Development of survey control and problem based learning in Heritage Tunnels, North Derbyshire, UK

Derek SPALTON (UK) Giacomo ANDERSON (UK) Richard SELF (UK)

Key words: Problem-based-learning, Control, Heritage Tunnels

SUMMARY

Over several years, students have undertaken a Postgraduate (PG) Field course in North Derbyshire, with the aim of creating 3D models of the tunnels on a former Railway Line. In recent years the cohort has increasingly become more Internationally diverse. The most recent cohorts have had less experience in using LiDAR technology and therefore have struggled to complete the survey within one day.

The objectives of the research:

- To create a robust survey control system within a difficult environment
- Allow for different rates of progress in the field
- Develop Problem based learning practice

Working with students, attempts were made to establish control over a short range, but due to restrictions on the scanner positions, one wall was always within 2 metres preventing a measurable return signal using the standard targets.

After some investigation, small tiltable prisms were found that could be attached to the wall in four positions near the scanner. These formed strong 3D control, with a good array and have been positioned in the central sections of the tunnel (the tunnel in question being curved and over 400m long), with the adoption of mini prisms work can be performed with a variety of instruments and has allowed GPS locations to be transferred into the tunnel, for more control fixing.

Due to the heritage and to prevent vandalism (as the controls are permanent to avoid extended damage) the prisms have been fitted with covers and sprayed black. As a teaching aid the students are posed with Problem Based Learning (PBL) and asked to consider how they can leave control to return the later. They can plan solutions with a series of options that were presented to them to try and establish a working control. They were then shown the working solution and asked to identify the benefits and limitation of such a system.
The outcome of the research has produced several benefits for the students, staff and the Trustee of the tunnels. They include improving problem solving skills and establishing GPS control points in a tunnel, Further, allowing students to work at different rates while providing improved spatial awareness of survey control. Aligning to the stakeholders, developing unintrusive control points and significant time savings.

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1. BACKGROUND

Over several years, students have undertaken a Postgraduate (PG) Field course in North Derbyshire, with the aim of creating 3D models of the tunnels on a former railway line. In recent years the cohort has increasingly become more Internationally diverse. The most recent cohorts have had less experience in using LiDAR technology and therefore have struggled to complete the survey within one day.

The purpose of using the heritage tunnels is to allow the students to have a practical experience with real infrastructure and being exposed to real-life problems related to surveying in subterranean environment, whilst working in a relatively low-risk environment, as the route is now a trail used for cycling and walking. On the route there are 6 tunnels (Monsal Trial 2022) and whilst two of these are fairly short, all others have distinctive bends and have a moderate length (some of the main tunnels are over 400m long). The focus of this research utilises two tunnels, The Chee Tor tunnel and the Litton Tunnel (Figure 1) which very similar composition, profiles and lengths.

Figure 1 Litton Tunnel Portal (Geograph 2023)

The principle aim of this research project is that of developing a repeatable control system that has limited impact on the existing structure, whilst expanding materials to expose students to problem solving.
The objectives of the research:

- To create a robust survey control system within a challenging environment
- To allow for different rates of progress in the field
- To develop problem-based learning practice

2. PAST PRACTICE

Over the last 5 years students have undertaken a field course on the Monsal Trail, to generate 3D models of tunnels. These models have then allowed students to monitor and assess the condition of the structures aligned to ISO 55001. The course itself takes 3 days and the first cohorts were small (6-8 students) which all had previous experience of using the required surveying instruments.

The nature of the tunnel alignment and restrictions on the length of working day (the tunnels are only internally lit during hours of daylight) meant that student had to progress at a steady pace, typically covering 100m in 2 hours and sharing a moving network of targets (Albourae, 2021) along the route (see Figure 2). With the original smaller "experienced" groups there was enough time to have staggered starts and ample working space, whilst still allowing the main footway/cycle route to be unhindered. Within the Health and Safety Risk Assessment, working was only permitted in 1 tunnel as the number of first aiders is typically 2 and this allowed for quick response and for the vehicle to be close by, the tunnels are spread over approximately 9 kilometres of the trail.

