University of Southern Queensland

Faculty of Engineering and Surveying

Dynamic Tracking of a Race Car

A dissertation submitted by

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ABSTRACT

A race car driver's track position at any time is essential to safe driving, smooth driving (which can minimise vehicle and driver fatigue and concentration loss) and most importantly, a quick lap time. Unfortunately, in order to find the best line can take a lot of work and laps, generally due to the fact that a driver's perception of track position differing from the actual track position of the vehicle.

Robotic Total Stations (RTS) and Global Positioning Systems (GPS) are becoming more common for the use of machine guidance in the construction, farming and mining industries. Similar systems can be used to report a race vehicles position on the track.

By using RTS or GPS, in a way so the driver can study their line taken for each lap, the driver can be made aware of differences between their actual position and their perceived track position. The report should be viewed not on the track but afterwards together with lap times, so the driver can take time to study and adjust their line taken. This procedure will allow the driver to view the line taken to achieve the quickest lap times, whilst saving time and completing a minimum number of laps. Also this can lead to fine-tuning a driver’s technique by highlighting individual laps and sections of the circuit that may require a change in the driver’s technique. Therefore once the project has been completed a better understanding of the applicability of both RTS and GPS to track and map a race cars track position will be known, as well as which is the better system for the task.

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Dated: 02 / Nov / 2006

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Joshua King

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ACRONYMS

The following abbreviations have been used throughout the text and bibliography:-

RTS	Robotic Total Station.
TSCe	Trimble Survey Controller
GPS	Global Positioning System
TGO	Trimble Geomatics Office
PC	Personal Computer
ATS	Advanced Tracking Sensor
RTK	Real Time Kinematic
HRT	Holden Racing Team
CAMS	Confederation of Australian Motor Sport.
ECU	Engine Control Unit (ECU)
VCS/DVS	A category of the V8 Supercar formula
CTD	Category Technical Delegate
AVESCO	Australian Vee Eight Supercar Company Pty Ltd
USQ	University of Southern Queensland

CHAPTER 1

INTRODUCTION

1.1 Background to the Research

The use of Robotic Total Stations (RTS) and Global Positioning Systems (GPS) for machine guidance in the construction, farming and mining industries is becoming more common. Machine guidance and vehicle tracking is still a relatively new technology, and the extent of the applications of this technology is still unknown as "new applications appear on a daily basis" (Hazel Baker 2002). The machine guidance industry is also expanding rapidly and the market is producing higher and new demands on the development of this technology.

Similar systems to those that are currently being used for machine guidance can also be used to report a race vehicle's position on a race track. Instruments used for this dissertation include, a Trimble S6 Robotic Total Station and a Trimble 5800 Global Positioning System. Other systems are available that have machine guidance capabilities, but this equipment was used as it is leading technology and has the survey accuracy and capabilities required for testing.

The position of a race car on a track can affect safety, smooth driving (which can minimise vehicle and driver fatigue and concentration loss), and most importantly a quick lap time. Optimal track position and line can produce a quick lap time, this can be established by accurately tracking the vehicle to give the driver a display of where improvements on track position can be made.

To determine the optimal line for the car on the track requires a drivers' knowledge of what line works on different corners. This is easy to visualise on a plan where a total view of the race track can be seen at one time. Once on the track however it is much more difficult for a driver to establish an optimal line. Tracking the vehicle and providing a visual report to the driver greatly aid's their ability to select a fast line.

To create a quick lap there can be a lot of work and a lot of laps involved, generally due to the driver's perception of track position differing from the actual track position of the vehicle. By using RTS or GPS, in a way the driver can study their line taken for each lap, the drivers' technique can be fine-tuned by highlighting individual laps with the corresponding lap times, therefore sections of the circuit that may require a change in the driver's method of driving can be emphasized and the driver can take corrective action sooner.

1.2 Aim

The aim of the project is to evaluate the suitability of RTS (Robotic Total Stations) and GPS (Global Positioning Systems) for dynamic tracking of a race car to optimise the driver’s line on the track and improve performance.

1.3 Objectives

The objectives of this dissertation are;

1. Review existing literature and projects relating to dynamic tracking using GPS and robotic total stations.

2. Design a testing regime for both GPS and RTS for high-speed tracking including the mapping of a suitable test track.

3. Test the utility (accuracy, effect of latency, logging rates and the difference in alignments) of Total Stations and GPS for high-speed vehicle tracking under controlled conditions.

4. Analyse the results of these tests in order to report on a vehicles track position at any time.

5. Report and document the results.

1.4 Justification

The current systems of vehicle tracking for race car drivers have limited capacity to accurately identify the actual vehicle position. Current systems rely on time and speed to calculate the distance travelled by the vehicle along the racetrack. This information only provides a vehicle position along the track not the actual vehicle position between the outer edges of the track. To achieve a point accuracy of less than 0.500 metres provides a useful output that can be used by a driver to improve their race line and to outline where driver errors are being made.

The driver can be made aware of differences between their actual position and their perceived track position. The report should be viewed not on track but afterwards together with lap times, so the driver can take time to study and adjust their line taken. This procedure allows the driver to view the line taken to achieve the quickest lap times, whilst saving time and completing a minimum number of laps.

Most professional motor racing categories are currently trying to limit the costs involved in racing for race teams so the race category can maintain operations. The race vehicles and drivers are still required to perform at a high level in order to maintain viewer number and therefore sponsorship participation. This technology if successfully developed will include an improvement on current race vehicle efficiency and costs. Tyre usage/wear and engine wear, are major expenses related to racing, through the appropriate use of this technology less time on the track will be required to achieve a fast lap time to prepare for racing, therefore less tyres are used and less engine time is required for drivers to adjust to new circuits. The availability of this technology may also provide future safety initiatives for the regular on road driver. Most of the technology used in professional racing categories is filtered through the manufacturers to the everyday user, (when the technology becomes cost effective to market). This can lead to quicker vehicle accident location in an emergency or locating stolen cars may become simpler.

High accuracy (Survey Grade) GPS and RTS does not appear to have been tested under these circumstances before. It is always useful to test the extent of the capabilities of new technology so design errors or possible advantages can be found to create new more advanced technology for differing applications in the future.

1.5 Overview of Dissertation

The structure for the remainder of this dissertation is outlined to provide the reader with a sense of direction for the research.

The second chapter is aimed at providing a basis to relate the work in this dissertation to any previous research and to draw from previous conclusions. This has been done by;

1. Discovery of accuracy and equipment function information, relating to dynamic tracking using Robotic Total Stations and Global Positioning Systems.

2. Critical Review of previous research and testing to develop a procedure for testing equipment and data reporting. The critical review of previous literature will also explore the relevance/validity it has toward the purpose of this dissertation.

3. Reporting on the relevant information found to establish an appropriate testing programme.

Chapter 3 outlines the testing regime, data analysis method, proposes a realistic timeline and details possible resource requirements for the completion of this project. The testing involved took place at a race circuit where measurements of the track surface were completed using standard survey methods with GPS and Total Station prior to Vehicle Testing. The data collected from the vehicle was then compared and presented relative to the measurements of the track.

Chapter 4 details the testing results and an explanation of the project outcomes.

Chapter 5 comments on conclusions and proposes recommendations.

1.6 Conclusions

Robotic Total Stations (RTS) and Global Positioning Systems (GPS) are becoming more common for the use of machine guidance in the construction, farming and mining industries. Similar systems can be used to report a race vehicles' position on the track. By evaluating the usefulness of RTS and GPS for the dynamic tracking of a race car to improve the driver's line and performance and reporting in a way so the driver can study their line taken for each lap, the driver can be made aware of differences between their actual position and their perceived track position.

The research resulted in a report that outlined the applicability of GPS and RTS for dynamically tracking a race car. A process was also developed to show the driver the differences between their actual track position and their perceived track position.

Chapter 2 reviews literature and other research which relates to the work done in this dissertation and draws conclusions from prior testing and develops an appropriate procedure for equipment testing and data reporting.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

To provide a knowledge of the usefulness of RTS and GPS for the purpose of dynamic vehicle tracking, the workings and capabilities of the equipment being used for this research project is detailed through this chapter. The instruments being used are the Trimble S6 Robotic Total Station and the Trimble 5800 Global Positioning System. (See Figure 2.1.)

Trimble S6
(Robotic Total Station)

Trimble 5800
(Global Positioning System)

Figure 2.1: Two Current Instruments Used for Machine Guidance

Further knowledge and discussions of situations where the equipment is designed to be used, is outlined in the literature review also. The third part of the literature review includes previous testing completed by others and reporting on outcomes from the testing.

2.2 Trimble S6 (Robotic Total Station)

2.2.1 Robotic 'Mag Drive' Servo

The Trimble S6 Total Station uses an innovative servo system called 'Mag Drive Servo Technology'. This technology is based on frictionless electromagnetic drive. The Mag Drive system allows servo motors to be directly mounted on the horizontal and vertical axis, therefore removing the requirement for mechanical gearing. By integrating this technology with the angle sensor, speedy angle values can be provided and used by the angle processor. (Lemmon & Jung, 2005).

The Mag Drive servo system allows high accuracy high speed turning capabilities that due to the frictionless movement uses less power, removes servo noise and minimises instrument wear. (Lemmon & Jung, 2005). This means the Trimble S6 has an improved ability to track a high speed race car as opposed to other Robotic Total Stations. See (Table 2.1.)

Table 2.1: Comparison of Instrument Turning Speeds

Instrument	**Turning Speed (As Specified)**
Trimble S6	115°/ sec
Trimble 5600	60° / sec
Leica TPS 1200	45° / sec

The servo drive consists of the main magnetic holder, in which are two areas of magnets and soft iron. These are spread in concentric cylindrical sections, which are separated by an air gap that provides enough room for a motor winding. The winding is divided into 3 separate components to supply control for changing the direction of rotation and also offering a fine control for small rotational movements. (See Figure 2.2)

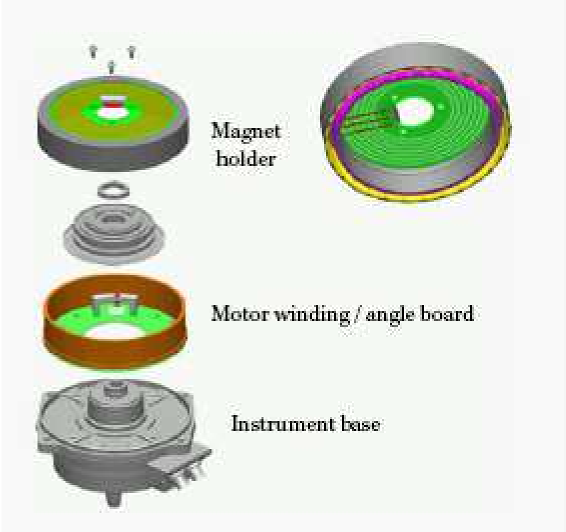


Figure 2.2: Integrated angle and servo system.
(*Source: Lemmon & Jung, 2005*)

A current is applied through the winding and by using electromagnetic forces the magnetic holder can be rotated allowing a quiet, frictionless, non-contact rotation that provides fast, smooth movement. (See Figure 2.3.) This is a useful and necessary feature that allows good accurate tracking of a fast moving vehicle.

The magnetic servo drive has three basic working modes;

1. Driving Mode. Movement is controlled by the tangent screws or through system processes (Remote Operation)

2. Friction Mode. The instrument drive can be rotated manually

3. Holding Mode. The drive works similarly to a clutch, which locks the instrument in position and prevents movements.

The working modes of the magnetic direct drive system offer high quality performance that is of a higher standard than that of the more conventional systems. This makes the instrument a useful choice for many tracking applications.

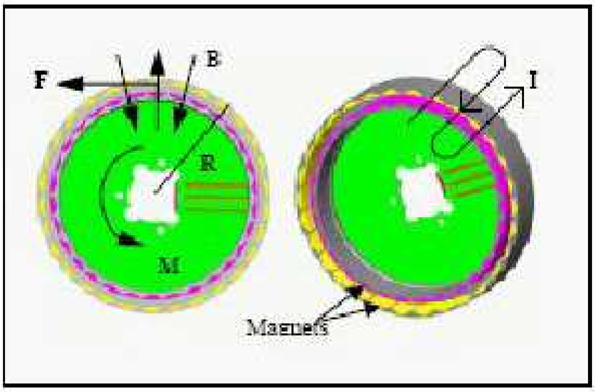


Figure 2.3: Servo drive operation.
(*Source: Lemmon & Jung, 2005*)

2.2.2 Angle Sensor

The Trimble S6 uses an optical based sensor unit that is directly integrated with the magnetic servo drive. As well as accurately determining angles, the angle measurement system also compensates for, deviations of the plumb axis, collimation errors, trunnion axis tilt and arithmetic averaging which reduces sighting errors.

The angle sensor unit consists of glass circles, which include both a fine and a coarse code pattern. Each of these codes is inscribed in two tracks on the glass circles. An absolute code is distributed on one track and an incremental code is distributed on the other track. By using two separate tracks a uniform accuracy and resolution is formed around the glass circle. To ensure that the absolute encoder is tough and less prone to mounting errors, each of the sensors is located on opposing sides of the disk.
(See Figure 2.4.)

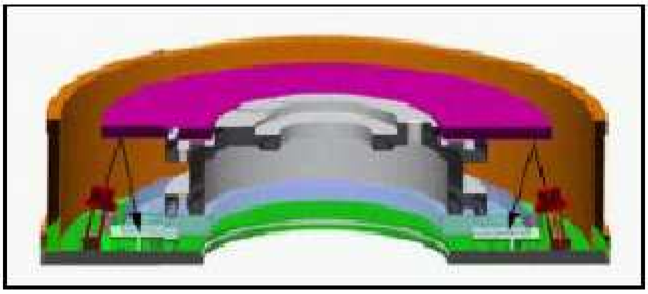


Figure 2.4: Cross-section of an Angle Sensor Unit.
(Source: Lemmon & Jung, 2005)

The angle sensor is mechanically integrated into the servo drive housing. The central unit contains the optical glass disc, the laser transmitter, image area detector and the servo drive windings. The angle sensor is designed not only to display and store angle data but also to support the servo system with fast data for angle calculations. (Lemmon & Jung, 2005)

The angle sensor rapidly acquires accurate angles but also compensates for deviations of the plumb axis, collimation errors, trunnion axis tilt and arithmetic averaging of readings for the reduction of sighting errors.

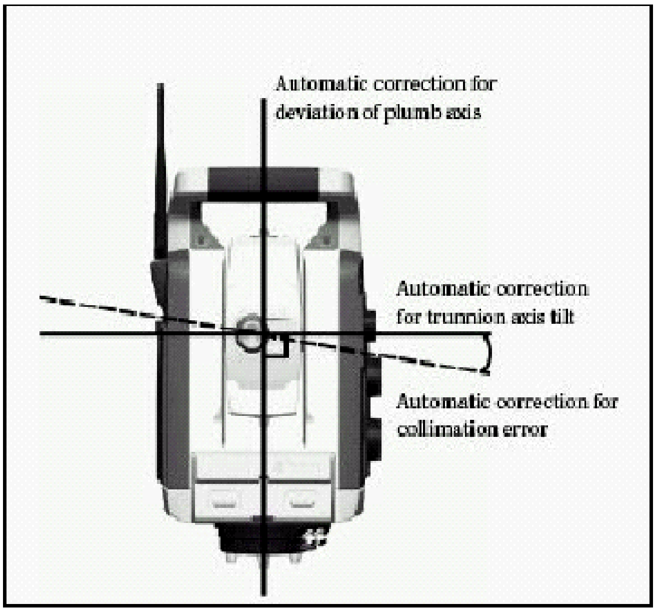


Figure 2.5: S6 automatic corrections.

