

Kinematic Laser Scanning and Point Cloud Analysis on a Budget



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Abstract

In the railway environment there are uses for the two traditional forms of laser scanning. Both airborne laser scanning for mapping and terrestrial laser scanning for full 3D modelling have been used in appropriate situations. These have been extremely valuable tools on the projects where they have been used, however within the constrained linear environment of a railway, there is an additional need not served by these two methods.

The traditional solution was to use a tunnel profiler, set up and orientated square to the track. This method has also been used throughout the city railway tunnels. It provides discrete profiles at each location observed, but due to the time taken for setup, it has tended to be used at regular and spaced intervals.

In recent times alternatives to this third method have become available. These are usually based on a rotating axial laser on vehicle mounts. While these perform well they are fairly expensive. A less expensive solution had to be found.

This paper examines the use of a number of lasers intended for the robotics industry, mounted on a vehicle and processed to give the required results. The setup discussed was less expensive than other alternatives and provided a satisfactory solution to the problems faced.

Other issues discussed include the different positioning requirements and how the data can be used in an engineering sense. The engineering results come with some limitations but are none the less useful. These limitations are discussed and the results are compared to conventional survey data.

There are many uses for this approach including mapping and analysis of existing features and the identification of critical areas for new infrastructure. Once identified these critical areas can then be further measured and analysed using traditional survey and calculation methods.

Background

Railways primarily manage a long narrow corridor which in most cases was built from 80 to 150 years ago.

As a government owned asset, the Government, on behalf of the people they represent, seek continually to improve service and capacity at minimal cost. Additional or newer demands on the system include air-conditioning in trains and double deck carriages increasing capacity. New technology also needs to be made available to both train staff and passengers. This includes mobile phone coverage and modern communication from train staff to train controllers. These features will sometimes cause modification to the vehicle profile of the rolling stock and sometimes require additional infrastructure to be placed on the inside of tunnels and bridges and will require engineering design and sign off to maintain safety. Community standards have risen over time and greater expectations on safety and evacuation have given rise to additional infrastructure required within this narrow corridor.

There is high demand for management of the space that trains travel in. This space is traditionally managed by field survey and calculations, to determine the clearance between the theoretical limit of a standard train with all allowances, and the infrastructure. Using surveyors to do this task was necessary but at times a waste of valuable resources as the piece of infrastructure was found to be relatively clear. RailCorp's predecessor, Rail Access Corporation, found a cost effective way of filtering the information to target the scarce and valuable resource of field survey to where it can be of most benefit. This development has since been refined and developed to a point where some internal groups use it as their first tool in determining if a proposal should be investigated further.

The Data Collection System

The data collection system is part of the Asset Inspection and Mapping System (AIMS). The system collects data for inspection and mapping. This system has previously been described, as far as the inspection and imaging parts are concerned (see Asset Mapping with AIMS Ref iii, 2007). The laser system has been examined in this paper.

The railways needed to examine a number of long corridors with the view of catering for larger train carriages within these corridors.

Infrastructure had been constructed to be outside a particular envelope. As long as the infrastructure was outside this envelope no detail records were required. From time to time there are requests to use a larger envelope. These requests may have been for a single large load like a transformer for a large power station, or for a regular service using a larger envelope. When these requests come in, all bridges,



The Field Recording Vehicle



Field Collection Computers

tunnels and other infrastructure had to be re-examined. This task was too large to use conventional survey and a new method was needed. Two 180 degree proximity scanners were acquired and mounted back to back to give full profile coverage. These scanners are set to a range of 8 meters and scan at 1 degree intervals completing approximately 72 scans per second.

The scanners are mounted on one end of the recording vehicle and connected to logging computers on board the vehicle. The positioning system uses a number of sensors including a differentially corrected GPS receiver, solid state gyroscopes, two axis-tilt sensors and axle mounted pulse senders. Data from these various sensors is also recorded on logging computers using a single time reference to tie the information together.

The Post Processing System

After data collection, there are a number of files available to the system. These files contain data for all or part of the days recording and need to be processed and managed to enable useful information to be extracted.

Data is collected on a run basis but needs to be processed on a named track basis.

These two are not the same.

