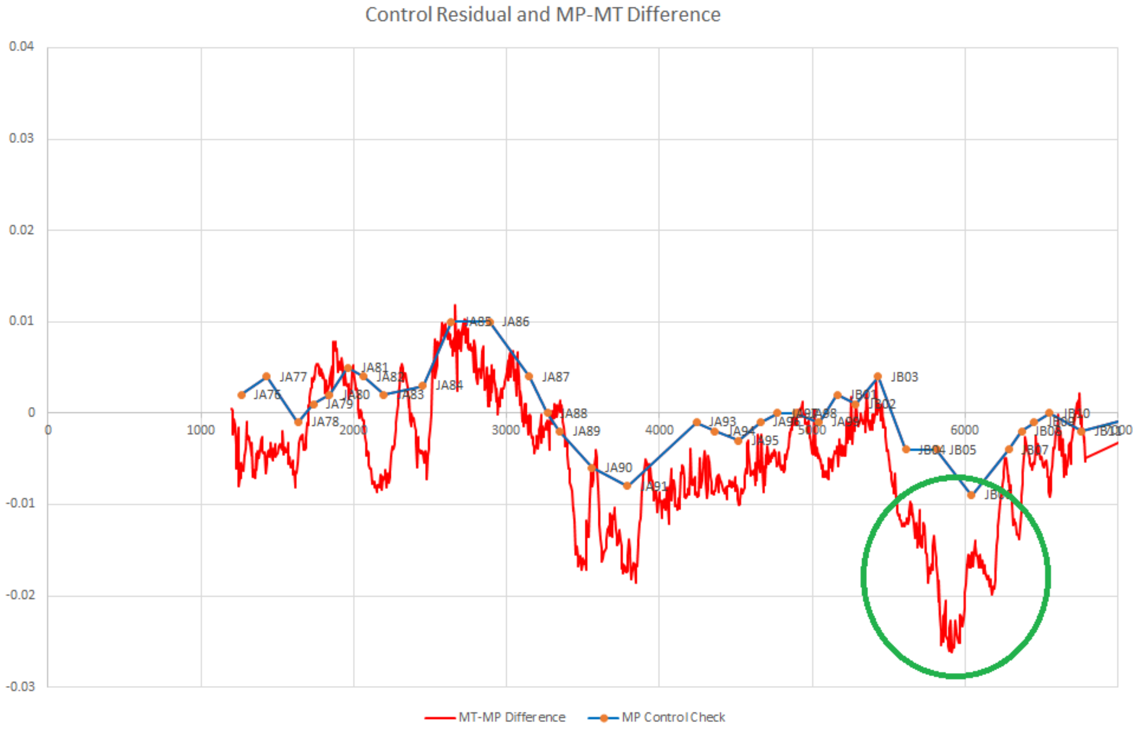

Figure 5: Difference in point cloud 1 (values in metres).