(*Source: Lemmon & Jung, 2005*)

Deviation of the plumb axis most likely occurs if one or more of the tripod legs slips or moves due to unstable ground or ground movement i.e. (when tarmac expands when heated). Compensation for the errors in this movement is essential to achieving accurate measurements and results. Most current total stations have dual axis compensators that correct for deviations in horizontal and vertical axis due to mislevelment. The dual axis compensator of the S6 uses a light beam that is reflected toward a liquid surface. A sensor is then used to detect the angle of the beam of light in two different directions to automatically correct for any mislevelment.

Horizontal collimation error in a theodolite causes systematic errors in the horizontal as well as vertical directions. Collimation error is caused by the instruments crosshair, not been parallel with the instruments optical axis and not being located on the exact mechanical centre of the telescope. (Nicole Jones 1998) (See Figure 2.6). The Trimble S6 can determine collimation errors from pre-measurement tests. Angular measurements are performed on both faces so a collimation error can be calculated and stored in the instrument. The calculated collimation errors are then applied to each angle observed. Thereby any single angle read is automatically corrected for collimation, therefore eliminating the need to measure on both instrument faces.

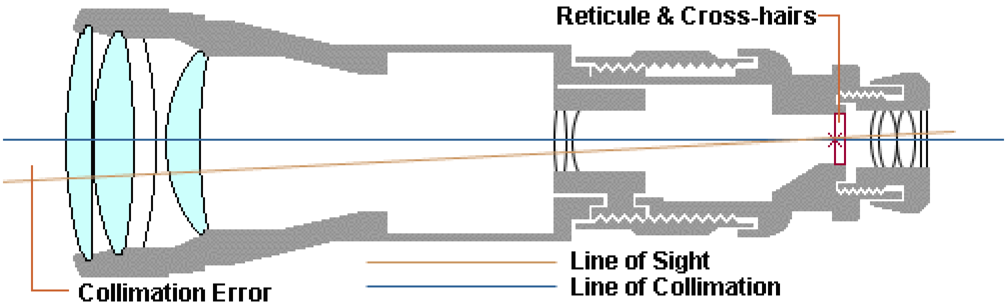


Figure 2.6: Cross Section through a Theodolite Telescope

(Source: Nicole Jones 1998*)*

Trunnion axis tilt error is the difference between the trunnion axis and the plane perpendicular to the plumb axis. The Trimble S6 can determine the trunnion axis tilt error by performing a pre measurement trunnion axis tilt test, which is similar to the solution of collimation errors. Angular measurements are taken on both faces where the trunnion axis tilt error is calculated and stored in the instrument. The corrections are then applied to all subsequent horizontal angles. **(**Lemmon & Jung, 2005)

The S6 can reduce sighting errors that are caused by the misalignment of the instrument or by instrument movement whilst measuring by;

- Using Autolock Technology. Autolock automatically locks onto and tracks the target, therefore reducing manual sighting errors.
- Sure Point accuracy assurance. When the instrument is aimed at the target the servo motors are designed to hold the aimed angle. This ensures the errors due to small sighting movements of the instrument are eliminated.
- Automatically averaging angles during distance measurement. When measuring in standard mode (STD) the instrument takes approximately 1.2 seconds to measure each distance. During this time angles and distances are averaged to obtain the best possible accurate measurement. It is possible to also use other measurement methods which average more measurements to further reduce measurement errors.

2.2.3 Distance Measurement

The Trimble S6 uses two modes of measuring distances. The first mode is the Direct Reflex mode which uses direct reflex technology to measure distance without the assistance of a reflective prism. The second mode is the prism mode that requires the use of the reflective prism. Prism Mode can be performed either as standard, tracking or averaging.

Standard Prism Mode takes 1.2 seconds to measure a distance, although the instrument can perform quicker, a number of measurements are taken and then averaged within the 1.2 second time frame.

Averaging Prism mode continuously takes standard measurements (of 1.2 seconds long) and continues to average each set of measurements until the observation is stored. That is every 1.2 seconds the measurement is averaged with the measurement performed previously.

Continuous topo mode continuously tracks the target prism taking measurements at a minimum of 1.0 second intervals. This mode is particularly useful for vehicle tracking as it offers quick measurements with a good accuracy. (See Table 2.2). Measurements being taken at 1.0 second intervals give a good number of observations of a vehicle moving at speed. (See Table 2.3).

Table 2.2: Trimble S6 Distance accuracy of Prism Mode

Distance measurement	
Accuracy (S. Dev.)	
Prism mode	
Standard	± (3 mm + 2 ppm) ± (0.01 ft + 2 ppm)
Tracking	± (10 mm + 2 ppm) ± (0.032 ft + 2 ppm)

Table 2.3: Expected distance between point measurements for the Trimble S6.

Measurement Time 1.0 second (Trimble S6), speed at which measurements are taken.

Tracking Speed (km/h)	**Tracking Speed (m/s)**	**Distance Between Measurements (m)**
80km/h	22.22 m/s	22.22 m
60km/h	16.67 m/s	16.67 m
40km/h	11.11 m/s	11.11 m
20km/h	5.56 m/s	5.56 m
10km/hr	2.78 m/s	2.78 m

2.2.4 ATS (Advanced Tracking Sensor)

ATS automatically locks onto the target and the instrument will continuously track the target, giving an elevation and slope for the target position. The S6 ATS is designed for high speed low latency situations including machine control. Advanced tracking mode has a specified latency of less then 200 milliseconds, with a selectable output rate between 1 and 6 Hz. Angle and distance data is synchronised (Figure 2.7)and used together to interpolate a vehicles position, which provides current precise information. Onboard software is also used to further correct errors involved with data latency. This allows for greater accuracy when tracking machinery. The instrument used with synchronisation allows ATS to track a moving vehicle as close as 30 metres at a speed of 46 km/hr.

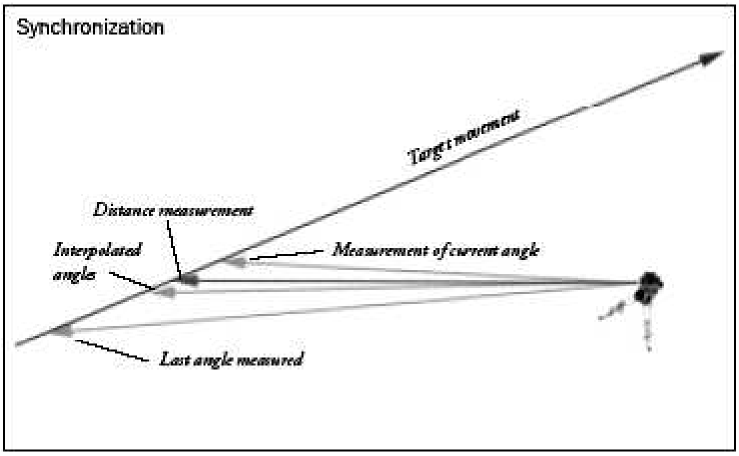


Figure 2.7: The Synchronisation Process
(Source: Trimble 2006)

2.3 Trimble 5800 GPS

2.3.1 RTK GPS

RTK GPS includes a roving station and a base station which provides a real time ground based position. The RTK GPS uses differential positioning where the base station along with the rover acquires a position from GPS satellites. Corrections are calculated from the difference between the GPS positions and these are communicated between the systems using a radio connection. From the corrections and the differentiated position acquired from satellites accurate real time ground coordinates can be fixed and stored in a data device to allow viewing and data editing at a later time. RTK measurements can be taken at a maximum speed of 1.0 second intervals using the continuous topo function, (See Table 2.4). This rate of measurement is sufficient to acquire relevant measurements and results.

2.3.2 Integrated system

The Trimble 5800 GPS is a fully integrated system that means there are no external wires and all the components are completely incorporated within the rover system. (See Figure 2.8) The 5800 is a lightweight piece of equipment that is very robust. The 5800 GPS can with stand a 2-meter drop on a hard surface and is also submergible to a depth of 1 meter. Therefore the Trimble 5800 GPS is robust enough for taking measurements on a high speed vehicle. The Trimble 5800 also has 2 MB of internal memory. This amount of memory makes data collection for post-processing easy and efficient, whether for static or kinematic surveying.

Figure 2.8: The Fully Integrated Trimble 5800 GPS

(Source: Trimble 5800 Data Sheet 2006)

Table 2.4: Expected distance between point measurements of the 5800 GPS.

Measurement Time 1.0 seconds (Trimble 5800 GPS), speed at which measurements are taken.

Tracking Speed (km/h)	Tracking Speed (m/s)	Distance Between Measurements (m)
80km/h	22.22 m/s	22.22 m
60km/h	16.67 m/s	16.67 m
40km/h	11.11 m/s	11.11 m
20km/h	5.56 m/s	5.56 m
10km/h	2.78 m/s	2.78 m/s

2.4 Previous Testing Undertaken

Due to the nature of this dissertation not many tests have been completed previously on fast moving vehicles. The technology used on the survey instruments (RTS and GPS) is relatively new and the extent of the uses for the technology is still being determined. Most testing has been completed by tracking relatively low speed vehicles at a high accuracy, for the purpose of machine guidance for construction and farm use. Cars are tracked using GPS, taxis and many road trains use the technology, although it's used for the general location of the vehicles and at a low positional accuracy.

Some previous testing of instruments used for vehicle tracking includes;

- Evaluation of a hydrographic technique to measure on-farm water storage volumes, *Latency Correction* (Gibbings and Raine 2003)

- Testing of Robotic Total Stations For Dynamic Tracking, *RTS use and expected accuracy,* (Garget 2005)

- Development of a GPS-based System for Monitoring Driver Performance, *GPS use for tracking and speed calculations,* (Zhang 2003)

- V8 Supercar Teams
    - HRT (Holden Racing Team, use other means of calculating track position, but somewhat inaccurate, no report/image for the driver).

    - Stone Brothers Racing (Ford, would like to use the idea but the race class is limited by current CAMS and AVESCO rules and regulations).

2.4.1 Latency Correction

"A latency correction factor, which ensures the GPS position corresponds to the location where the depth was measured was calculated from the difference in offset when the same transect across the storage was measured at the same speed in opposite directions." "This latency correction factor was subsequently applied within the HYDROpro software to each of the hydrographic observations." (Gibbings & Raine, 2003)

Using a similar technique to Gibbings and Raine the latency error can be calculated and applied to measurements to give a more relevant and correct result. This can be done by measuring a line in opposite directions. A steep "U" shape change in height (similar to a dam) pronounces the difference between the measurements in opposite directions. The difference between the two lines of measurements gives twice the latency error, (there is latency error in each direction of measurements).

2.4.2 RTS use and expected accuracy

Previous testing of Robotic Total Stations completed by Garget, concluded that the overall accuracy of an RTS is dependent on two main factors:

1. The speed of the moving target: and
2. The distance from the RTS to the target.

Garget also stated that, the dynamic accuracy of an RTS is improved as the target distance is increased.

This information suggests that the total station should bet up as far from the prism as possible, that still allows measurements to be taken. By doing this the required turning speed from the instrument is reduced and the dynamic accuracy is improved.

2.4.3 GPS use for tracking and speed calculations

Previous testing regarding the accuracy of speed and heading data has been completed with the following conclusions. The experiment regarding the variation of speed data from the GPS shows that the unit is within 2.2km/h for a constant velocity of 30km/h, 40km/h, 50km/h and 60km/h. The mean of speed data for circular motion is 0.42 m/s less than the linear motion. The maximum fluctuation in respect to the mean is 3km/h. Since the normal speed in the urban area is around 50km/h or 100 km/h. This accuracy of speed data from GPS unit is sufficient for the application of driving performance monitoring. (Zhang 2003)

The experiment of heading data from the GPS unit shows the variation is within 3 degrees. The variation of angular rate of change of direction will be the double of the heading data, which are around 6 degree/s. This is supported by the data from the circular motion testing with constant velocity. The heading data is clearly shown the trend of directional change during the circular motion testing. The maximum difference between the mean and the trial data of angular rate of change of direction is 5.9 degree/s. The accuracy of angular rate of change of direction is sufficient for the application of driving performance monitoring. Therefore the angular rate sensor can be omitted from the system. (Zhang 2003)

Although this testing gives a basic understanding of the expected accuracies, accurate road location, higher speed race type applications and latency calculations will be required to be investigated in greater detail.

2.5 Existing Technology

The technology currently used by motor racing vehicles in Australia to give a vehicle's on track location includes vehicle sensors and lap timing. The technique of using this relatively simple technology provides pit crew and engineers with a relatively inaccurate track position. The vehicles telemetry system does update the car location on the circuit. The data analysis system that is used creates a track map based on lateral acceleration and vehicle speed. It doesn't use GPS or conventional survey methods to position the car on the circuit. Whilst on circuit the telemetry system uses this known track map and references the car position based on the lap distance travelled to that point, the distance is derived from the vehicle speed data and time to that point.

The current regulations regarding the use of technology at Australian V8 Supercar race events are listed in APPENDIX E.

Currently there is a restriction on the use of GPS and RTS for vehicle positioning, but this is mainly due to cost restrictions to maintain a level competition. With the cost of GPS and RTS continuously reducing and the ability of this technology to reduce overall costs it is a large possibility that this technology can be introduced to Australian motor racing in the near future.

The Indy Car racing league uses cables buried underneath the track to record each cars passing as well as a high speed camera which takes a picture at every ten-thousandth of a second. This only provides a lap counter and lap timing device it doesn't provide a continuous position of the vehicle on the track.

2.6 Conclusion

After completing the above literature review a further knowledge of the equipment being used has been achieved. From this literature review also, a number of conclusions can be made. Latency will be a major source of error particularly in GPS measurements and measurement speed will effect RTS measurements also. To achieve the best results from the RTS two major points need to be considered.

1. The speed of the moving target: and
2. The distance from the RTS to the target.

According to Garget (2005) and Chua (2004) these two points are major factors affecting RTS accuracy.

To obtain the best possible results from GPS approximately 7 satellites should be visible when taking measurements and a clear view of the sky should be established, clear of trees or other obstructions.

Chapter 3 explains methods used for testing the RTS and GPS equipment. These methods produce a process to test conclusions drawn from chapter 2. The methods also establish the accuracy and consistency of the GPS and RTS systems and while testing the suitability for dynamically tracking a race car.

CHAPTER 3

METHODS

3.1 Introduction

As before the aim of the project is to evaluate the suitability of RTS (Robotic Total Stations) and GPS (Global Positioning Systems) for dynamic tracking of a race car to improve the driver's line and performance. To achieve the objectives regarding the aim of the project the following steps were completed;

Field Testing, including

- Vehicle tracking on the race track using,
    - RTK GPS and
    - RTS

Data Analysis, including

- Analysis of measured data to provide accurate vehicle position
- Visual output to inform driver of on track vehicle position

3.2 Project Planning

1.0 Primary Research:

A review of pre-existing research and literature including articles, books, journals, magazines and other appropriate sources will provide a good understanding of the equipment being tested and expected results on accuracy and reliability.

2.0 Data Collection and Testing:

Testing will be completed by tracking a race car using RTS and GPS at varying vehicle speeds. A track outline will have to be measured for accuracy testing and also for visualisation purposes.

3.0 Analysis:

Data collected from the data collection and testing stage will need to be refined to make a clear output for visualisation purposes, using Trimble Geomatics Office and Terramodel software packages. The visual output will need to be able to be presented on paper for the driver to study.