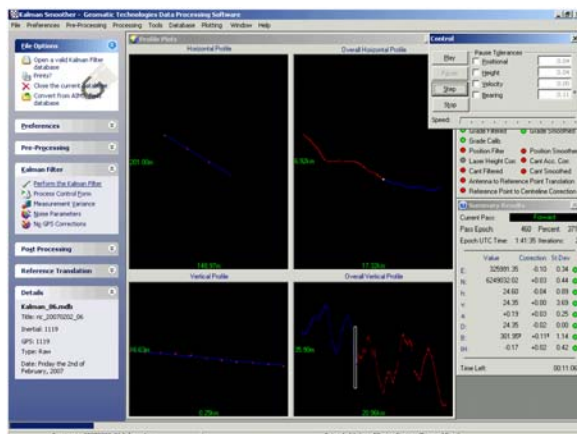
We have used a real time differentially-corrected GPS receiver to give position as data is recorded. The disadvantage of this is that GPS does not work uniformly throughout the rail corridor. There are areas where we obtain very good data, areas where we receive adequate data and areas where we get no data at all.



Filtering GPS and Gyroscope Data

One of the areas of most interest is tunnels, where we get no data from the GPS. We have also found that you can not always get accurate differential GPS positions. This is especially the case where we are regaining position after some obstruction. The various GPS chipsets appear to have very different properties in this area as well as the general noise level of the position data. To help with cleaning the GPS data and

to cover the periods where there is no GPS data we have fitted an **axle pulse counter** to the vehicle. By counting the pulses at each logging epoch (1 second as given by the GPS unit) we can determine the distance travelled between the logging epochs. This data is very good but sometimes also includes noise which needs to be identified and removed.



Running the Kalmun Filter

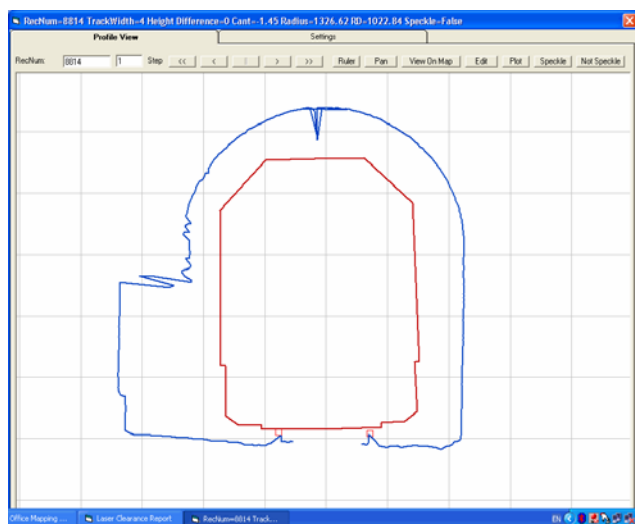
The calculation process includes a step to eliminate noise in the gyroscope observations and to calculate and remove drift by using GPS where available.

Two axis tilt sensors are used to calculate grade and cross tilt. Grade helps with the 3D positioning and the cross tilt allows for correction of position due to antenna height. Both tilt sensors (grade and cross) are affected by accelerations. Corrections for these accelerations need to be made to the tilt measurements before they are used.

Once the entire data cleanup is completed we are then in a position to combine all the remaining data in to a single position solution for each logging epoch. This is done using a least squares process involving a Kalman filter in both a forward and reverse direction with a final position derived by putting these two together. RailCorp uses software by Geomatic Technologies that uses the Kalman filter process and others, to carry out these tasks.

Track Geometry

To correctly calculate the clearances to a railway vehicle we need to know some details about the geometry of the track that the vehicle travels on. In cases where the



Laser Profile showing Vehicle Profile

geometry is not known we use some software to fit straights, curves and transitions to the position data previously calculated. This program works by analysing the versine measurements at each epoch to the adjoining epochs. The change of this measurement should be smooth with straights having a value of zero and curves having a constant value. This calculation is similar to the string-lining method of curve alignment that was extensively used in the latter half of last century.

In most of the metropolitan track network of Sydney the track geometry is known and maintained by the appropriate regional surveyors. In this case we simply load in that alignment and snap the imagery to this alignment. The necessary alignment information for each epoch can then be readily derived.