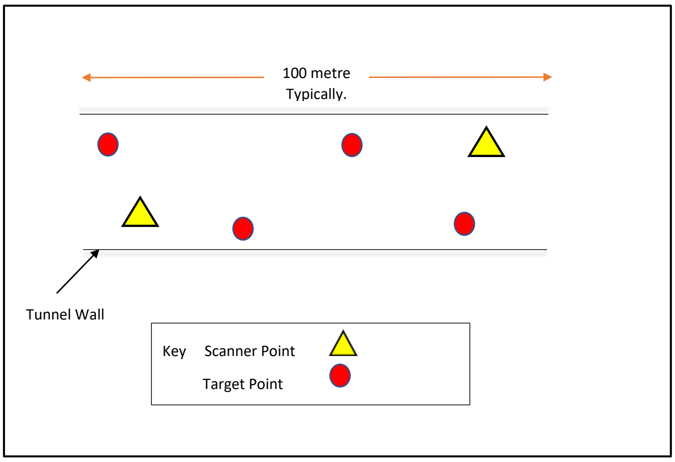

Figure 2 Typical Target and Scanner configuration

Since COVID restriction were lifted there has been a large increase in the number of International students joining the cohort. These students are very well motivated but have limited practical experience with the instruments used, and often struggle with spatial issues for controls. The cohort is therefore more than double in size and even with additional preparation work the progress is typically 50m in 90 minutes. Further to this, students seem less organised and often muddle up targets, forget to save data and move kit which is being used by other groups. This impacts greatly on the whole cohort as the process needs to be repeated two or even three times.

3. PROBLEMS WITH SURVEYING THE TUNNELS

Beyond the issues generated by the students, there are a series of issues that need to be addressed whilst "shooting" LASER's along tunnels (Gikas, 2012). These issues are discussed with the cohort and the adoption of the tunnel as a piece of infrastructure adds weight to the discussions as the module also includes recording of assets under ISO55001.
One of the main issues encountered within the tunnels is poor lighting. Whilst artificial lighting exists in the tunnels, the light levels are low. In itself this does not impact on the use of LASER equipment as these function equally well in the dark as they do in the light. The challenge is based mainly around locating and adequately sighting the target/prisms used as "tie points". The usual resolution is to increase the amount of artificial lighting which was not always possible here.

Secondly, within a tunnel, particularly those with a curved alignment and gradient (as here), once the LASER comes with a working range of the wall lining there is an opportunity for refraction (Janus & Ostrogórski, 2022) to occur which when measuring to millimetre tolerance can become an issue. This is mainly addressed in the process here by ensuring any target is set up at least one metre from the tunnel walls (see Figure 3). This became an issue as there was a need to set up points that could be easily revisited. There was also a need to line of sight between an instrument and the required number of targets which needed to be addressed in any measurement.

Figure 3 Image showing the offset from the wall for scanners and targets (Anderson, 2022)

The final issue which needs to be considered, although there are others which are less significant in this process, and beyond the scope of this paper, is the tunnel atmosphere (Schulz, 2008).

This again did not always occur as a couple of the tunnels were significantly shorter and had a predominately straight alignment. The longer tunnels however, which could not be surveyed by some groups in less that 8 hours, required shorter shots to be taken to minimise the atmospheric correction, this however compounded the rate of progress.

4. DEVELOPING A SOLUTION (PROBLEM-BASED LEARNING)

During the 2022 Academic Year the cohort being larger and having less experience and several groups having slow progress it was decided to try to create a series of fixed reference points. Usually pins or stations could be established to tie into the following day. The tunnels however have heritage status and there are restrictions on establishing stations or leaving equipment over night, as they are unlit at night and not secure. An alternative solution was sought. The linings of the tunnels are heavily lined with soot and have limited returned reflective signals. On top of this, longer reference points suffer from acute angles and refraction along the tunnel walls, which are uneven and deformed.