4.0 Comparison of Systems:

Outputs and reports of both GPS and RTS should be viewed and analysed for appropriateness for the intended use. The better system for the purpose of tracking race cars should be identified and discussed why the decision was made for that particular system.

5.0 Conclusion:

Discuss the analysed data and provide conclusions regarding the accuracy and usefulness of the two systems (GPS and RTS) for the tested purposes. The usefulness of the output report will also be discussed.

3.3 Lessons from Literature Review

Prior research has supplied information about the equipment being used and the methods of previous testing, therefore allowing me to establish a testing regime to use the equipment in the best possible manner and to achieve the best possible results. The Literature Review has revealed the following points need to be considered when testing and analysing results.

a) RTS equipment was set up to have a clear view of the entire race track.

b) The RTS equipment was set up to achieve the longest possible sight lines (500-700 metres, Trimble S6 general specifications) for tracking and accuracy purposes.

c) GPS Latency is an issue, prior testing to find an applicable value to cancel latency errors. By measuring one line in a forward direction and the same line in a reverse direction, the difference between the measured lines equals twice the latency, (Gibbings and Raine 2003). By applying the latency value to measurements taken of the moving vehicle a true position can be established.

3.4 Data Collection and Testing

3.4.1 Testing S6 RTS

Figure 3.1: Trimble S6 Robotic Total Station

(Source: Trimble 2006)

3.4.1.1 Components and Operation of an RTS.

The four major components used to track the race vehicle, include;

1. Robotic Total Station
2. 360° Prism (target)
3. Remote Keypad
4. Radio Communication (Keypad to Total Station)

The remote keypad has radio communications to the robotic total station which allows the user to operate the RTS at some distance away.

The RTS initially takes a measurement of the prism and the Automatic Tracking Sensor (ATS) can establish a connection from the RTS to the prism. This is where remote tracking of the prism begins. The measurements are transmitted to the remote keypad which allows inputs by the operator to be made, which are then relayed back to the RTS. Once the target begins to move the ATS guides the instrument to follow the prism. Measurements of the moving prism can be taken automatically at user defined intervals or the prism can be measured when stationary. The remote keypad has complete control of the robotic total station and all functions available at the instrument can also be performed through the remote keypad. (See Figure 3.2)

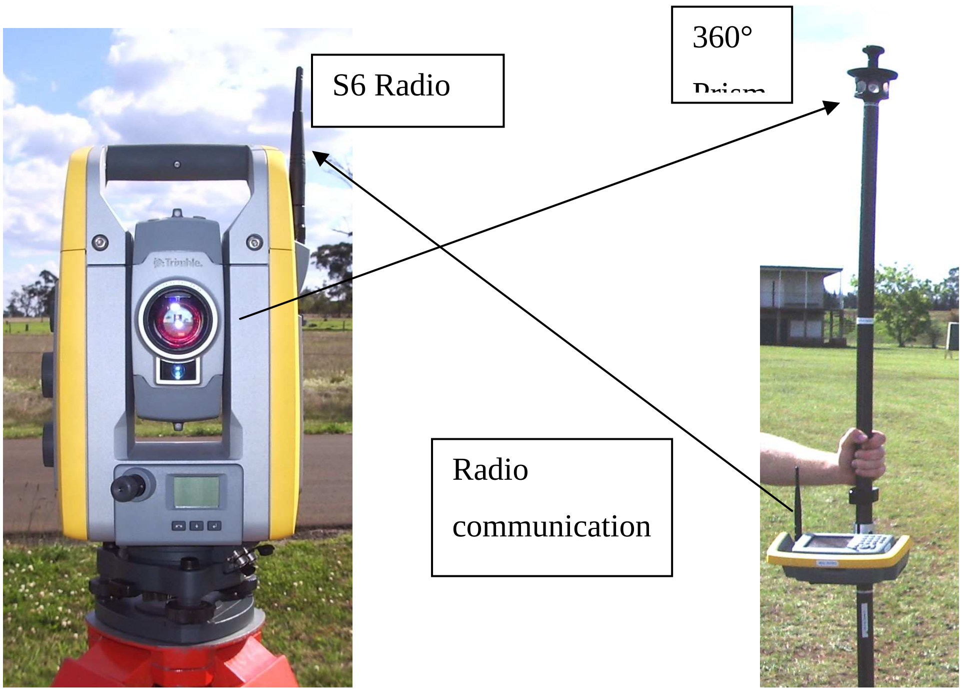


Figure 3.2: Operation and Components of a Robotic Total Station.

3.4.1.2 RTS Equipment Positioning/ Set up.

To achieve constant tracking of the race vehicle the RTS equipment was set up to have a clear view of the entire race track. This allowed constant tracking of the prism which achieved a constant measurement of the moving vehicle, this provided the best possible output. According to the equipment specifications, when the line of sight to the prism is interrupted the RTS can loose its fix on the prism and a connection will have to be re-established by directing the RTS to the prism.

As the instrument needs to be set up in a position to achieve a clear view of the prism at all times, the target prism was located on the vehicle in a position so that it was unimpeded in a 360° view. This eliminates any interference from vehicle components in the tracking process and allows clear vision to the prism at all times as the vehicle travels around the circuit.

The RTS equipment was set up to achieve the longest possible sight lines (500-700 metres, Trimble S6 general specifications) for tracking and accuracy purposes. For tracking purposes longer distances give the equipment a better chance to follow the moving target as the turning capability of the instrument is *115degrees/sec.* Garget 2005 concluded that the overall accuracy of an RTS is dependent on two main factors:

1. The speed of the moving target: and
2. The distance from the RTS to the target.

Therefore longer sight distances provide better accuracy and better tracking abilities.

3.4.2 Testing 5800 GPS

Figure 3.3: Trimble 5800 Global Positioning System

(Source: Trimble 2006)

3.4.2.1 Components and Operation of a GPS.

The three major components used to track the race vehicle with GPS, include;

1. Base Station
2. GPS Receiver
3. Data Collector/Controller

GPS base station

The GPS base station takes satellite information and establishes a co-ordinated ground position. This provides a basis to create differential co-ordinates and measurements between the GPS base station and the GPS receiver. This is used for a Real Time Kinetic (RTK) system. A Trimble base station was used for testing purposes.

GPS receiver

The GPS receiver was attached to the vehicle being tracked. Satellite information is used to establish a co-ordinated ground position, similar to the base station, and through radio communications a corrected differential position can be calculated and measured at the receiver. This provides a position of the vehicle at any point in time. The receiver used for testing was a Trimble 5800 GPS.

Data Collector/Controller

The data collector/controller used was connected to the receiver and stored on the vehicle in a secure position. This device is used to control the GPS and enter required settings and other inputs, while also being the main storage device for measured data. The controller stored the GPS measurements of the moving vehicle's position and the controller allows this information to be edited at a later time.

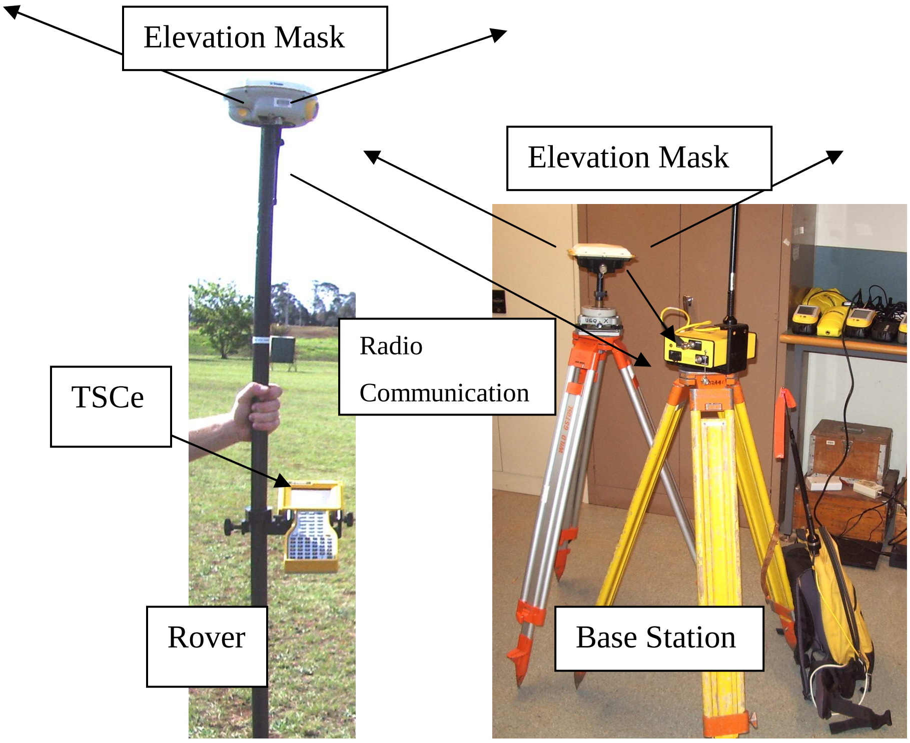


Figure 3.4: Operation and Components of a Global Positioning System

3.4.2.2 GPS Equipment Positioning/ Set up.

The GPS base station needs to be set up in an area that provides a clear, unobstructed view of satellites while also allowing for a clear radio connection to the GPS receiver.

The GPS receiver was attached to the vehicle in a position to limit obstructions from the vehicle itself. Objects surrounding the race track, such as buildings and trees may also affect the ability of the GPS receiver to connect with satellites.

The data collector/controller was attached to the GPS receiver to store measurements of the vehicles position. The data collector was kept in the vehicle so it was connected to the receiver at all times.

GPS Latency is a large issue that can introduce errors in all GPS tracking measurements. Prior testing can be completed to establish a latency error then an applicable value can be used to cancel latency errors.

By measuring one line in a forward direction and the same line in a reverse direction, the difference between the measured lines equals twice the latency, (Gibbings and Raine). By applying the latency value to measurements taken of the moving vehicle a true position can be established.

3.4.3 Field Testing

To evaluate the suitability of RTS (Robotic Total Stations) and GPS (Global Positioning Systems for the dynamic tracking of a race car to improve the driver's line and performance, testing included;

1) Comparing measurements of the vehicles position over a predetermined line; and
2) Comparing measurements between GPS and RTS to give a difference between instrument errors.

(Testing took place on a temporary private track at the University of Southern Queensland.)

Comparing measurements of the vehicles position over a predetermined line was done by measuring using static survey methods to measure an established line using both GPS and RTS. By measuring the same point with the GPS and RTS a direct comparison was made to establish a base difference between survey systems. This baseline was also used to compare tracking measurements to give point deviations from the control line. These point deviations include instrument error and driver error.

Comparing measurements between GPS and RTS to give a difference between instrument errors was done by using measurements from dynamically tracking the vehicle and finding a difference between the instrument measurements. This provides a difference in instrument errors between GPS and RTS for dynamic measurements at various speeds.

3.5 Data Analysis

Measurement data taken using the S6 was stored directly into a TSCe (Trimble Survey Controller). The TSCe can be linked to a PC using a parallel port to USB connection. An ActiveSync program was used to communicate between the TSCe and PC. From here the data was transferred from the TSCe to a PC for processing and reductions. The data can be transferred using differing formats. The format used for this process is the **.dc** file format. This allows the data to be processed in TGO (Trimble Geomatics Office) or Terramodel using the import data commands or by dragging the data files into the program window.

Measurement Data taken using the GPS was also be stored directly into a TSCe. Downloading the information is the same process to that of the S6 above. The files used were also .dc file format to allow processing to be completed by TGO or Terramodel, in the same way as the S6 data files.

3.5.1 Software used

The processing, reduction and analysis of measurement data was completed using a number of software packages including;

i. Trimble Geomatics Office (TGO)
ii. Terramodel
iii. Microsoft Excel

Trimble Geomatics Office is used for editing and processing raw data. The software allows the data to be spatially co-ordinated to allow comparisons and a detailed analysis.

Terramodel can also be used for editing and processing but has a better ability to output paper based maps and plans. This allows a print out to be created to give to the race car driver, so a simple visualisation of track position can be created.

Microsoft Excel can be used to edit raw data files to create compatible formats and can be used for a statistical analysis or comparison of measurements.

3.6 Conclusions

All testing described in this chapter was completed successfully and the results will be discussed in Chapter 4. The GPS and RTS were put through tests to establish their appropriateness for tracking a race car.

Unfortunately testing the equipment on a race car was not possible due to equipment restrictions, this meant the vehicle and facility for testing had to be changed. Unfortunately this led to the inability to test the equipment on a legitimate race track using a race car. Due to this change, the testing had to be changed but the best attempts were made to mimic race track conditions. This was done by scaling down a race track to minimise track distance and vehicle speeds.

The results achieved using the tests as stated in Chapter 3 were useful and provided a good basis for comparison. The software outlined in Chapter 3 was practical and made providing statistics for showing the difference between the systems easy. The software was also useful for developing and output for the driver to view the line they took and to adjust and improve their technique.

CHAPTER 4

RESULTS

4.1 Introduction

The continuous tracking accuracy of RTK GPS and RTS is a significant issue for any undertaking requiring the dynamic measurement of a moving vehicle. Errors in the accuracy and slower measurement rate of the GPS and RTS equipment is amplified when tracking a faster moving vehicle. Issues affecting RTK GPS accuracy and measurement rates include;

- Co-ordinate measurement time
- Point Processing time

Issues affecting RTS accuracy and measurement rates include;

- Distance measurement time
- Point Processing time

When dynamically tracking a moving vehicle all the above points influence the measurement rate and measurement accuracy. This chapter will discuss test results and compare the differences between GPS and RTS in order to provide an outcome determining each systems accuracies and applicability for dynamically tracking a race car. Results from tracking the vehicle provide an indication of driver error and the point differences between GPS and RTS measurements.

In determining the applicability of GPS and RTS, the measurements were set to record at 1 second intervals. This was a reasonable recording speed given the vehicles testing speed. At higher vehicle speeds the measurement rate/interval would need to be increased to maintain a reasonable accuracy of tracking the test vehicle.

A number of statistical values were calculated from the test data. These values included

- Standard Deviation (σ),
- Absolute Mean $|x|$, and
- Maximum error.

Microsoft excel software was used to evaluate and graph the data, which will be discussed in greater detail later in the chapter. In order to place the data in excel to evaluate and graph the results, the data had to be exported from Terramodel into an excel format, erroneous or non-essential data had to removed as well as considering the quality of the data. The data once in excel was refined to produce a useful output.

Once the data was processed appropriately the analysis of the results could be undertaken. The results analysis will be discussed later in this chapter.

4.2 Analysis of Results

Using mathematical methods and statistics it was possible to analyse the results to produce an instrument error between the GPS measurements and RTS measurements at different measurement modes (static or dynamic). Driver error together with instrument error can also be shown in the results.

4.2.1 Static Comparison

To analyse the data and establish a set of results, RTS measurements were set as a control line and offsets to GPS measurements were calculated. The offset data was then placed into excel where graphing and statistical analysis gave a clear indication of the errors between the GPS and RTS when measuring static points. Table 4.1 shows the absolute mean error (average error), standard deviation of the errors and the maximum error between the measurements.

Table 4.1: Error calculations of the GPS and RTS control line measurements.

0.00788	**Absolute Mean (metres)**
0.00657	**Standard Deviation (metres)**
-0.027	**Maximum Value (metres)**

The errors shown provide a good example of the expected accuracy difference between the systems. Figure 4.1 graphically shows the relation of the errors between the equipment and the distance along the track (chainage). This graph shows no real systematic error and all errors are within the expected equipment tolerances.