Location without reliable GPS position

There is, however, a third case. There are parts of the network where we get no useful GPS information for considerable periods. In these cases the positioning system is not able to provide a position that can be used for curve fitting or snapping to existing alignment. In this case we need to use additional information to position the vehicle. The process we have adopted is to work backwards. The laser data that we shall look at shortly can be used together with known locations of infrastructure and the known alignment to derive position from the alignment. In simple terms we can interpolate between known locations to gain the information required.

Processing Laser Data

Once we have determined the vehicle position at each epoch and snapped this position to the track we can begin to process the laser data.

The first step is to combine the two sets of data using the known relative position of each laser to the vehicle. After combining the two sets of laser measurements, the next step is to add the track related information for each profile. This information includes radius of curvature, super elevation or cant, position in space and orientation. This step can take several hours and is often run overnight. The data volume is about 3.6 million laser readings per kilometre of track run. The greater Sydney metropolitan network comprises about 1100 km of track that is regularly recorded by this vehicle.

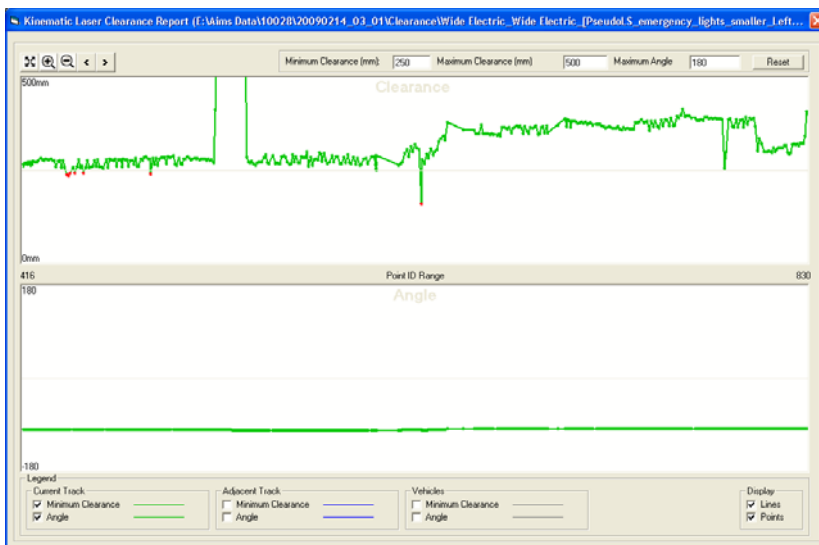
The corridor envelope and train profile

With this process completed, we are able to view the data and step through each profile. This is useful but it would be far better to see a train in the profile to see how close the train might get to some piece of infrastructure.

Rolling Stock Profiles

In the open competitive market we face today, there are many different vehicles running on a rail network. To cater for this, there are a number of standard shapes used and each vehicle must fit inside one of these standard shapes. These shapes can be defined by a co-ordinate system for the cross section of the vehicle and some parameters to do with bogie separation and length. Once defined these vehicle profiles can be stored in a library and reused as required. In addition to the standard shapes there are special shapes required from time to time. These are also created and stored

in the library for later use. The standard vehicles are not rigidly tied to the rail, but rather allowed to move by small amounts. These movements include shifts and rotations about various points to reflect both maintenance and suspension characteristics. The various parameters

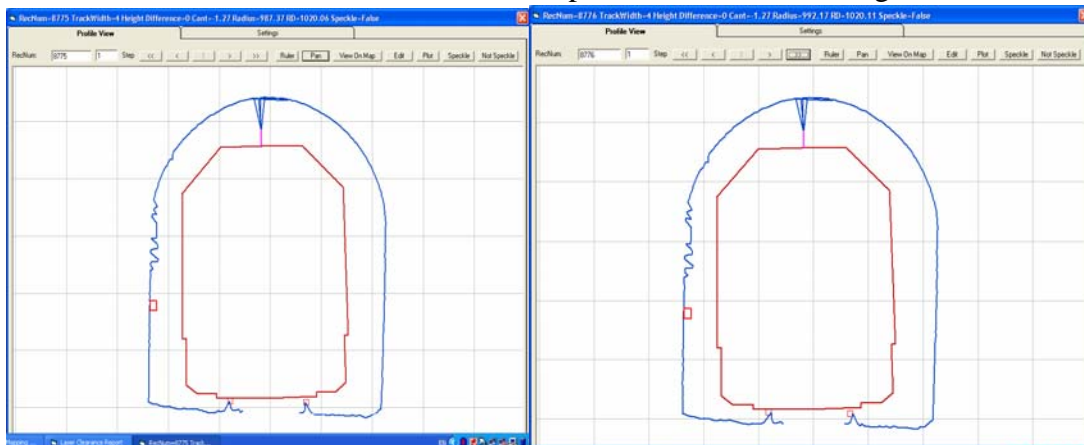


Clearance Report

can be set in the software. In addition to all of this, there is an additional safety margin applied. The size of the safety margin varies from place to place with later lines having a larger allowance in this area.