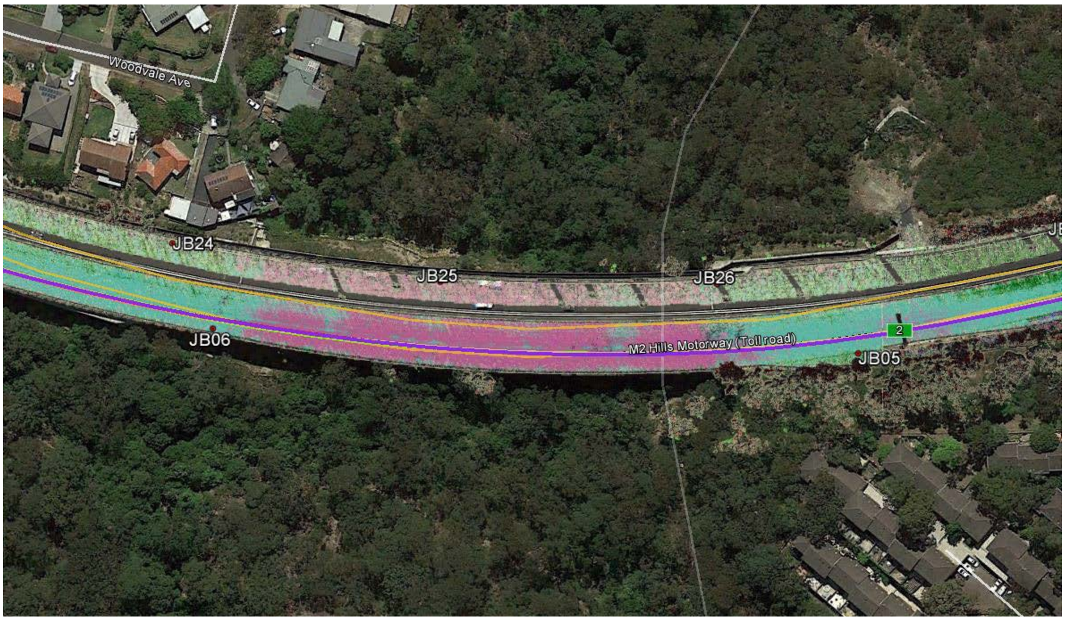

Figure 6: Image of point cloud deviation 1.

Data Comparison 2

In this example, we investigate the large deviation in the top right of Figure 7. An image of the deviation is provided in Figure 8.

This survey indicates a variable deviation between two control points. The point clouds agree at each of the target points, but diverge in the middle of the points to 31 mm. This indicates that a satellite error may have occurred between the control points in the trajectory calculation of the initial scan (Figure 9). This example shows how MP scanning can be used and applied to both verification surveys and monitoring or subsidence surveys.

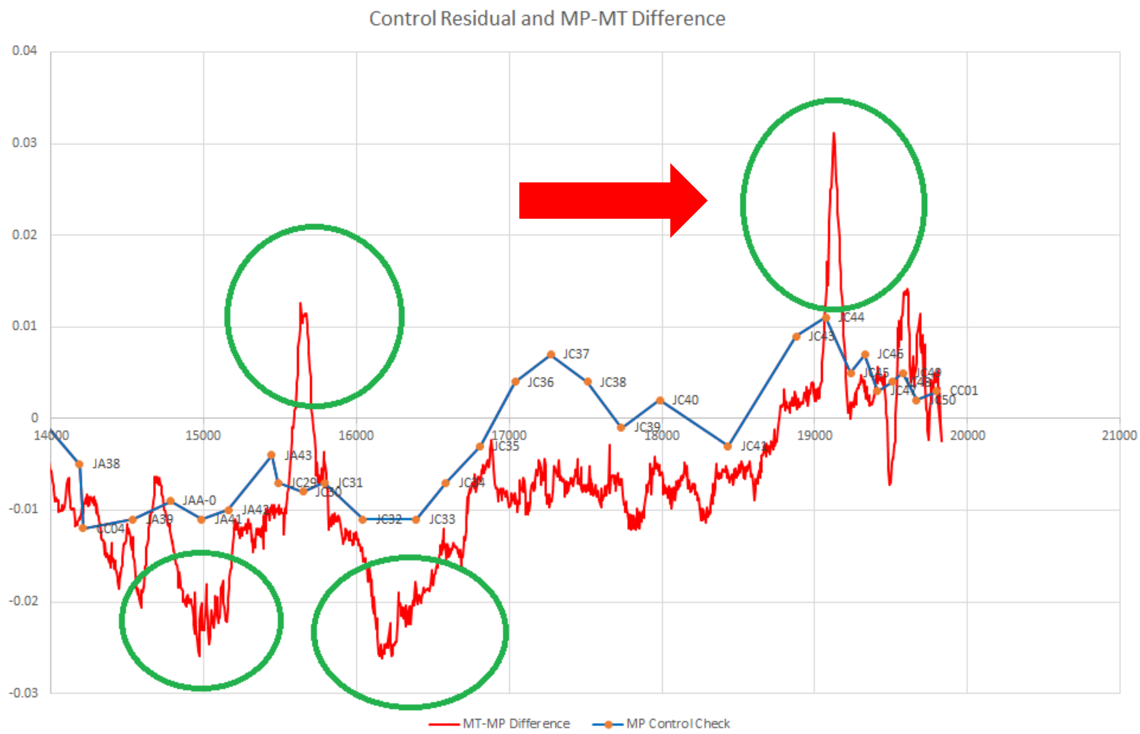

Figure 7: Difference in point cloud 2 (values in metres).