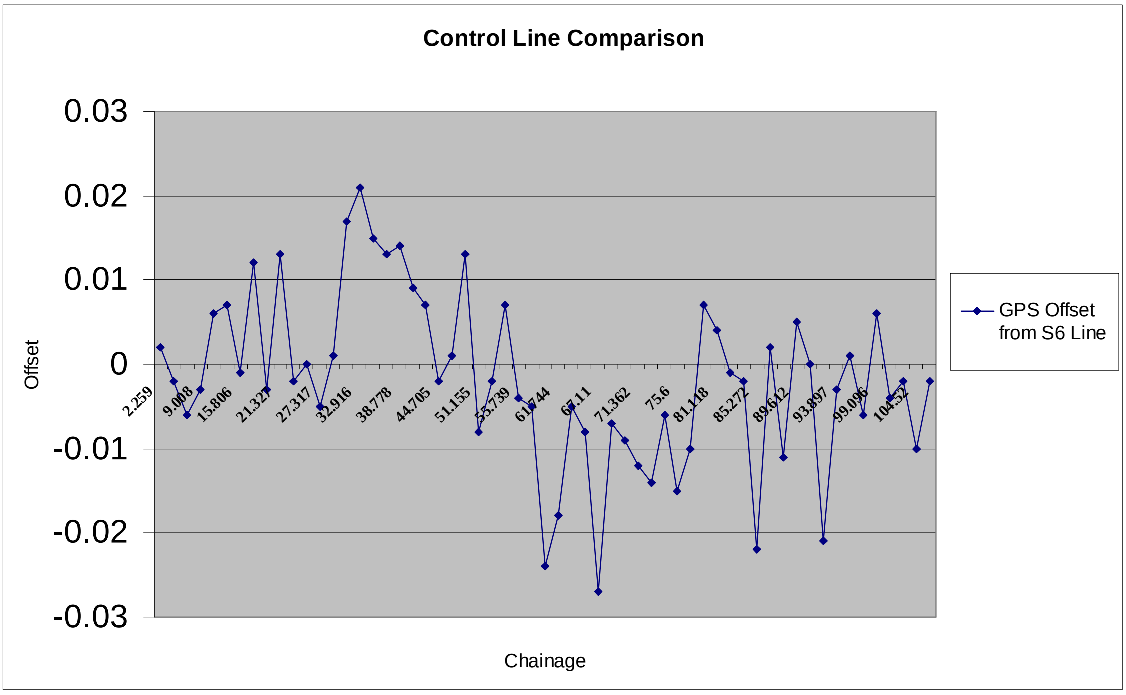


Figure 4.1: Comparing GPS control line measurements to S6 control line measurements

The track shown in Figure 4.2 displays the data as seen in Terramodel. The green points are the GPS measurements and the red line and points are the RTS measurements. There is little difference between the systems and an accurate display of the control line is shown. The graphical display of the line to be followed by the vehicle, gives the driver a greater ability to visualise the track or line.

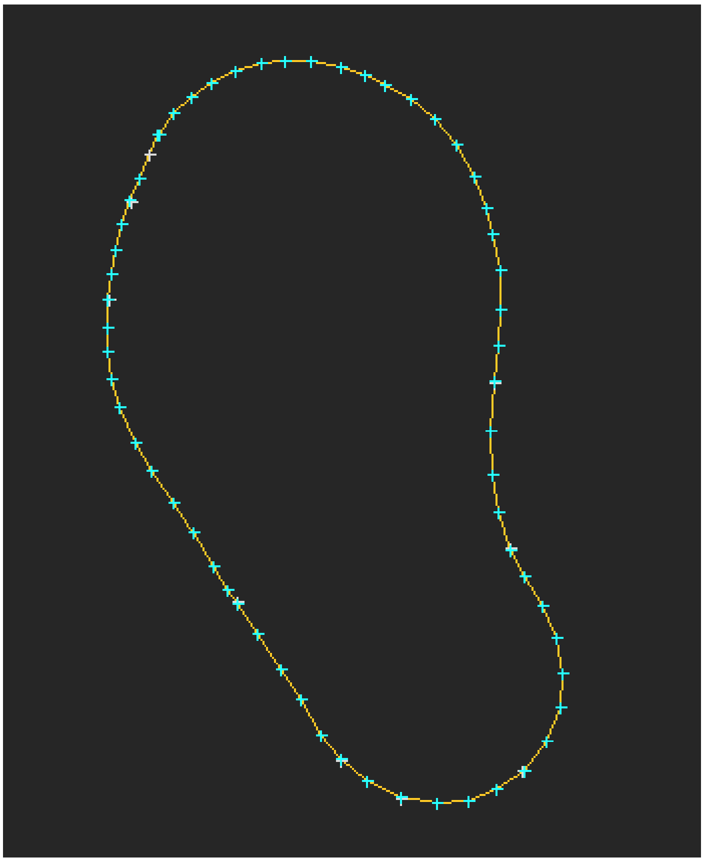


Figure 4.2: GPS and RTS control line.

4.2.2 Dynamic / Control Line Comparison

To analyse the data and provide an example of driver error and instrument error each system's dynamic tracking measurements were compared with the control line. RTS measurements were used as the base control line and offsets to dynamic RTS and GPS lap measurements were calculated. The offset data was again placed into excel where graphing and statistical analysis gave a clear indication of the errors between the dynamic and static RTS control line.

4.2.2.1 RTS Comparison

Laps were completed at two speeds 10km/hr and 20km/hr. A minimum of two (2) rounds of six (6) laps, per speed was completed, providing enough data to view any trends. The offset of the RTS prism and GPS from the wheel alignment was set at 0.500m to provide a stable platform for the system. This meant the control line as measured needed to be offset outward by 0.500m.

4.2.2.2 RTS Comparison at 10km/hr

Below Table 4.2 shows the absolute mean error (average error), standard deviation of the errors and the maximum error of the dynamic measurements at 10km/hr, compared to the control line.

Table 4.2: Error calculations of the RTS dynamic tracking measurements at 10km/hr.

0.50091	**Absolute Mean (metres)**
0.30737	**Standard Deviation (metres)**
-1.414	**Maximum Value (metres)**

Six laps were completed in this test and the point errors have been plotted below (see Figure 4.3). The errors shown provide a good example of the driver error plus the instrument error of the RTS system. Figure 4.3 graphically shows the offset or error of the RTS at 10km/hr and distance along the track (chainage).

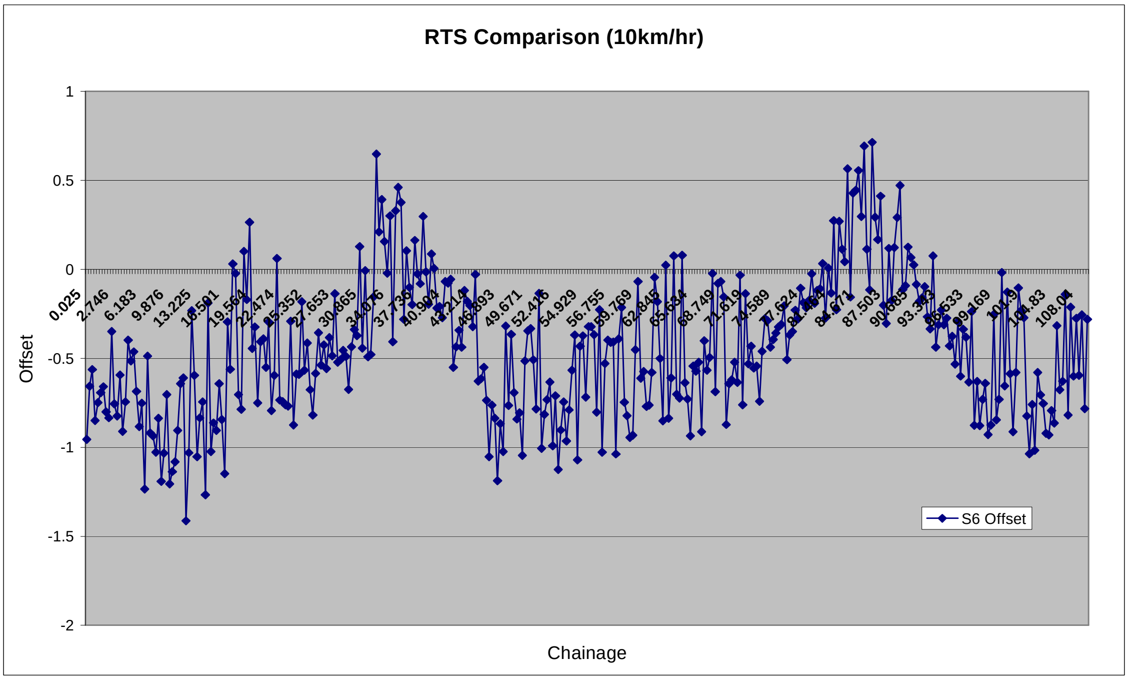


Figure 4.3: Comparing RTS control line measurements to RTS dynamic measurements at 10km/hr

The track shown in Figure 4.4 is the dynamic measurements of the RTS at 10km/hr. The blue points and lines are the dynamic RTS measurements and the orange/brown centreline and red points is the control line, from which the offset measurements are calculated. It can be seen clearly on this image where the driver has moved off the line and where the driver has moved across the line.

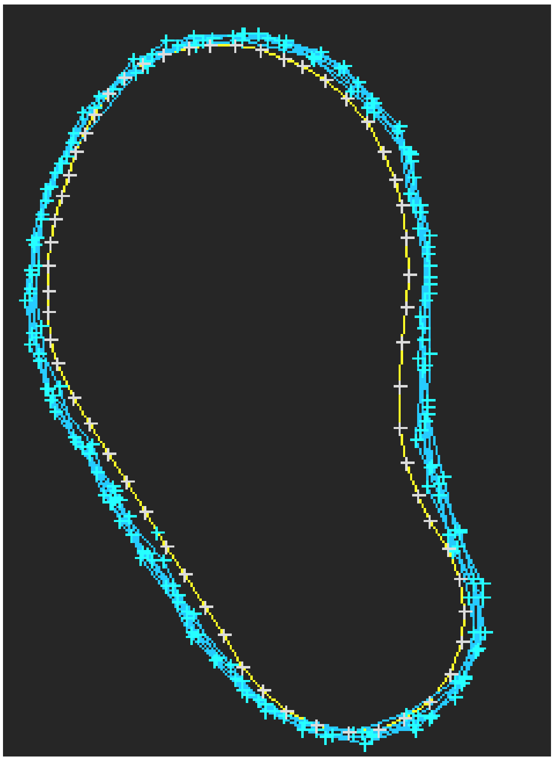


Figure 4.4: Dynamic RTS and static control line at 10km/hr.

4.2.2.3 RTS Comparison at 20km/hr

The higher speed of 20km/hr was a good indication of how the RTS would handle higher speed applications. Due to the small 110 metre circuit and tight corners, problems with the distance between point measurements and errors were magnified. As the higher speed meant that less points per lap were measured more laps were completed to obtain an appropriate amount of data. Seven (7) laps were completed in this test at 20km/hr. Table 4.3 shows the error calculations of the RTS dynamic tracking measurements at 20km/hr compared to the static control line. The errors have increased from the 10km/hr which proves an increase in error with speed.

Table 4.3: Error calculations of the RTS dynamic tracking measurements at 20km/hr.

0.591919	**Absolute Mean (metres)**
0.437977	**Standard Deviation (metres)**
-1.917	**Maximum Value (metres)**

Seven laps were completed in the 20km/hr test and the point errors have been plotted below (see Figure 4.4). The errors shown provide a good example of the driver error plus the instrument error of each system at 20km/hr. The statistical data and the graph show an increase in error with an increase in speed. This increased error is a total of an increase in instrument error plus an increase in driver error can also be expected. Figure 4.4 graphically shows the offset or error of the RTS at 20km/hr and distance along the track (chainage).

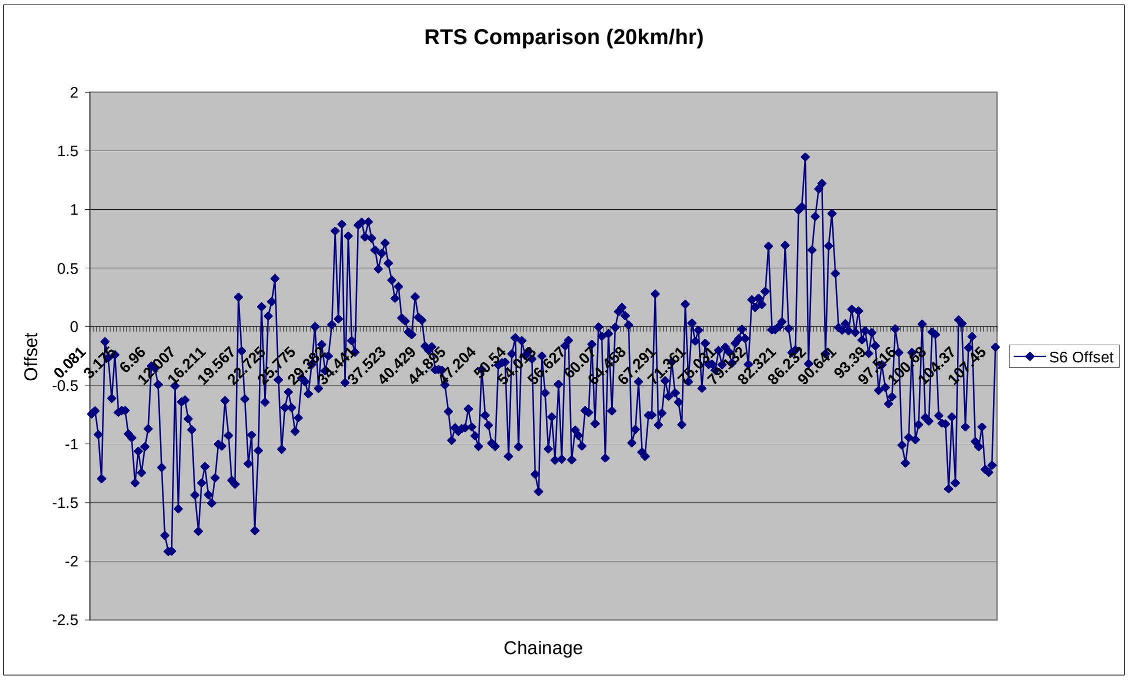


Figure 4.5: Comparing RTS control line measurements to RTS Dynamic measurements at 20km/hr

The track shown in Figure 4.6 outlines the difference in distance between point measurements at 20km/hr from that at 10km/hr. The cyan points and red lines are the dynamic RTS measurements and the orange/brown centreline and red points is the control line, from which the offset measurements are calculated. The effect of the increased distance between points is pronounced at this speed, particularly around corners. The lines between points run across the control line therefore creating an error in the driver's line.

