Lateral Sway Of Road Trains

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Abstract

To date Main Roads relies almost exclusively on computer simulation to ascertain the dynamic behaviour of the various road trains which are in widespread use across the state of Western Australia. As a method of confirming the accuracy of these computer based models, this study aims to develop a system which may be employed to gather data from vehicles while they are in service. This has involved the design of an accelerometer-based data gathering system coupled with computer based analysis techniques to provide a comparison for simulations. Primarily the study has been interested in monitoring the lateral sway of vehicles, however it is expected that the results may be applied to other motions such as vehicle roll.

1.0 Introduction

Main Roads is responsible for the use of roads by road trains in the state of Western Australia. To make informed and safe decisions as to which roads are available for use by road trains, Main Roads requires reliable information about the motion of as many different road train configurations as possible. This project has been commissioned by Main Roads to investigate a way of electronically measuring and analysing the 'lateral sway' of road trains while they are involved in active duty.

The lateral sway, or 'off-tracking' of a truck is the difference in paths traced out on the road between the front and end sections of the truck. This difference is a combination of steady state offsets and oscillations. It is a result of a number of factors including driver steering actions, properties of the vehicle, properties of the road, vehicle speed and other external disturbances. The maximum typical deviation is termed the 'swept width' and this may be compared to the width of the road as one factor in determining how safe the use of a specific road is by a particular vehicle configuration. A significant component of the swept width is termed the 'Camber Induced Offset.' This is the component of the swept width which is due to a steady lateral offset in the paths traced out by the front and rear of a truck and is due to the camber of the road.

Currently, Main Roads relies almost exclusively on data from computer simulations which are performed by external contractors with no involvement by Main Roads personnel. The aim of this project has been to design, build and test equipment that can measure/monitor the lateral sway on a variety of vehicle combinations. The development of data analysis software has also been central to the project.

A couple of preliminary studies have been undertaken by Main Roads to gain an insight into lateral sway of road trains. Prem (1999) conducted a series of tests where vehicles were driven down a well mapped test track. The test trucks left a paint trail as they drove, thus marking out their paths. The characteristics of the road were then compared to the motion of the vehicle. Prem drew conclusions about how road characteristics and vehicle length affected vehicle off tracking. The work by Peters (2004), as yet unpublished, has investigated the use of commercially available generic accelerometer/logger systems and these were used to measure the dynamic behaviour and braking abilities of four trailer road trains.

2.0 Hardware Development

The system that has been developed focuses on measuring the relatively low frequency changes in lateral position of the vehicle at various points along its length. Furthermore it must satisfy a number of design criteria. The system has been designed to cope with noise as a result of vehicle vibration and electromagnetic interference. Sampling speed and accuracy have also been a priority as the system must be sensitive enough to measure the relatively small accelerations that occur in vehicle sway. Ease of use has been a crucial consideration in the design as the system will need to be moved between vehicles and will eventually be operated by people with little or no background in electronics. The data logging device also has to be simple to operate and capable of recording over potentially long time periods at high sampling speeds. Furthermore, it has to be able to measure at relatively high frequencies at a sufficiently high resolution.

A number of ideas were examined regarding the general implementation of hardware to fulfil the above design criteria. These involved the use of global positioning systems (GPS) as well as various systems centred on measuring the sway using optical devices such as cameras and infrared lasers. Accelerometers were chosen as the most suitable type of sensor due to their relatively low cost and ease of use.

The hardware of the developed measurement system comprises three main components. These are the individual accelerometers, a data logger and the cable network. The accelerometers are 'off the shelf' two axis models which were chosen as a compromise between cost and accuracy. They are designed specifically for measuring relatively low accelerations between +/- 2g. While the chosen accelerometers are capable of outputting a pulse width modulated signal, the analogue output is utilised instead to reduce hardware complexity. The data logger instead digitises the signal from each accelerometer. The accelerometers may be placed along a road train as shown in Figure 1 so that sway can be measured and compared at several positions along the vehicle.