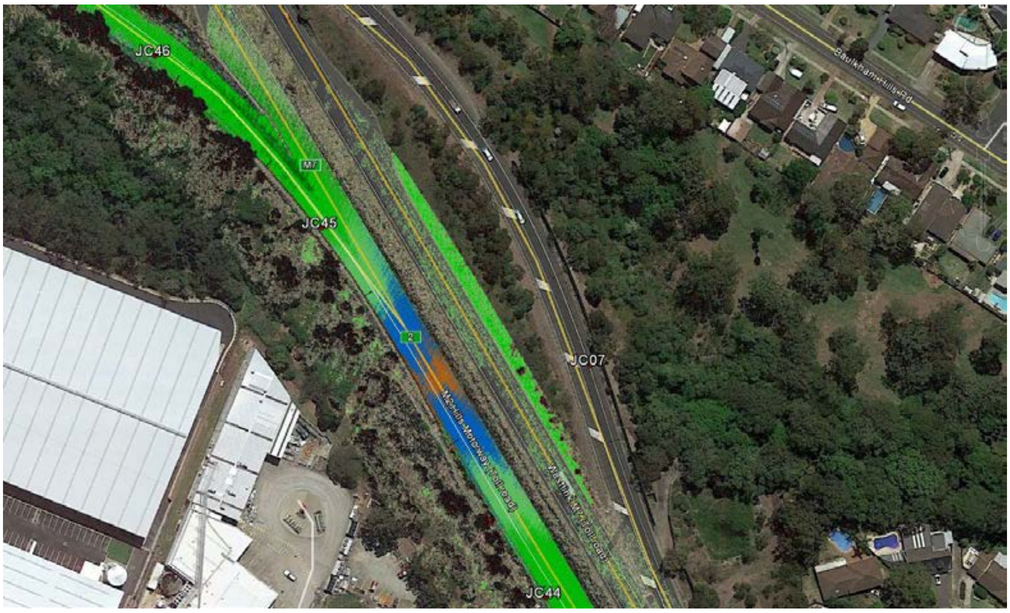

Figure 8: Image of point cloud deviation 2.

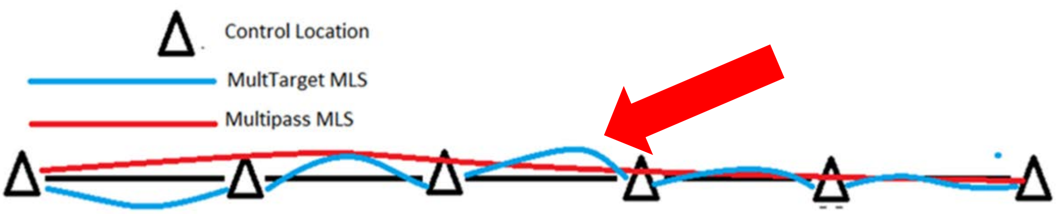

Figure 9: Possible cause of point cloud deviation.

3.2 U.S. Dataset

MNG was invited to participate in a MP MLS survey along 20 km of a motorway in Florida in 2015 (Figure 10). The contractor we worked with was required to provide MLS data urgently and had completed a MT survey of the site. The aim of our survey was to demonstrate the advantages of MP by collecting data along the same stretch of freeway. The MT survey had checked all local control and placed targets along each side of the corridor. MNG collected the MP data and carried out a similar analysis to that done in section 3.1.

Figure 10: Motorway in Florida.

3.2.1 Analysis of Target Coordinates

The first task undertaken was to check the control coordinates of the targets with those supplied by the contractor. It was found that one of the target control points disagreed with the measured height by 78 mm (Figure 11).