Location of Rail Heads.

The process described here is reliant on finding the rail head in the laser profile. The resolution to which this can be done, is the prime factor contributing to the overall



Proposed duct shown on left – right image shows incorrect rail detection

accuracy of the system. We therefore use this system to determine where the tightest points are, then arrange for a ground survey at these locations to confirm the findings and give a better resolution.

The key, and sometimes the weakness, in this approach is in detecting the rails in the laser scan. The rails are within a defined area on each scan and have certain characteristics that allow us to automatically detect which points are on the rail heads. Finding the rail among the laser points is critical to the process used for clearance calculations.

Once the rails are located, the virtual vehicle can be placed on the rails. This then allows us to determine the closest point to the train and compare this to the requirements in the standards. This can be done in bulk and analysed. We then look at the smaller clearances to filter out anything that is not relevant. Examples of things which are detected but not relevant include paper rubbish about the track. Paper is often picked up by the air movement and the laser detects the paper. This then gives a false reading. We also find vegetation that hangs close to the trains. Although this vegetation needs to be managed, we are looking for the solid structures behind the vegetation.

When analysing the data there are a number of common types of infrastructure which are often looked at separately. We can tag laser points and classify them as each of these types of infrastructure and then process one or more types at a time. This allows us to exclude things like platform copings which are intentionally placed close to the train, from clouding the bulk calculation. We then process the platforms separately applying different tolerances in the standards. Other types of infrastructure that we would typically separate out include overhead wiring and ballast.

Availability of field surveyors

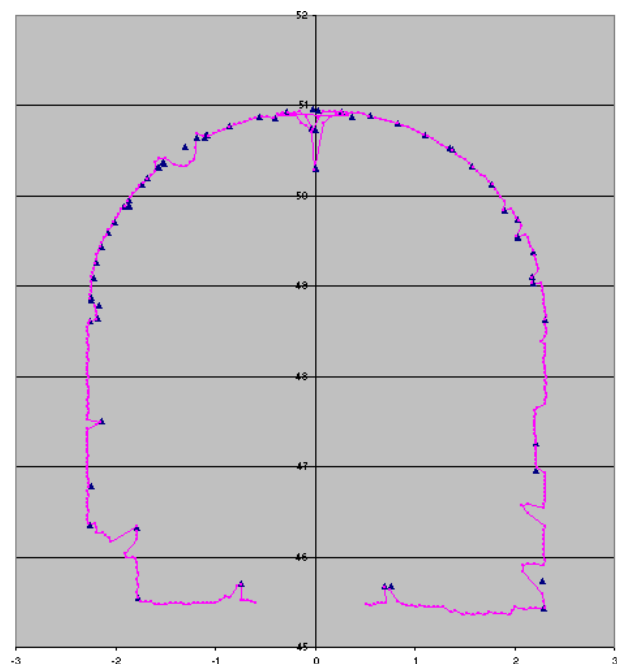
Field surveyors are in short supply throughout the rail industry and being able to target this valuable resource where it is most needed increases efficiency.

We have had a number of instances where laser profiling has been processed and field surveys used to confirm the results. Analysis of these comparisons have found the results to be encouraging but not to the point that the surveys can be eliminated.

There are differences between the laser profile and a field survey profile. These differences can be categorised in to a number of groups.

Firstly there is the issue of finding the same location to take the field survey profile. In some cases this is easy because we can use existing infrastructure as a reference point. In other locations reference points are not available. If the field survey is in a different location, the value of comparing the two profiles is lost.