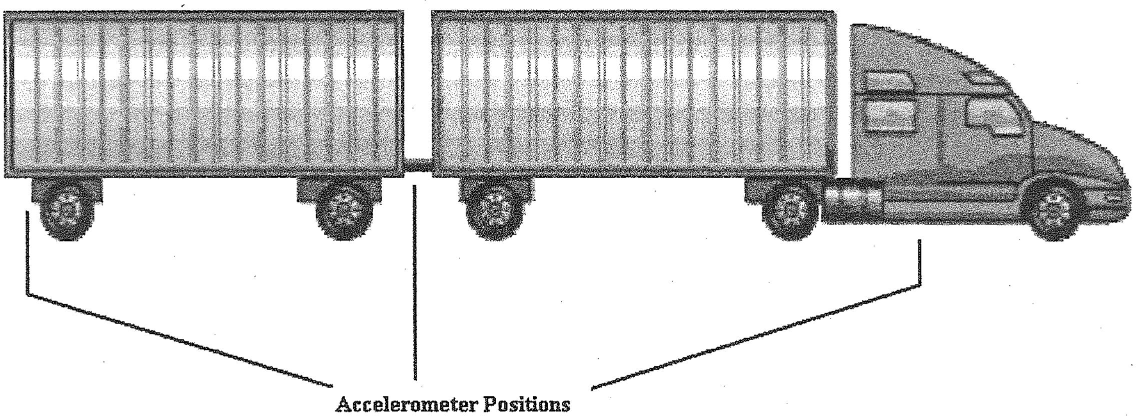

Figure 1 Diagram of ideal accelerometer positions

The cable network has to be as resilient as possible against noise from the environment. Since potentially long distances (up to roughly 40m) have to be spanned, it was decided that an unshielded twisted pair cable with a low pass filter installed at the data logger end would be a suitable solution. The filter has been designed to remove frequency components in the signal above 10Hz. This value was chosen because sway frequencies are expected to be below 10Hz and it is desirable to remove higher frequency road noise, vibration and electromagnetic interference. Standard category 5 cable with RJ-45 ports are used. This cable is easily crimped at the correct length and the terminals clip securely into place in only one orientation. This configuration substantially improves the useability of the system by individuals with no experience with such electronic systems.

Finally, the data logger is a crucial component of the system. The chosen logger is an off the shelf system manufactured by Dataq Instruments. It can log up to 8 differential analogue channels simultaneously at a rate of up to 14000 samples per second with a resolution of 16 bits. This logger was particularly appealing as it is capable of storing the information to SD memory cards (the same as those found in digital cameras). This is an attractive option as it allows for up to 1GB of storage without interruption of the recording process. Furthermore, successive cards may be used to extend the capacity. This means data may be removed from the logger without having to remove the system or connect a computer directly to the logger. This is a highly portable, non-volatile and cost effective way of storing data.

The system is capable of running from voltage sources between 9 and 30 volts. As a result, it can run from small sealed lead acid batteries for many hours or be connected to the vehicle's electrical system through the cigarette lighter.

3.0 Testing Of The System

A number of trials were performed with the hardware in a laboratory setting to ensure that it would operate as expected. These tests were performed to gain familiarity with the use of the accelerometers and to record calibration data for each channel of the respective accelerometers. Readings were taken while each accelerometer was moved over a known path by hand and the data analysed to confirm that the signal could be integrated to give the position of the sensor over time.

To calibrate the sensors, they were held at known angles and the corresponding output voltages were recorded. An interpolating polynomial was then generated to map the output voltages to the accelerations for each channel of each accelerometer. It was vital to calibrate each channel separately because of variations between individual sensors. The results of a system test are shown in figure 2. It can be observed that in these tests the data is relatively noise free.

The second stage of testing was conducted on a car and trailer. These trials were conducted along a straight road at speeds of 40, 60 and 80 kilometres per hour. At each of these speeds, a data set was gathered with the trailer unloaded and another with the trailer evenly loaded with 350kg of gravel. For each speed and each loading state, the vehicle was driven straight along the road for one test and then the run was repeated while performing multiple lane changing manoeuvres.