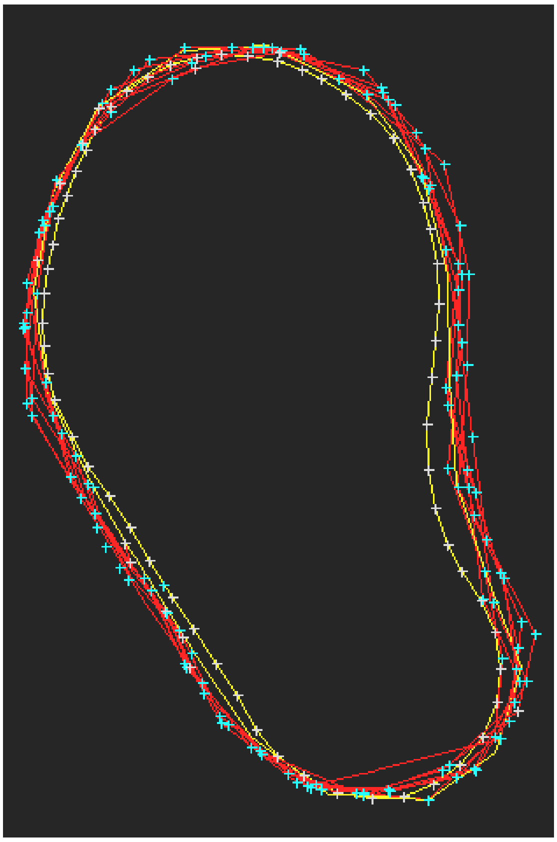


Figure 4.6: Dynamic RTS and static control line at 20km/hr.

4.2.2.4 GPS Comparison

As per the RTS comparison laps were completed at two speeds 10km/hr and 20km/hr. These measurements were taken simultaneously with the RTS, so the number of laps and the conditions were the same for both systems. The systems were vertically aligned which provided a good basis for comparison.

4.2.2.5 GPS Comparison 10km/hr

The 10km/hr speed gave a good indication of how the GPS would handle the dynamic tracking applications. Due to the lower speed and the tight circuit, the digital display of the measurements gave a good indication of where errors were made and where adjustments needed to be made to the driver's line. The display shows the six (6) laps together and the variation between each lap as well as consistent mistakes made each lap by the driver. Table 4.4 shows the error calculations of the GPS dynamic tracking measurements at 10km/hr compared to the static control line.

Table 4.4: Error calculations of the GPS dynamic tracking measurements at 10km/hr.

0.271626	**Absolute Mean (metres)**
0.16085	**Standard Deviation (metres)**
0.753	**Maximum Value (metres)**

Six laps were also completed in the GPS test and the point errors have been plotted below (see Figure 4.5). The errors shown (as per the RTS tests) provide a good example of the driver error plus the instrument error of the GPS system. Figure 4.3 graphically shows the offset or error of the GPS at 10km/hr and chainage.

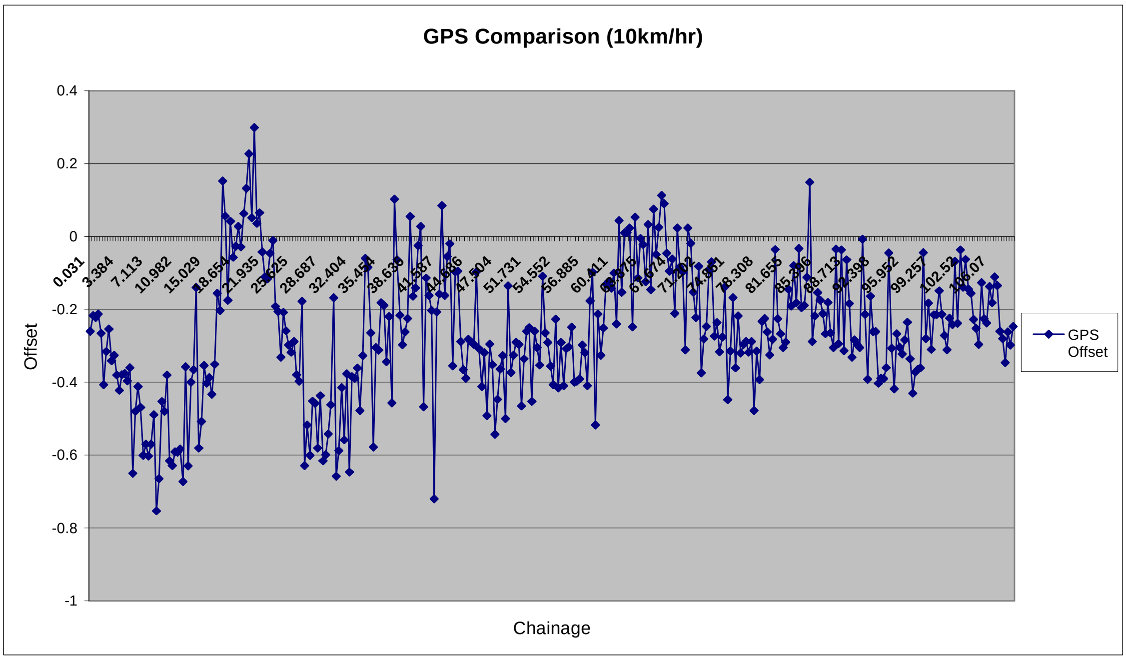


Figure 4.7: Comparing RTS control line measurements to GPS Dynamic measurements

The track shown in Figure 4.8 shows the dynamic measurements of the GPS at 10km/hr. The blue lines are the dynamic GPS measurements and the red centreline is the control line, from which the offset measurements are calculated. Compared to the RTS measurements the GPS points are less spread and follow a better shape that is more similar to the control line.

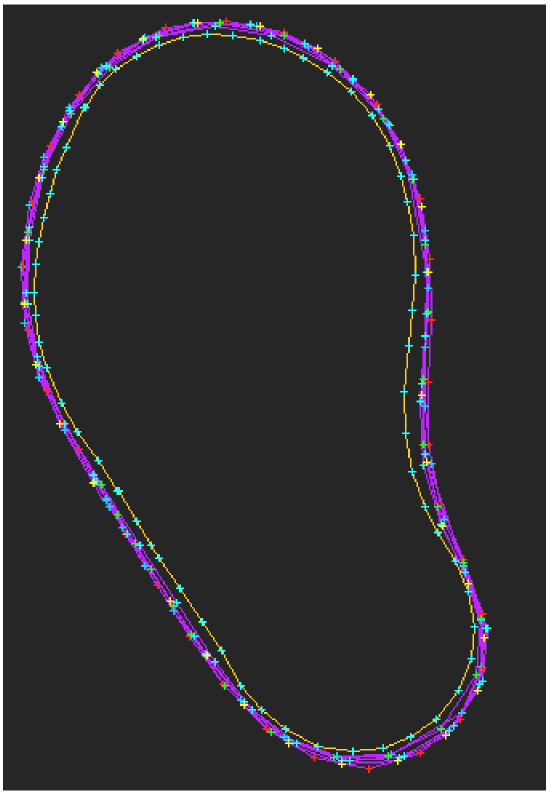


Figure 4.8: Dynamic GPS and static control line at 10km/hr.

4.2.2.6 GPS Comparison 20km/hr

As per the RTS tests the higher speed of 20km/hr was a good indication of how the GPS would handle higher speed applications. Due to the small 110 metre circuit and tight corners, problems with the distance between point measurements and errors were also magnified. In keeping consistent with the RTS measurement and as the two systems were run simultaneously seven (7) laps were completed to test the GPS at 20km/hr. Table 4.5 shows the error calculations of the GPS dynamic tracking measurements at 20km/hr compared to the static control line. Overall the errors have increased from the 10km/hr which proves an increase in error with speed, which is consistent with results from the RTS tests.

Table 4.5: Error calculations of the GPS dynamic tracking measurements at 20km/hr.

0.223523	**Absolute Mean (metres)**
0.173482	**Standard Deviation (metres)**
-0.935	**Maximum Value (metres)**

The errors shown on the plot below are less than those shown on the corresponding RTS plot. The substantially smaller errors are proved by GPS statistics in Table 4.5 compared to the RTS statistics of Table 4.3. The statistical data and the graph show an increase in error with an increase in speed when comparing the GPS measurements at various speeds. This increased error is a total of an increase in instrument error plus an increase in driver error can also be expected. Figure 4.6 graphically shows the offset or error of the RTS at 20km/hr and chainage.

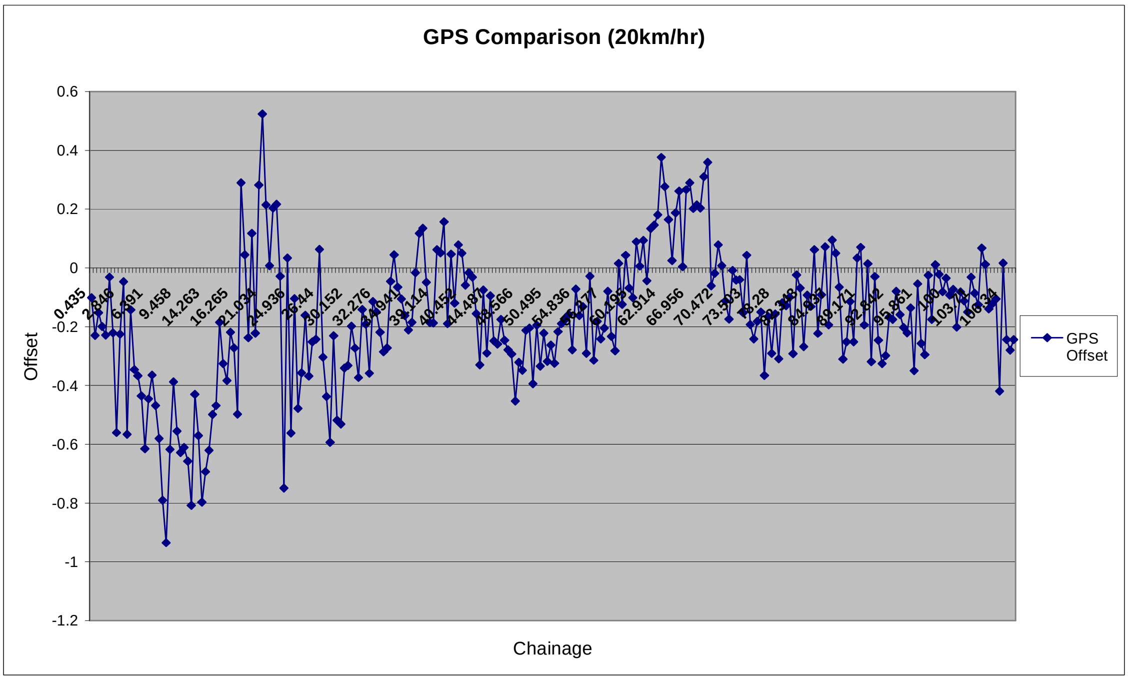


Figure 4.9: Comparing RTS control line measurements to GPS Dynamic measurements

The track shown in Figure 4.10 shows the dynamic measurements of the GPS at 20km/hr. The yellow lines are the dynamic GPS measurements and the red centreline is the control line, from which the offset measurements are calculated. At 20 km/hr the GPS points are obviously different and less spread around the circuit than the RTS measurements at the same speed. The line taken by the driver is much clearer and from this more specific improvements can be made to the driver's performance.

Figure 4.10: Dynamic GPS and static control line at 20km/hr.

4.3 Dynamic GPS / Dynamic RTS Comparison

The dynamic GPS / dynamic RTS comparison gives a direct measurement of the differences between the two systems when simultaneously tracking a moving vehicle. By analysing each lap separately the offset data is more meaningful and the difference between the systems is simpler to comprehend. This analysis shows also any relationship between the offset between the systems and the section of the track where the differences occur. For analysis purposes the RTS measurements were used as a control line to calculate offsets.

The differences between the systems were calculated as separate laps. When the differences were put together in excel and the statistics were calculated for all the laps as a whole (see Table 4.6).

Table 4.6: Difference calculations of the GPS dynamic tracking and RTS dynamic tracking measurements at 10km/hr.

0.342974	**Absolute Mean (metres)**
0.223135	**Standard Deviation (metres)**
0.897	**Maximum Value (metres)**

The graph below shows the amount of difference between the systems and the chainage at which the difference occurs. As shown in Figure 4.11 the greatest errors occur at the approximate chainages' of 30 metres, 50 metres and 80 metres. A trend occurs across all laps where the greatest errors occur at these approximate chainages. These larger errors occur at the chainages of the corners, the larger or most pronounced errors seem to occur at the tightest corner, at the 80 - 90 metre chainage area.

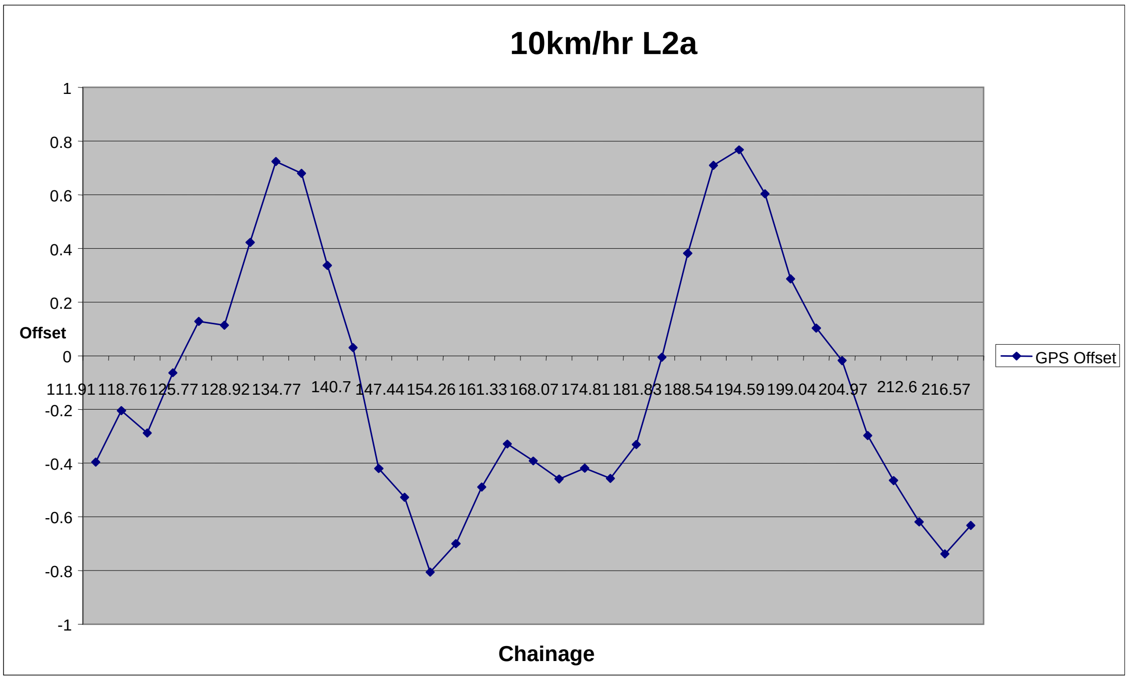


Figure 4.11: Lap 2, Dynamic GPS and Dynamic RTS at 10km/hr.

The diagram below shows a digital display of the difference between the systems and the line measured at 10km/hr. As both systems were measuring at the same time variations between the lines gives the difference in instrument error between the GPS and the RTS. The yellow line in Figure 4.12 is the RTS measurements, the white line is the GPS measurements and the purple inside line is the RTS static control line. In this figure the difference between the systems can easily be seen to occur at the greatest around the corners.