Working with the students, attempts were made to establish control over a short range. The chosen tunnel as the Chee Tor tunnel which has a slightly better section with the side walls falling out at a shallower rake than the other tunnels. As can be seen in figure 4, this tunnel still suffers greatly from surface sooting.

Figure 4 Profile of the Chee Tor tunnel (Anderson, 2022)

Due to restrictions on the scanner positions, one wall was always within 2 metres preventing a measurable return signal using the standard targets. Attempts were made to locate a series of flat targets, some fixed to the walls using adhesive and others leaned against the wall or on the tunnel floor. This only proved partially successful as the angle of incidence (Jeong & Kim, 2018) of most of the shots meant that the signal did not return (See Figure 5 showing a line of targets). This led to the control being clustered in a small zone of one wall and the degree of accuracy of the registration being very poor. Further to this, the fixing methods at the time were limited to locating past fixing points on the wall, possibly from redundant services. It should also be noted at this point that no permission was in place to drill the walls and the walls were generally wet due to seepage and condensation.

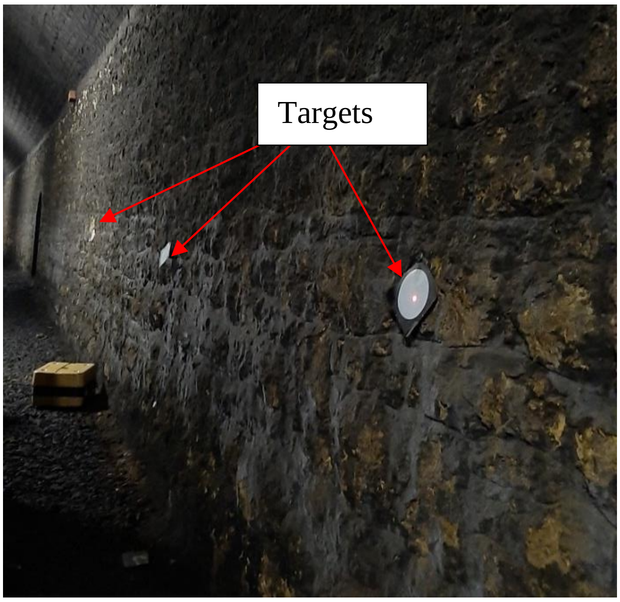

Figure 5 Targets fixed to redundant service fixings (Anderson, 2022)

Attempts to scan enough points, a minimum of three with one additional for redundancy, proved pointless and the process was abandoned, leading to an additional day of scanning. A more flexible and permanent solution was required, although the students would be asked to consider possible remedies. Working with the Peak Parks Authority (PPA), relevant permission was obtained and the Team explored possible methods, which would also be used by the PPA to establish some form of control within the tunnel. Early potential systems had to be fixed flat to the wall and remain in-situ, not only would such a target have issues with a limited working arc but also required excessive intrusion to the wall, which was not acceptable to the PPA.

Figure 6 Tiltable rotatable fixed targets (Anderson, 2023)

After some investigation, small tiltable prisms (see Figure 6) were found that could be attached to the wall in four positions in close proximity to the scanner. These formed strong 3D control, with a good array, both horizontal and vertical displacement (Figure 7) and were been positioned in the central sections of the tunnel, chainage 220 to 250m, (the tunnel in question being curved and over 450m long), with the adoption of mini prisms work can be performed with a variety of instruments and has allowed GPS locations to be transferred into the tunnel, for more control fixing.