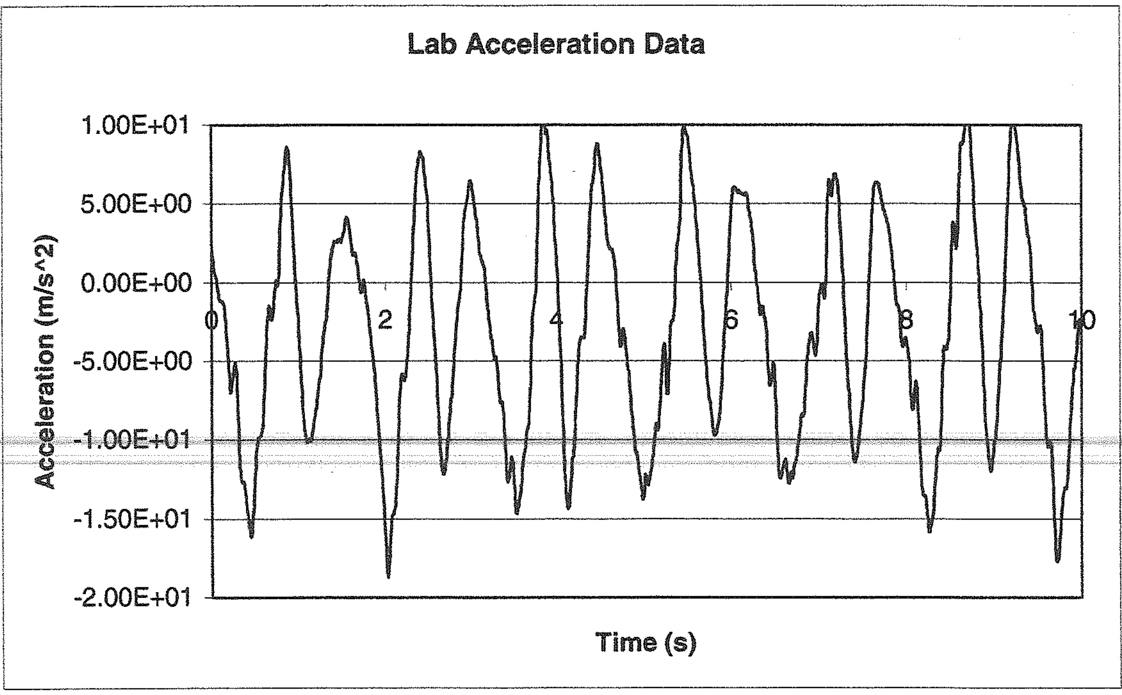

Figure 2 Data gathered from laboritory experiments

One accelerometer was placed on the dash board of the vehicle, another on the hitch and a third on the tailgate of the trailer. The cables were secured to the vehicle to limit their movement and the battery and logger were placed in the centre console of the cabin. Each accelerometer was mounted in a plastic box which was attached to a steel bracket. The bracket was then secured in position with double sided tape. In general it was confirmed that the system was able to be deployed quickly onto a vehicle.

The raw data from these tests was observed to have a very low noise content despite the use of longer cables and potential interference from the environment. A section from a complete data set from the rear accelerometer is shown in figure 3. Full data sets range up to 60 seconds in length. Significant oscillation can be observed in the acceleration data with a range of magnitudes and frequencies. It can also be seen that the accelerometers measure a small constant offset and a time based drift. These effects are unavoidable without the use of more expensive sensors and must be removed during data analysis.

4.0 Data Analysis

A number of ways of analysing the accelerometer data are being investigated and some have shown promise. As can be seen in figure 3, the acceleration data contains a number of anomalies which result in the need for a certain degree of pre-processing as well as integration to give position information of the various locations on the vehicle over time. To date, analysis has involved both frequency and time based techniques. These techniques are still being refined. When lateral sway data can be confidentially obtained, the various sway motions can be compared to give an idea of the swept width of the road trains over time as well as provide an insight into motion dynamics such as trailer roll and rotation in the horizontal plane. A full analysis of data collected from the trailer tests will be included in the final report.

Based on the assumption that the accelerometers generate an error that is a combination of a constant offset and a time based drift, one analysis method developed so far has involved the correction of data through polynomial fitting. After double integration, the linear error in the acceleration data will manifest itself as a cubic error in the position data. This error can then be removed as seen in figure 3. This has so far resulted in a close correlation between measured data and the observed trailer motion.