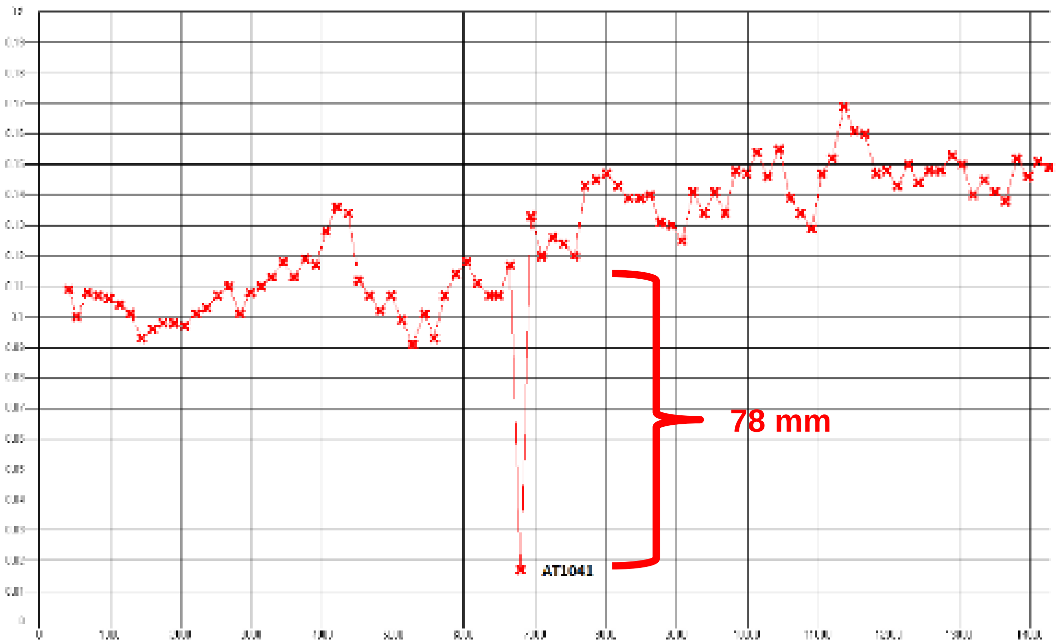

Figure 11: Comparison of control coordinates vs. MP MLS, showing observed spike in control at AT1041.

The discrepancy occurred at point AT1041 (eastbound carriageway) but did not affect AT1150 on the westbound carriageway (Figure 12).

Figure 12: Control coordinate discrepancy.

What happened to this survey? Under the stress of time constraints and contractual obligations, we found that the data had already been delivered to the customer. The coordinates of AT1041 were not checked in the field.

It seems the MLS data had been processed as follows:

- The MLS data from each carriageway was processed separately, using the appropriate targets.
- When transforming the MLS dataset from its ‘standard’ WGS84 (GNSS) reference frame to the North American Datum, neither control point AT1041 nor AT1150 were used as a common point.

When comparing the MT point cloud (delivered) to the MP point cloud (validation survey), we can see how this 78 mm was distributed (Figure 13):

- On the eastbound carriageway, the point cloud model was 19 mm above the control mark.
- At the bridge overpass (crossing the freeway), there is a 44 mm discrepancy between the eastbound and westbound carriageway where the point clouds met.
- On the westbound carriageway, the point cloud model was 15 mm below the mark.
- The 78 mm error had been spread across the bridge overpass.