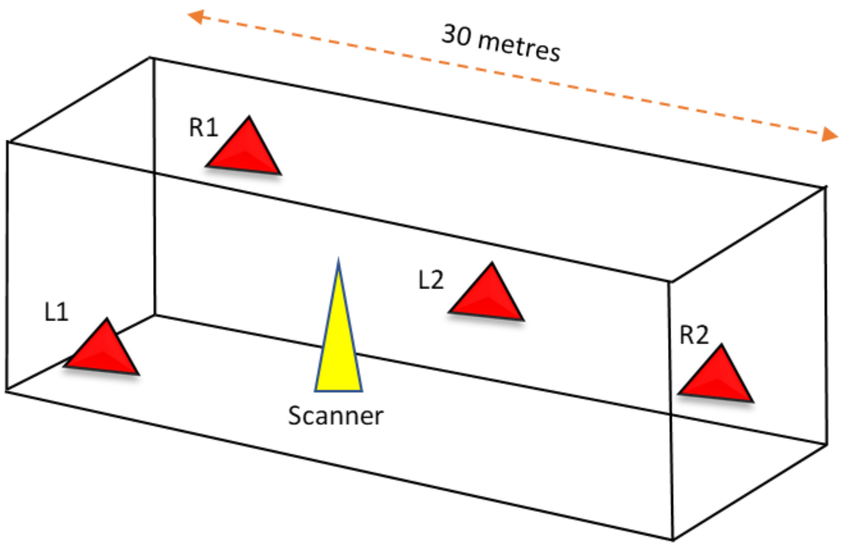

Figure 7 A depiction of the target around the scanning position

Due to the heritage and to prevent vandalism (as the controls are permanent to avoid extended damage) the original prisms would have been fitted with covers and sprayed black and required 4 screws to attach them to the wall. After discussion with the supplier, they suggested a product that tilted (120-degree arc) and rotated (in one direction) that could be fixed to a metal resumption point, designed to fix the magnet target frame to without displacement.

A number of previous studies have covered the topic of target-based point cloud registration using LiDAR instruments in conjunction with various types of targets. Of particular note is the research conducted by Becerik-Gerber et al. (2011), who aimed to compare the accuracies of different target types for both time-of-flight and phase-based LASER scanners. One of the key findings of this research project was that the main factor with regards to the overall accuracy and success rate of the registration process was the positioning and orientation of the targets. This is even more crucial when considering the shape of tunnels, which tend to be very linear and are made up of repeating geometries which limit target positioning and make the overall registration process more challenging. As such, one of the principle issues with regards to placing the targets within the tunnel for this research project concerned the need to offer both good horizontal and vertical separation in order to guarantee a tighter and more accurate registration. This was further exacerbated by the irregularly-shaped surfaces along the tunnel walls, which made the installation of adequate resumption points even more challenging. Generally it was found that the sections of masonry at or near refuges along the tunnel offered the best location to install resumption points and the associated prism fittings as they were mostly made up of relatively flat surfaces. The layout of the target points was carefully planned to offer sightlines to the proposed setup locations of the instruments, guaranteeing ease of capture during scan operations. On top of this, the targets were staggered both laterally (being placed of both sides of the tunnel) and vertically in order to reduce the degree of rotational freedom that the point cloud data could have during the registration process.

Some of the resumption points were placed within the refuges along the tunnel walls and, despite ease of installation in these locations, it was observed that target capture was made significantly more challenging due to difficulties in establishing reliable sightlines between the instrument and three or more targets. In some instances during the target capture process, it was noted that the relatively poor lighting conditions still had an impact and made the sighting of the prisms particularly challenging from certain locations. This resulted in the scanning operations requiring both the use of flashlights and on-board LASER pointers to orient the instrument towards the relatively small targets. This being said, the instrument itself was able to easily capture the prism in all instances where a clear line of sight was established, regardless of the lighting conditions and working distances involved.

5. PRACTICAL TEACHING IMPACTS

As a teaching aid the students are posed with Problem Based Learning (PBL) and asked to consider how they can leave control to return the later. They can plan solutions with a series of options that were presented to them to try and establish a working control. They were then shown the working solution and asked to identify the benefits and limitation of such a system. When editing the data they can run reports on the raw data and assess the working range errors based on one position being a static base for comparison. The data output has been sampled (see Figure 8) and it can clearly be seen that the data has a significantly smaller misclosure.