The analysis so far has focused on shorter data sets of between 10 and 12 seconds in length. These produce a more reliable indication of the position of the vehicle over time. With refinement, the approach outlined will be applicable to longer data sets of up to several minutes. The data gathered from the trailer has shown that some data sets are more difficult to analyse than others. For example, the data gathered from the accelerometer placed on the car dashboard has a much higher offset in the acceleration. This increases the size of the error in the position data relative to the magnitude of the sway. The current analysis method assumes that the motion of the trailer is an oscillation around some mean. Removing the mean leaves the oscillating sway behaviour. Further complications arise when analysis is attempted on sets gathered during lane change manoeuvres.

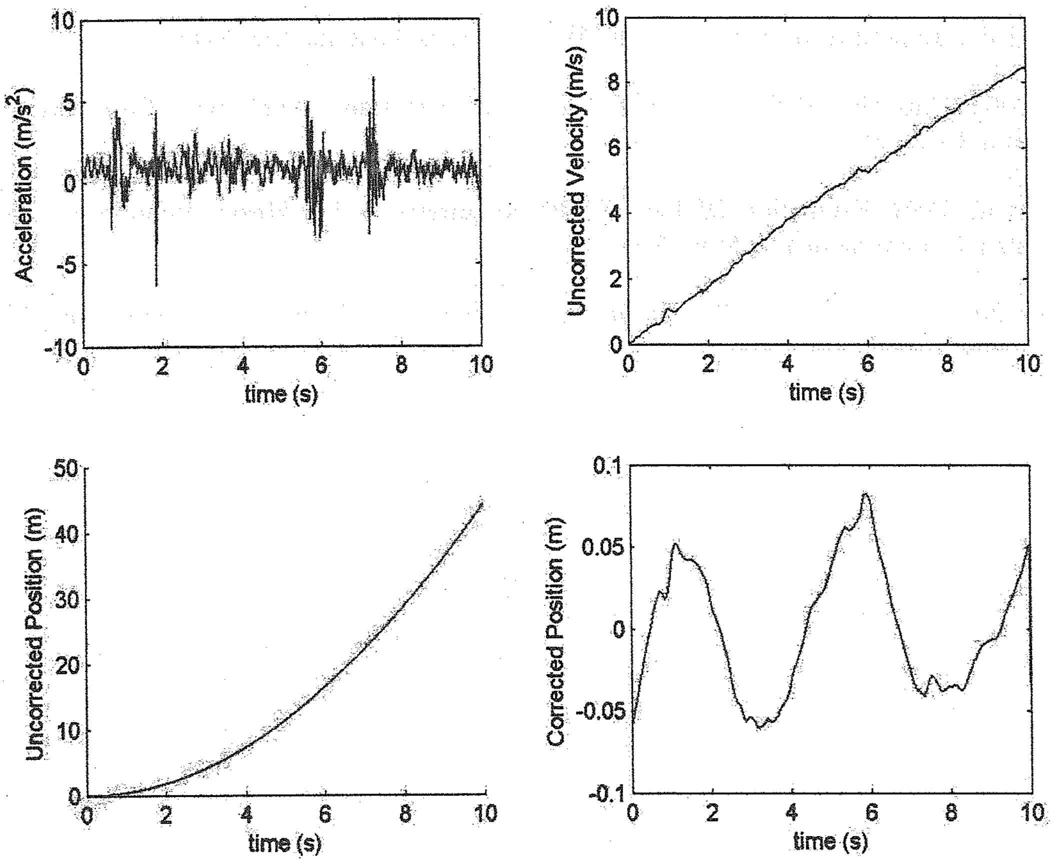

Figure 3 Example of trailer data (accelerometer located at rear of trailer)

Frequency based analysis of the data is currently underway. It is expected that information gathered from this approach will describe the dynamic characteristics of the vehicle. The aim is to determine the major frequency components of the oscillations and their relative magnitudes.

5.0 Conclusions

The system that has been developed has performed satisfactorily however there is a need for refinement in future versions. It is expected that the current system will act as a platform for a more advanced measurement system which may be permanently deployed on vehicles in service.

Preliminary results appear promising and testing has indicated that the output of the analysis thus far is at least indicative of the actual motion of the trailer. Refinement and verification of the analysis technique is underway and results will be included in the final report.

6.0 References

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