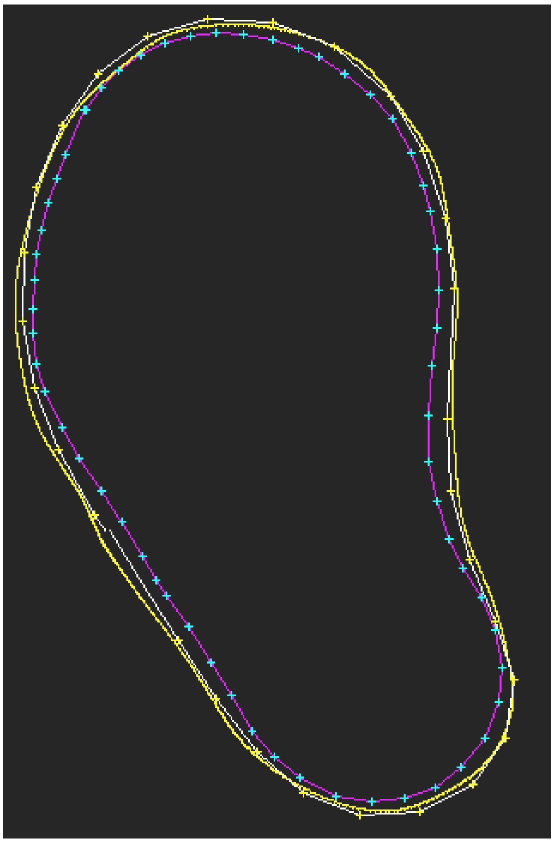


Figure 4.12: Digital Display of Lap 2, Dynamic GPS and Dynamic RTS at 10km/hr.

At 20km/hr the difference between the dynamic GPS measurements and the dynamic RTS measurements is similar to the differences at 10km/hr, however the difference of errors is more pronounced. As shown in Table 4.7 the errors have increased with the speed and the larger differences can be clearly seen in Figure 4.13.

Table 4.7: Difference calculations of the GPS dynamic tracking and RTS dynamic tracking measurements at 20km/hr.

0.531261	**Absolute Mean (metres)**
0.421616	**Standard Deviation (metres)**
2.585	**Maximum Value (metres)**

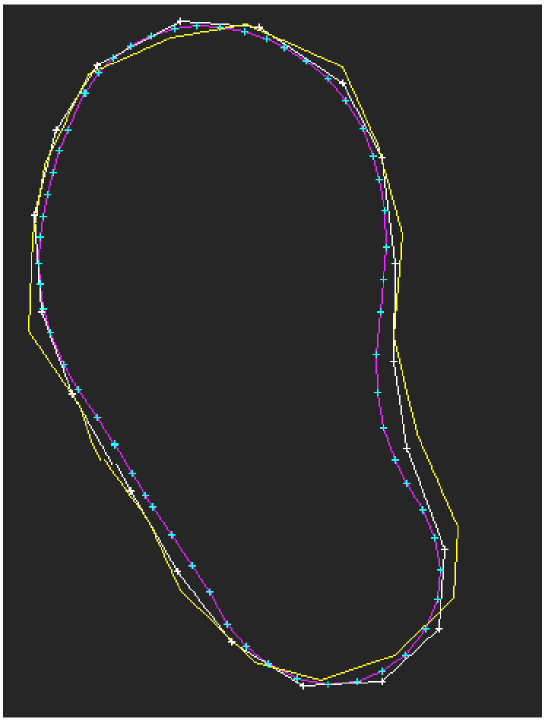


Figure 4.13: Lap 2, Dynamic GPS and Dynamic RTS at 20km/hr.

4.4 Discussions

4.4.1 Static Comparison

A control line was marked and later measured with both systems simultaneously. The static measurements were compared and offsets between the measurements were calculated. This static comparison between both systems gave the expected minimum differences between the two systems. This control line also provided a line for the driver to follow as well as providing a basis for comparing dynamic measurements to a control line. The offset data was then placed into excel where graphing and statistical analysis gave a clear indication of the errors between the GPS and RTS when measuring static points.

The results proved the expected differences between the systems with a maximum difference between measurements being -0.027 metres. This proves that both systems static measuring capabilities and accuracies are similar and a comparison of the static and dynamic measurements provides a relevant result.

4.4.2 Dynamic / Control Line Comparison

4.4.2.1 RTS/GPS Comparison

To decide which system is the most suitable for dynamically tracking a race car, comparisons need to be made between the two systems simultaneously and at different speeds. The simultaneous measurements were taken at 10 km/hr and 20 km/hr to show the change in accuracy for an increase in speed.

4.4.2.2 RTS/GPS Comparison at 10km/hr

The results from the comparison of each system's dynamic measurements against the control line give a clear indication of the system accuracy, and consistency of measurements. When comparing the results of the GPS to the RTS, the most suitable system for dynamically tracking a race car becomes apparent. The results tables of the error calculations of the each system at 10km/hr shows that GPS has a lower mean error, a smaller standard deviation (which means there is less variation between measurements) and a smaller maximum value, (see Table 4.8).

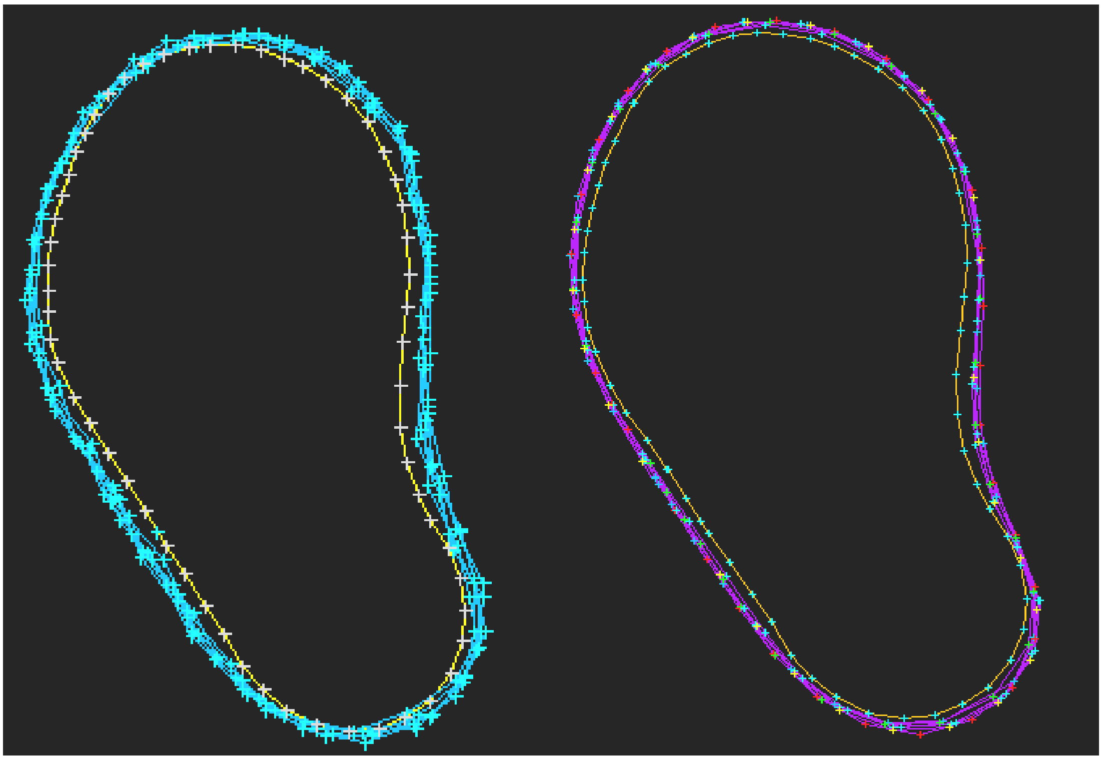
The RTS measurements however are not as consistent and point deviations or variations from the control line are larger than that of the GPS measurements. This again is obvious when viewing Table 4.8.

Table 4.8: Comparison of error calculations of the RTS/GPS dynamic tracking measurements at 10km/hr.

Error calculations of the RTS at 10km/hr. Error calculations of the GPS at 10km/hr.

0.50091	**Absolute Mean (m)**	0.271626	**Absolute Mean (m)**
0.30737	**Standard Deviation (m)**	0.16085	**Standard Deviation (m)**
-1.414	**Maximum Value (m)**	0.753	**Maximum Value (m)**

The images in Figure 4.14 shows the point measurements of the RTS is a little more "cloudy" then the GPS measurements. When the images of each systems point and line measurements are viewed together the differences between the systems is again easy to see. The GPS has a more consistent line and less variation between measured points and the control line. The GPS measurements also follow the shape of the control line, therefore driver mistakes can be easily seen.



Dynamic *RTS* and static control line at 10km/hr. Dynamic *GPS* and static control line at 10km/hr.

Figure 4.14: The Difference between the two systems at 10 km/hr is obvious when results are viewed together

4.4.2.3 RTS/GPS Comparison at 20km/hr

The results from the 20km/hr test show a similar trend to the 10km/hr test in that the GPS again has a lower mean error, a smaller standard deviation and a smaller maximum value, (see Table 4.9). Although the errors have increased with the increase of speed, the GPS measurements are still more consistent with less variation from the control line.

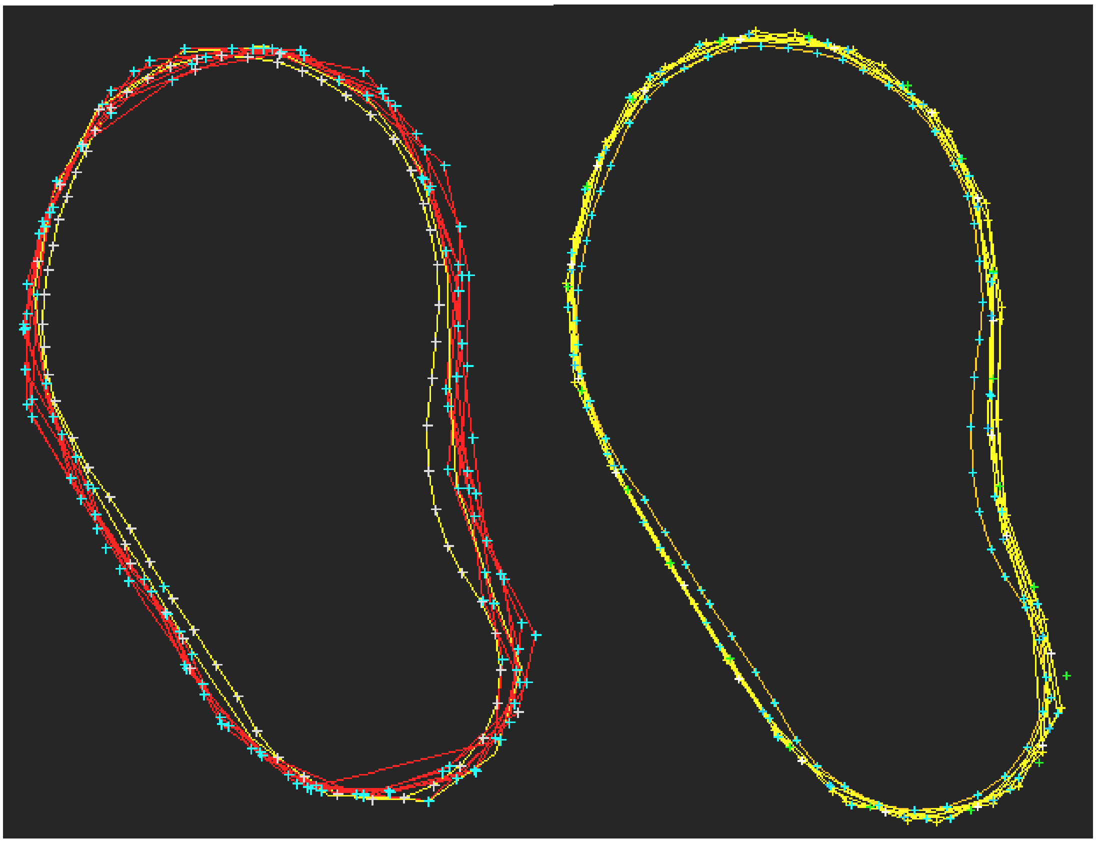
Table 4.9 again shows that the GPS is more accurate when dynamically tracking. The table of errors also shows that the GPS errors increase less with the increase of speed than the RTS errors.

Table 4.9: Comparison of error calculations of the RTS/GPS dynamic tracking measurements at 20km/hr.

Error calculations of the RTS at 20km/hr.		Error calculations of the GPS at 20km/hr.	
0.591919	**Absolute Mean (m)**	0.223523	**Absolute Mean (m)**
0.437977	**Standard Deviation (m)**	0.173482	**Standard Deviation (m)**
-1.917	**Maximum Value (m)**	-0.935	**Maximum Value (m)**

Figure 4.15 shows a digital display of the differences between the two systems at 20km/hr. The results again show that the GPS is predominantly better than RTS. The accuracy of GPS point measurements is better than the RTS and this can be seen due to the large variation between RTS measurements and the small variation between GPS measurements.

The images in Figure 4.15 show more clearly the differences between the systems and the better system is easily depicted. The RTS measurement point “cloud” is substantially exaggerated from the 10km/hr comparison, whereas the GPS measurements have only a slightly increased standard deviation.



Dynamic *RTS* and static control line at 20km/hr. Dynamic *GPS* and static control line at 20km/hr.

Figure 4.15: The Difference between the two systems at 20 km/hr is obvious when results are viewed together

4.4.3 Dynamic GPS / Dynamic RTS Comparison

To clearly view the differences between the GPS and the RTS, each lap was studied individually and trends were drawn between laps. Viewing each individual lap made comparisons between the systems simple to calculate and obvious to see. The greatest differences between the systems can be seen at the 20km/hr testing. Table 4.7 shows the difference between the systems at 20km/hr. It is obvious from this table that there is a large variation between the GPS and RTS systems.

From analysing trends between laps it can be seen that the greatest errors seem to occur at chainages of 30 metres, 50 metres and 80 metres. These chainages are where the corners of the track occur and the vehicle is changing direction. From Figure 4.13 it can be seen that the Yellow RTS line has the highest deviation from the control line particularly at the corners. The large variation of these measurements and the jagged appearance of measurements suggest that the distance measurements were in error. The Trimble S6 robotic total station takes 0.4 seconds to read distance measurements, once this occurs the distance measurement is placed with read angles and a point is stored. This means at times the distance measurement may not be coincident with the angle measurements, which leads to the variations that can be seen in Figure 4.13.

4.5 Conclusions

According to the results it can be stated that the GPS is the most appropriate instrument to be used when dynamically tracking a race vehicle. The GPS measurements were much more consistent and accurate than the RTS measurements. With capability of the GPS providing a higher accuracy and the option to create faster more regular point measurements, this system is the most viable option to give a driver an appropriate output to improve their line and performance.

The RTS based on current and previous testing had inherent errors in the measurements due to the instrument only capable of reading measurements at 0.4 seconds. This has proved to create significant errors as speed increases. The difference is noticeable even with a small change from 10km/hr to 20km/hr.

CHAPTER 5

RECOMENDATIONS AND CONCLUSIONS

5.1 Recommendations

Due to time and equipment restraints the full capabilities of the GPS and RTS equipment was unable to be tested. Point measurements were limited to 1 second intervals to maintain consistency between systems, also the time required to minimise system measurement speed for both GPS and RTS was not available.

The track size was limited to a 110m circuit due to the limited availability of appropriate vehicles and track time. This meant that a regular race track was not available for use so therefore a scaled down racetrack was used at a lower speed. The lower speed, tighter corners gave a reasonable similarity to regular race track situations, therefore the results have a relevance to normal racing situations. As a regular track and race car were not able to be used lap timing became too difficult and therefore was not used. Under regular race track circumstances lap timing would be used to identify fast laps and could also be used in the processing of data to obtain a further link between GPS and RTS data. This will provide a better accuracy and place RTS and GPS point data together to create a better comparison of line measurements.