The second group of differences occur where the field survey chooses to ignore an item that would appear to give the wrong impression of what is at the location (e.g. a ladder against a wall). The laser can not make such a determination and will locate anything that the beam hits. An additional difference in this group is where the laser misses a small



Comparison of AIMS from 14th Oct 07 and Survey from July 07
at Up Shore 5-276 North Sydney Station Portal
Survey Data in Blue AIMS in Pink

object like a pipe or sign. A field survey would intentionally locate a small object but the laser may miss such an object due to the sampling nature of the measurement. The third group of differences is due to the resolution issue. Comparisons undertaken to date indicate that when the rail head is correctly identified, the results are very good.

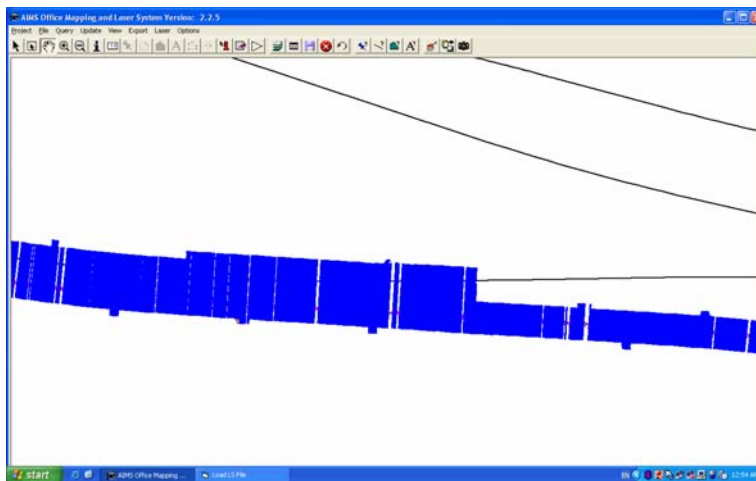
Use in Proposed Infrastructure

The most common use for this data has been analysis of proposed infrastructure. Actual examples of such infrastructure for which we have carried out laser scanning include new high voltage power cables, new operational and emergency lighting and communications cables.

In each case the designers give us the cross-sectional shape of the infrastructure and the intended location. Having constructed the shape, the object can be placed at the desired height and then slide it out to the existing laser profile. We can then calculate a clearance to the vehicle. This process allows us to rapidly find the problem areas and the designers can then concentrate their efforts in these areas. This process saves many hours of field survey work identifying those locations where there is plenty of clearance and also where there is insufficient room.

Additional Side Benefits and Potential Other Uses.

If we were to construct a 1mm by 1mm vehicle and tag the overhead wiring correctly, we could use this system to measure the unloaded position of the overhead wires. This



Laser points imported into map.

task is time consuming and difficult and is currently undertaken by the field surveyors. Using this tool may increase efficiency of the field surveyors. We would like to also extract the wire data and try to incorporate it into a 3D CAD model together with the other survey information.

We can export the laser points to a point cloud, then use this data in a

similar way to other laser processing. The data has different characteristics to other laser data but may still be of use.

One of the minor issues discovered at this stage can be seen in the diagram above. There appears to be gaps in the data and some bunching of data at the edges of these gaps. After some investigation, we have found this to be caused by the operating system on the logging computer. During the real-time data logging, every now and again MS Windows needs to carry out some function which it does by effectively taking over the computer. When this occurs, we don't lose data, but lose the timing of the data and so the data is reported as being logged later. To reduce this issue we have two approaches, the first being faster computers being installed in the vehicle, and the second is a software process to detect the issue and adjust the data as required. Both these are being implemented at the moment and we are hopeful that the 3D view will be improved. Note that there is almost no affect on the clearance calculations.

Conclusions

The use of AIMS laser to analyse the close approach of trains and infrastructure has proved to be a valuable tool to filter the information and target the limited manpower available to where it will be of most value. This value has been realised in the analysis of existing infrastructure and the design of new infrastructure. The limitations of the current hardware will be addressed as more suitable equipment comes on the market. AIMS Laser provides advantages and benefits in:-

- Planning of new permanent infrastructure elements
- Evaluation and granting of train paths with non standard rolling stock
- Routine vegetation management
- Survey expertise

References

Rail Mapping Project, John Latella and Mark Butler, Association of Public Authority Surveyors 1995

Mechanised Rail Inspection, Finbar Holand, Permanent Way Institute (NSW) 2003

Asset Mapping with AIMS, Mark Butler, Association of Public Authority Surveyors 2007