Chee Tor Tunnel Original Field Data

	Working range error in mm		
Target	X plane	Y plane	Z plane
23	12.5	23.1	17.9
24	9.7	12.6	15.3
25	24.7	19.0	11.6

Litton Tunnel Test with Tilting Prisms

	Working range error in mm		
Target	X plane	Y plane	Z plane
Test 3	1.5	0.8	2.2
Test 4	0.3	1.2	0.6
Test 5	1.9	0.0	2.1
Test 6	3.4	1.1	0.7

Figure 8 Comparative data between the original and new systems

6. CONCLUSIONS

The outcome of the research has produced a number of benefits for the students, staff and the Trustee of the tunnels. Firstly, it has improved problem solving skills and can be run during the sessions, posing a series of issues that need to be resolved in the field, when provided with limited options. Secondly, as a by-product it has enabled the establishment GPS control points in a tunnel. The students now have to opportunity to work at their own rate, in the knowledge that they can continue the collection of data at a later date. This flexibility provides for students with less confidence, experience and critically those with academic support plans. It provides for improved spatial awareness of survey control and lets the students see the implication of poor control first hand. This also contributes to extending critical reflection on field practice and quantifying the resultant data.

It has benefited the PPA as they now have access to the control and the measures undertaken have limited intrusion upon the structure. Finally, but not least, the measures undertaken provide the cohort with significant time savings which indirectly reduces exposure to Health and Safety risks in the field.

7. POSSIBLE FURTHER RESEARCH

Developing the research currently completed could look towards GNSS tagging and linking control to GNSS network, this could have many benefits for Asset Management. The work could be extended to the other tunnels on the route and cascaded down to undergraduate scanning project work on small structures such as bridges.
Opportunities exist to further assess the performance of the targets within the tunnel and align the work to performing oblique sightings, and surfaces of differing size and reflectivity.

REFERENCES

Albourae, A. (2021) “Accuracy assessment of terrestrial laser scanning and digital close range potogrammetry for 3D Cultural Heritage.” Available at: https://doi.org/10.32920/ryerson.14644533.

Becerik-Gerber et al. (2011) Assessment of target types and layouts in 3D laser scanning for registration accuracy. *Automation in Construction*, 20(5), pp. 649-658.

Gikas, V. (2012) “Three-dimensional laser scanning for geometry documentation and construction management of highway tunnels during excavation,” Sensors, 12(8), pp. 11249–11270. Available at: https://doi.org/10.3390/s120811249.

Janus, J. and Ostrogórski, P. (2022) “Underground mine tunnel modelling using laser scan data in relation to manual geometry measurements,” Energies, 15(7), p. 2537. Available at: https://doi.org/10.3390/en15072537.

Jeong, J. and Kim, A. (2018) “Lidar intensity calibration for road marking extraction,” 2018 15th International Conference on Ubiquitous Robots (UR) [Preprint]. Available at: https://doi.org/10.1109/urai.2018.8441893.

Monsal Trail (no date) Peak District National Park. Available at: https://www.peakdistrict.gov.uk/visiting/places-to-visit/trails/monsaltrail (Accessed: November 22, 2023).

Schulz, T. (2008) Calibration of a Terrestrial Laser Scanner for engineering geodesy. Zurich: ETH.

CONTACTS

Mr. Derek Spalton
University of Derby
Markeaton Street
Derby
UNITED KINGDOM
Tel. +44 (0) 1332 593185
Email: d.spalton@derby.ac.uk
Web site: https://www.derby.ac.uk/

Mr. Giacomo Anderson
University of Derby
Markeaton Street
Derby
UNITED KINGDOM
Tel. +44 (0) 1332 594104
Email: g.anderson3@derby.ac.uk
Web site: https://www.derby.ac.uk/

Mr. Richard Self
University of Derby
Markeaton Street
Derby
UNITED KINGDOM
Tel. +44 (0) 1332 591150
Email: r.j.self@derby.ac.uk
Web site: https://www.derby.ac.uk/