Calculating the GPS and RTS latency will provide an adjustment to add to the point measurements. By adding the adjustment of each system to the measurements a corrected position for each line can be established. Latency occurs when point measurements and storing the information is slower than the moving vehicle. The faster the moving vehicle the further behind the measurements become. When dynamically tracking a race car, this creates errors when the vehicle is changing direction and a point is stored at a position behind where the vehicle currently is. This leads to an inconsistent line measurement and can give an incorrect output. The latency calculation can also provide a basis for developing a numeric output for driver error. An equation for calculating equipment error and driver error is given below.

Total Error = Driver Error + Equipment Error
Equipment Error = Latency error + Random error

Therefore;
Total Error = Driver Error + Latency error + Random error

The random error involved in this equation is insignificant compared to the latency error and driver error. Therefore the random error can be omitted from the equation.

Total Error = Driver Error + Latency error

The Total error is known from the difference between the GPS and RTS measurements, if the latency has been calculated previously then the driver error can be found.

Latency can be calculated by adding accurate time information to each measured point. If a control line is measured and accurately followed and both systems start measuring simultaneously, the time can be used as a basis to compare measurements. From this, the differences between the systems and the control line, will give each systems latency error. Latency can also be calculated by using the method discussed in Section 2.4.1.

Overall in this dissertation I have proved that the Trimble GPS is a better system for the dynamic tracking of a race car. The accuracy and consistency of the GPS means a more useful output was developed for improving the driver's ability to select a fast line. The errors found in the Trimble S6 RTS measurements were related to the slow distance measurement time which produced some capricious measurements.

5.2 Conclusions.

The use of Robotic Total Stations (RTS) and Global Positioning Systems (GPS) for machine guidance in the construction, farming and mining industries is becoming more common. Similar systems can be used to report a race vehicle's position on a race track.

For tracking slow moving machinery such as tractors, bull dozers, graders, excavators, harvesters etc, the RTS and GPS systems appear quite capable of taking accurate consistent measurements. However for the use of high speed tracking these systems have limited capabilities. A race vehicles speed is generally faster than the speed at which a GPS or RTS can take measurements. Although the GPS continued to measure through tight corners and the lines measured still maintained reasonable shape and consistency the overall speed was still low. Further testing will need to be completed to test the full capabilities of the GPS (this was not able to be completed in this dissertation due to time and equipment constraints). This means the speed at which the systems take measurements is the greatest limiting factor. Other limiting factors include, the distance from the RTS to the vehicle/target and the RTS instrument tracking speed (the instruments ability to follow the target).

With a faster measurement speed from the GPS and RTS the lines measured will be much closer to their true value and can therefore be relied upon more heavily when analysing the vehicles track position. Faster measurement times would also expand the use of the system to be used on faster race car's such as Formula 1 and other vehicles such as high speed boats or motorcycles.

The GPS provided the most encouraging results by producing a mean Total offset error from the control line at 20km/hr of 0.223523m, a standard deviation of 0.173482m and a maximum offset error of 0.935m. When compared to the RTS errors of the same laps, the GPS errors are only 38% as large. The RTS errors are too large to create a useful output that can be used for identifying driver errors. The GPS however is substantially more accurate and consistent and is therefore more suitable for dynamically tracking a race car.

The output from the GPS provided good detail of the line taken by the driver and consistent errors made by the driver each lap became apparent. The digital display in Terramodel, of the driver's line gave a clear indication of where the driver needed to make improvements, particularly at the apex of two of the three corners. This meant that although latency error was still in the measurements a reasonable and useful output was still gained from the GPS measurements. However correcting for latency would still improve the results and output and also give a greater confidence that the errors being shown are driver error only.

In conclusion, from the results outlined in this dissertation it is apparent that the GPS system tested was the most suitable for dynamically tracking a fast moving vehicle. The RTS however was not considered suitable as the point errors became too large once the on track vehicle speed reached 20km/hr. The GPS although the most suitable still has a number of limitations. Tree cover around the track is detrimental to obtaining accurate clear measurement data. Measurement speed is also a limitation. GPS will have trouble tracking higher speed vehicles such as Formula 1, however if the GPS measurement time can be reduced to approximately 0.1 seconds then it will be very effective for dynamically tracking race vehicles.

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APPENDICES

APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

For: Joshua David King

Topic: Dynamic Tracking of a Race Car

Supervisors: Kevin McDougall
Peter Gibbings

Sponsorship: Faculty of Engineering and Surveying USQ

Project Aim:

The aim of the project is to evaluate the suitability of RTS (Robotic Total Stations) and GPS (Global Positioning Systems) for dynamic tracking of a race car to improve the driver's line and performance.

Objectives/ Justification:

The driver can be made aware of differences between their actual position and their perceived track position. The report should be viewed not on track but afterwards together with lap times, so the driver can take time to study and adjust their line taken. This procedure will allow the driver to view the line taken to achieve the quickest lap times, whilst saving time and completing a minimum number of laps.

Programme: Issue A, 14-Mar-06

1. Review existing literature and projects relating to dynamic tracking using GPS and robotic total stations

2. Design a testing regime for both GPS and RTS for high-speed tracking including the mapping of a suitable test track

3. Test the utility (accuracy, effect of latency, logging rates and the difference in alignments) of Total Stations and GPS for high-speed vehicle tracking under controlled conditions

4. Analyse the results of these tests in order to report on a vehicles track position at any time

5. Report and document the results

As time permits

6. Testing should be completed under various conditions where possible, to prove the usefulness of each system under any possible race condition. e.g. Trees on the infield, clear infield, hilly country.

Agreed: (student) (supervisor)

Date: 14/3/06

APPENDIX B

TEST RESULTS FOR ROBOTIC TOTAL STATION.

PART A - CONTROL LINE

PART B - TRACKING TEST RESULTS FOR ROBOTIC TOTAL STATION AT 10km/hr

PART C - TRACKING TEST RESULTS FOR ROBOTIC TOTAL STATION AT 20km/hr

PART A - CONTROL LINE

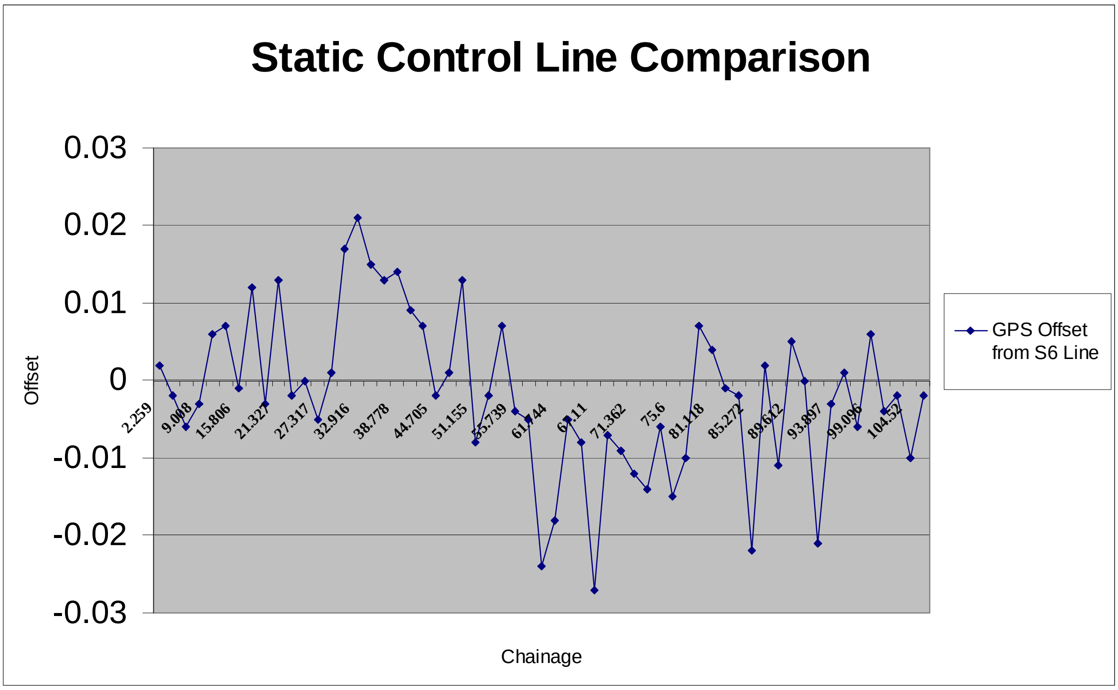

Figure B.1: A static comparison between GPS and RTS measurements.

Table B.1: Point data of differences between GPS and RTS measurements

Point Number	Offset (m)	Chainage (m)
5036(2)	0.002	2.259
5037(2)	-0.002	4.273
5038(2)	-0.006	6.325
5039(2)	-0.003	9.008
5040(2)	0.006	11.486
5041(2)	0.007	13.673
5042(2)	-0.001	15.806
5043(2)	0.012	17.499
5044(2)	-0.003	19.441
5045(2)	0.013	21.327
5046(2)	-0.002	23.43
5047(2)	0	25.273
5048(2)	-0.005	27.317
5049(2)	0.001	29.354
5050(2)	0.017	31.164
5051(2)	0.021	32.916
5052(2)	0.015	34.691
5053(2)	0.013	36.682
5054(2)	0.014	38.778
5055(2)	0.009	40.612
5056(2)	0.007	42.42
5057(2)	-0.002	44.705
5058(2)	0.001	46.722
5059(2)	0.013	49.038
5060(2)	-0.008	51.155
5001(2)	-0.002	53.626
5002(2)	0.007	55.746
5003(2)	-0.004	55.739
5004(2)	-0.005	57.784
5005(2)	-0.024	59.875
5006(2)	-0.018	61.744
5007(2)	-0.005	63.932
5008(2)	-0.008	65.489
5009(2)	-0.027	67.11
5010(2)	-0.007	68.373
5011(2)	-0.009	70.005
5012(2)	-0.012	71.362
5013(2)	-0.014	72.745
5014(2)	-0.006	74.217
5015(2)	-0.015	75.6
5016(2)	-0.01	77.007
5018(2)	0.007	79.591
5019(2)	0.004	81.118
5020(2)	-0.001	82.416
5021(2)	-0.002	83.828
5022(2)	-0.022	85.272
5023(2)	0.002	86.769
5024(2)	-0.011	88.167
5025(2)	0.005	89.612
5026(2)	0	91.23
5027(2)	-0.021	92.668
5028(2)	-0.003	93.897
5029(2)	0.001	95.532
5030(2)	-0.006	97.285
5031(2)	0.006	99.096
5032(2)	-0.004	101.161
5033(2)	-0.002	103.028
5034(2)	-0.01	104.52
5035(2)	-0.002	106.531

PART B - TRACKING TEST RESULTS FOR ROBOTIC TOTAL STATION AT 10km/hr

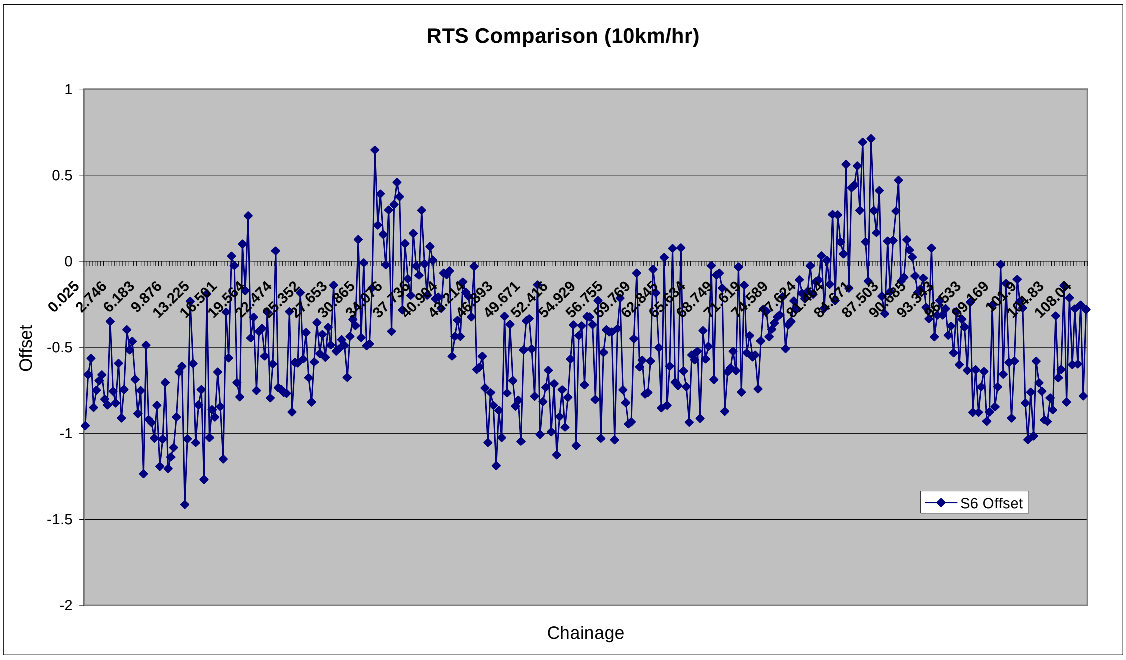

Figure B.2: RTS offsets from the control line at 10km/hr.

Table B.2: Point data of differences between RTS measurements and control line at 10km/hr.

Point Number	Offset (m)	Chainage (m)	Point Number	Offset (m)	Chainage (m)
9055	-0.956	0.025	9112	-0.644	15.99
9116	-0.658	0.599	9612	-0.845	16.014
9616	-0.563	0.608	9581	-1.149	16.501
9585	-0.85	0.893	9514	-0.295	16.535
9650	-0.749	0.973	9050	-0.562	18.435
9021	-0.693	0.988	9016	0.03	18.483
9553	-0.66	1.684	9645	-0.025	18.547
9146	-0.802	1.706	9142	-0.705	18.626
9085	-0.835	2.411	9081	-0.788	18.634
9518	-0.349	2.721	9548	0.101	19.243
9176	-0.756	2.746	9172	-0.171	19.298
9054	-0.824	3.311	9111	0.264	19.426
9115	-0.593	3.772	9580	-0.445	19.564
9615	-0.911	3.935	9513	-0.325	19.863
9584	-0.745	4.351	9611	-0.751	20.049
9020	-0.398	4.771	9080	-0.407	21.472
9649	-0.515	4.818	9141	-0.39	21.511
9552	-0.464	5.457	9644	-0.551	21.543
9145	-0.686	5.532	9015	-0.295	21.73
9517	-0.885	5.66	9049	-0.795	21.818
9084	-0.752	6.183	9547	-0.596	22.324
9053	-1.235	6.945	9171	0.061	22.471
9175	-0.487	7.264	9610	-0.735	22.474
9614	-0.919	7.64	9110	-0.744	22.575
9019	-0.937	7.714	9579	-0.762	22.589
9648	-1.028	7.802	9512	-0.768	22.73
9114	-0.837	7.958	9643	-0.292	24.326
9583	-1.192	8.197	9140	-0.875	24.441
9551	-1.034	8.373	9048	-0.588	24.478
9516	-0.704	9.618	9079	-0.591	24.523
9144	-1.205	9.876	9014	-0.182	24.535
9083	-1.137	10.277	9511	-0.568	25.156
9052	-1.082	10.692	9546	-0.414	25.352
9174	-0.905	11.222	9170	-0.676	25.404
9018	-0.644	11.691	9609	-0.819	25.426
9647	-0.61	11.796	9109	-0.585	25.573
9613	-1.414	12.044	9578	-0.357	25.609
9582	-1.031	12.095	9642	-0.538	26.599
9113	-0.233	12.248	9013	-0.425	27.155
9550	-0.595	12.353	9139	-0.558	27.318
9515	-1.053	13.225	9577	-0.384	27.488
9143	-0.835	14.105	9108	-0.486	27.647
9082	-0.745	14.229	9078	-0.138	27.653
9051	-1.268	14.997	9047	-0.523	27.673
9173	-0.19	15.212	9545	-0.508	27.709
9646	-1.025	15.245	9510	-0.456	28.136
9017	-0.863	15.337	9608	-0.49	28.291
9549	-0.906	15.942	9169	-0.675	28.457