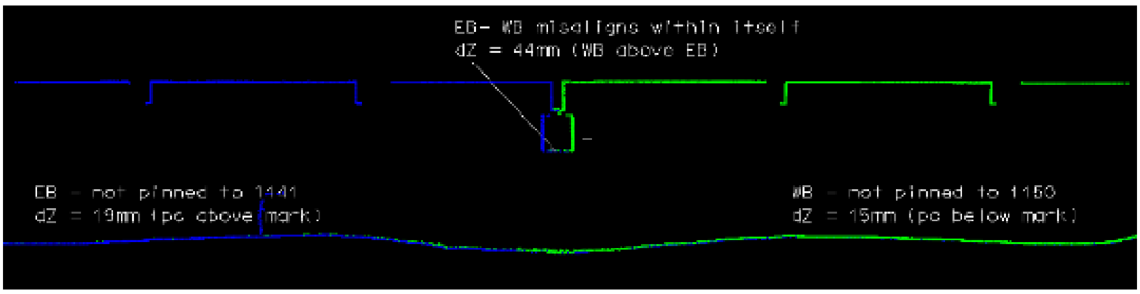

Figure 13: Cross section of overpass at discrepancy.

This dataset demonstrates the power of MP MLS to check control and validate surveys. It also highlights the errors that can be introduced to survey measurement if correct model validation is not completed.

4 DISCUSSION OF RESULTS

The datasets investigated in section 3 demonstrate the power of the MP approach as both a data collection and data validation method:

- Combining independent datasets to create an 'averaged' trajectory (control polyline) produces a 'survey-accurate' measurement that can be used to check control.
- The MP process shows that the 'jumps' present in scanning data caused by satellite errors (multipath and satellite configuration changes) are smoothed out. These jumps can occur at any time and can affect MT data, regardless of spacing between targets.
- MP data collection provides an ideal tool for data validation surveys, and also subsidence and monitoring surveys. Small changes in the road surface can be identified in extent and magnitude.

But what are the consequences of these findings? How do they affect what we currently survey and what implications do they have for other surveys in the future?

4.1 Validation of MP Approach

The survey data presented in this paper is further evidence that MP MLS provides 'survey-accurate' MLS data, independent of ground control. The MP approach also provides benefits in safety, cost and time. The data shows that:

- Less control is required on a MP MLS survey to achieve the required accuracy.
- Any errors in control can be identified from the MP MLS scan.

It is important to note that survey control and corridor targets are still required to check the accuracy of the scan and to provide common points for data transformation into the local reference system. Targets are particularly relevant in areas of poor GNSS coverage (i.e. urban canyons, tree-lined streets etc.) where the trajectory of the scanner is reliant on the IMU.

4.2 MP for MLS Validation Surveys

All MLS road corridor surveys require model validation. Current quality assurance procedures employ traditional survey techniques to 'validate' a road model at intervals along the corridor. While this approach is appropriate for traditional corridor surveys, it may be sub-optimal for validating MLS surveys. Some of the concerns are:

- Only a very small percentage of the road model is tested.
- Requires surveyors to be on the road to take the measurements.
- Relies on the integrity of the control survey.

The data presented in this paper suggests that a better alternative for validating road surface models is to use a second independent multi-pass MLS survey of the road. The multi-pass survey is independent as it uses different control targets than the original survey and is observed under different satellite configuration conditions. The advantages of using this approach are:

- 100% of the model is validated – not just a small subset.
- Errors in the control survey can be identified.
- All survey work can be completed from the safety of the scanning vehicle.

4.3 MP for Subsidence or Monitoring Surveys

The datasets indicate that MP is well suited to high-accuracy monitoring surveys, as the approach is suited to measuring both the extent and magnitude of any hardstand surface changes in the road corridor. These changes may be planned (e.g. road re-surfacing), or unplanned (e.g. subsidence).

MLS surveys for subsidence monitoring conducted on a regular basis can quickly identify any changes in the road corridor. Tools have been developed to allow the customer to easily visualise the difference in surface levels from one measurement epoch to another, allowing the identification of 'suspect' movement, where further, localised monitoring surveys can be undertaken.

5 CONCLUDING REMARKS

MNG has been involved in scanning since 2009. We have developed the multi-pass approach for MLS with its associated data collection methodology and data processing. MNG has always believed that the MP approach provides real benefits to our customers, in regards to high-quality and high-accuracy data. The datasets presented in this paper provide direct evidence of these benefits. The datasets also indicate that MP MLS provides an excellent platform for road corridor validation surveys and subsidence and monitoring surveys.

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