9641	-0.436	29.749	9163	-0.366	47.95
9012	-0.339	30.168	9102	-0.693	48.198
9046	-0.373	30.351	9604	-0.842	48.202
9138	0.127	30.74	9194	-0.807	49.023
9576	-0.443	30.865	9504	-1.046	49.277
9640	0.21	32.347	9006	-0.515	49.3
9011	0.392	33.354	9538	-0.345	49.671
9137	0.156	33.964	9572	-0.333	49.96
9045	-0.021	34.003	9040	-0.509	49.983
9543	0.299	34.076	9072	-0.785	50.21
9167	-0.408	34.387	9101	-0.136	51.547
9106	0.329	34.501	9668	-1.006	51.747
9508	0.46	34.786	9634	-0.815	51.806
9076	0.376	35.078	9193	-0.732	51.978
9639	-0.282	35.219	9503	-0.633	52.221
9010	0.103	36.337	9603	-0.992	52.287
9044	-0.102	36.778	9162	-0.712	52.416
9542	-0.198	36.933	9132	-1.125	52.427
9105	0.162	37.369	9005	-0.903	52.727
9507	-0.027	37.736	9537	-0.746	53.356
9166	-0.081	38.135	9039	-0.964	53.892
9136	0.297	38.153	9571	-0.79	53.998
9638	-0.015	38.613	9502	-0.568	54.665
9607	-0.197	38.904	9667	-0.369	54.805
9075	0.086	39.595	9071	-1.071	54.889
9009	0.005	40.188	9004	-0.432	54.902
9575	-0.218	40.28	9633	-0.374	54.929
9541	-0.208	40.568	9602	-0.718	55.182
9043	-0.273	40.622	9501	-0.322	55.208
9135	-0.069	40.904	9500	-0.323	55.244
9637	-0.078	41.069	9131	-0.368	56.013
9104	-0.056	41.325	9100	-0.803	56.105
9606	-0.551	41.469	9536	-0.228	56.221
9506	-0.436	41.788	9192	-1.029	56.255
9165	-0.343	42.124	9003	-0.529	56.349
9074	-0.437	42.492	9002	-0.397	56.714
9008	-0.119	42.869	9000	-0.411	56.755
9574	-0.18	42.982	9001	-0.41	56.755
9540	-0.203	43.136	9161	-1.038	56.839
9042	-0.323	43.214	9038	-0.391	56.969
9103	-0.029	44.09	9570	-0.214	57.176
9505	-0.628	44.649	9070	-0.747	58.246
9636	-0.615	44.76	9666	-0.822	58.738
9164	-0.552	44.842	9632	-0.946	58.903
9134	-0.736	44.872	9601	-0.933	59.214
9605	-1.053	45.27	9191	-0.451	59.463
9007	-0.763	46.611	9099	-0.068	59.769
9539	-0.838	46.82	9535	-0.613	59.921
9073	-1.188	46.827	9160	-0.574	60.016
9573	-0.867	46.893	9130	-0.771	60.405
9041	-1.025	46.998	9037	-0.763	60.81
9635	-0.32	47.697	9569	-0.58	61.128
9133	-0.765	47.877	9665	-0.046	61.856

9631	-0.183	61.987	9595	-0.187	77.624
9600	-0.502	62.044	9529	-0.217	77.876
9069	-0.852	62.61	9660	-0.175	77.898
9534	0.023	62.845	9094	-0.026	78.117
9190	-0.837	63.241	9626	-0.192	78.321
9036	-0.61	63.46	9031	-0.118	78.983
9129	0.075	63.793	9064	-0.109	79.489
9098	-0.702	63.988	9563	0.032	80.15
9159	-0.723	64.052	9185	-0.274	80.953
9568	0.079	64.225	9594	0.006	80.976
9664	-0.637	65.332	9528	-0.134	81.464
9630	-0.729	65.375	9124	0.273	81.568
9599	-0.936	65.437	9659	-0.228	81.915
9068	-0.544	65.634	9625	0.269	81.992
9533	-0.572	66.005	9093	0.112	82.248
9189	-0.523	66.016	9030	0.043	82.287
9035	-0.913	66.754	9063	0.564	83.112
9158	-0.402	66.977	9562	-0.156	83.617
9128	-0.568	67.348	9184	0.428	84.116
9567	-0.495	67.451	9527	0.443	84.296
9097	-0.025	67.67	9593	0.555	84.671
9598	-0.688	68.082	9658	0.296	84.936
9663	-0.08	68.73	9154	0.693	85.072
9629	-0.069	68.749	9624	0.113	85.126
9532	-0.155	69.177	9123	-0.115	85.265
9067	-0.872	69.205	9092	0.713	85.877
9034	-0.643	69.569	9029	0.293	85.883
9188	-0.621	69.846	9062	0.167	86.404
9157	-0.523	70.717	9561	0.411	86.892
9096	-0.636	70.965	9526	-0.202	87.266
9566	-0.034	71.027	9183	-0.304	87.503
9597	-0.761	71.176	9592	0.117	87.757
9127	-0.138	71.308	9657	-0.176	87.812
9662	-0.532	71.619	9153	0.122	88.145
9628	-0.432	71.651	9623	0.291	88.879
9531	-0.556	71.794	9122	0.471	89.207
9066	-0.544	72.528	9091	-0.114	89.264
9033	-0.742	72.679	9560	-0.092	89.67
9187	-0.462	72.939	9028	0.125	89.685
9565	-0.278	73.784	9061	0.066	90.374
9156	-0.289	74.054	9525	0.025	90.685
9126	-0.438	74.36	9656	-0.085	91.486
9596	-0.395	74.477	9622	-0.181	91.497
9661	-0.359	74.589	9182	-0.161	91.521
9095	-0.324	75.133	9591	-0.097	91.625
9530	-0.311	75.344	9152	-0.268	92.079
9627	-0.205	75.556	9027	-0.335	92.188
9032	-0.508	75.804	9121	0.076	92.198
9065	-0.37	76.035	9060	-0.438	93.024
9186	-0.35	76.869	9524	-0.313	93.051
9564	-0.23	77.494	9559	-0.229	93.343
9125	-0.279	77.599	9090	-0.312	93.583
9155	-0.107	77.624	9655	-0.275	94.002

9590	-0.43	94.094
9181	-0.376	94.287
9151	-0.533	94.617
9026	-0.293	94.62
9621	-0.601	95.128
9558	-0.337	95.795
9120	-0.382	96.432
9523	-0.634	96.533
9089	-0.238	96.591
9059	-0.877	96.827
9620	-0.63	97.573
9589	-0.878	97.715
9654	-0.73	97.753
9025	-0.64	98.192
9180	-0.93	98.294
9150	-0.875	98.324
9522	-0.254	99.105
9557	-0.846	99.169
9058	-0.73	99.414
9119	-0.018	99.483
9588	-0.656	100.251
9653	-0.129	100.617
9088	-0.587	100.718
9619	-0.912	100.944
9149	-0.58	100.965
9024	-0.105	100.993
9179	-0.232	101.457
9556	-0.272	101.897
9521	-0.824	102.238
9057	-1.037	102.841
9118	-0.76	103.064
9587	-1.016	103.586
9618	-0.58	103.604
9652	-0.706	103.859
9023	-0.755	104.083
9148	-0.921	104.337
9087	-0.931	104.5
9555	-0.794	104.833
9178	-0.864	104.895
9520	-0.317	105.381
9056	-0.677	105.848
9586	-0.629	106.688
9117	-0.141	106.753
9617	-0.819	106.919
9651	-0.212	107.385
9147	-0.601	107.504
9022	-0.276	107.505
9086	-0.597	108.04
9554	-0.255	108.31
9519	-0.783	108.394
9177	-0.281	108.926

PART C - TRACKING TEST RESULTS FOR ROBOTIC TOTAL STATION AT 20km/hr

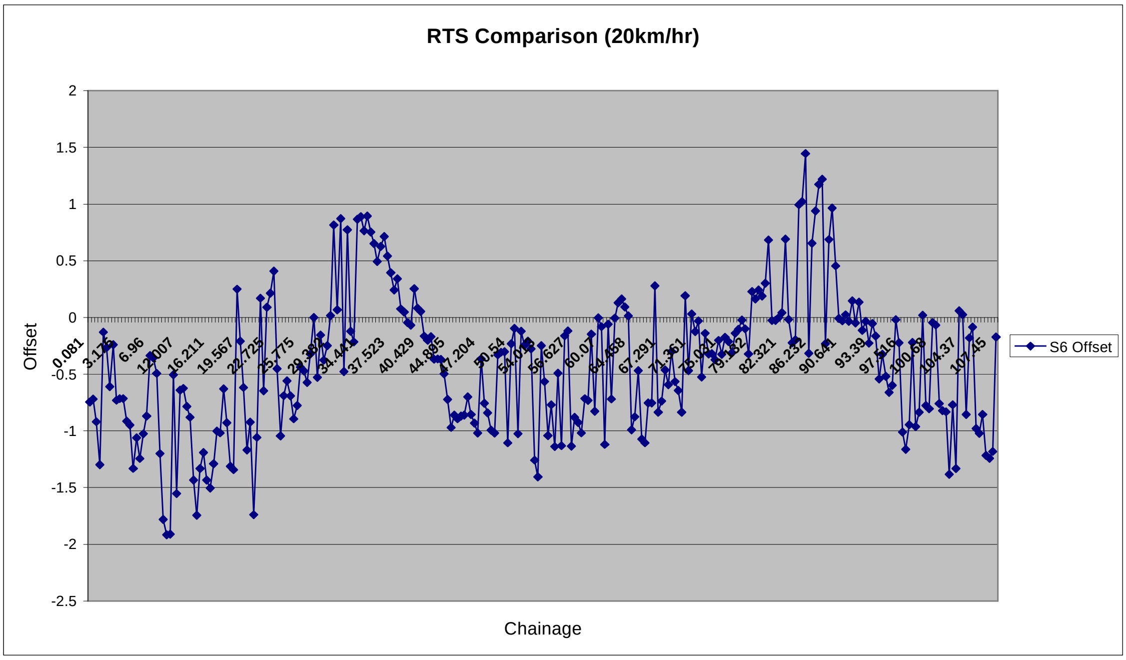

Figure B.3: RTS offsets from the control line at 20km/hr.

Table B.3: Point data of differences between RTS measurements and control line at 20km/hr.

Point Number	Offset (m)	Chainage (m)			
10072	-0.746	0.081	10551	0.09	22.372
10092	-0.718	0.127	10049	0.215	22.725
10013	-0.919	0.638	10529	0.409	23.161
10033	-1.297	0.742	10029	-0.452	23.362
10511	-0.128	1.045	10068	-1.044	23.964
10533	-0.265	1.394	10088	-0.69	24.026
10131	-0.61	1.451	10127	-0.558	25.082
10555	-0.24	1.56	10610	-0.691	25.215
10594	-0.73	3.082	10107	-0.893	25.509
10575	-0.715	3.175	10550	-0.776	25.587
10111	-0.716	3.402	10571	-0.439	25.775
10614	-0.914	3.482	10506	-0.47	25.986
10052	-0.947	4.31	10008	-0.573	26.108
10032	-1.331	5.574	10590	-0.32	26.244
10510	-1.062	5.715	10528	0	27.049
10532	-1.244	5.881	10028	-0.527	27.121
10554	-1.025	6.053	10048	-0.153	27.216
10012	-0.869	6.151	10067	-0.377	29.219
10091	-0.335	6.96	10087	-0.249	29.226
10071	-0.355	6.962	10609	0.017	29.382
10130	-0.493	7.91	10126	0.815	30.157
10613	-1.201	8.829	10007	0.067	30.308
10574	-1.781	9.352	10106	0.873	30.665
10593	-1.917	9.547	10549	-0.477	30.732
10110	-1.912	9.709	10570	0.774	30.769
10051	-0.505	11.436	10527	-0.121	32.291
10011	-1.553	11.713	10047	-0.216	32.31
10509	-0.641	12.007	10066	0.867	34.313
10553	-0.625	12.267	10086	0.89	34.441
10531	-0.786	12.349	10548	0.766	35.239
10031	-0.879	12.603	10608	0.895	35.401
10090	-1.435	12.809	10006	0.753	35.903
10070	-1.745	13.197	10125	0.653	35.909
10129	-1.333	14.491	10569	0.493	36.22
10573	-1.191	15.794	10105	0.627	36.348
10612	-1.434	16.209	10505	0.714	36.431
10109	-1.504	16.211	10589	0.542	36.847
10592	-1.289	16.324	10526	0.395	37.523
10508	-1.001	17.53	10046	0.242	38.366
10552	-1.018	17.799	10027	0.342	38.789
10050	-0.63	17.845	10065	0.075	38.964
10530	-0.928	18.132	10085	0.048	39.134
10010	-1.311	18.337	10547	-0.046	39.469
10030	-1.342	18.732	10005	-0.068	39.809
10089	0.251	19.102	10607	0.254	39.828
10069	-0.208	19.567	10504	0.081	40.214
10611	-0.616	20.736	10124	0.054	40.429
10128	-1.169	21.051	10525	-0.165	41.362
10572	-0.924	21.747	10045	-0.201	42.261
10108	-1.739	21.798	10026	-0.17	42.457
10591	-1.057	22.147	10568	-0.368	42.654
10507	0.17	22.199	10588	-0.366	42.67
10009	-0.645	22.279	10104	-0.37	42.953

10627	-0.496	44.593	10139	-0.754	65.641
10143	-0.722	44.654	10542	-0.753	66.116
10004	-0.97	44.895	10041	0.279	66.258
10546	-0.862	45.124	10520	-0.836	66.311
10587	-0.856	46.812	10080	-0.738	67.291
10123	-0.932	46.829	10602	-0.462	68.155
10524	-1.019	46.904	10060	-0.593	69.405
10567	-0.365	47.204	10583	-0.3	69.438
10103	-0.756	47.426	10119	-0.566	69.456
10003	-0.841	48.537	10021	-0.644	69.681
10025	-0.994	48.614	10622	-0.835	69.948
10044	-1.019	48.827	10563	0.192	70.257
10142	-0.329	49.118	10099	-0.469	70.285
10545	-0.307	49.683	10138	0.032	71.361
10083	-0.302	50.109	10519	-0.123	71.406
10626	-1.105	50.259	10541	-0.029	71.57
10063	-0.231	50.54	10040	-0.525	71.835
10605	-0.095	50.659	10079	-0.14	73.155
10502	-1.025	51.226	10601	-0.321	73.514
10523	-0.121	51.307	10562	-0.318	74.177
10122	-0.246	51.727	10118	-0.371	74.752
10002	-0.21	51.86	10582	-0.202	74.841
10024	-0.276	53.274	10621	-0.324	75.031
10586	-1.258	53.385	10020	-0.175	75.194
10566	-1.406	53.613	10518	-0.212	75.395
10043	-0.249	54.013	10059	-0.31	75.412
10501	-0.566	54.132	10540	-0.14	75.832
10102	-1.042	54.411	10137	-0.104	75.935
10625	-0.77	54.446	10098	-0.021	76.322
10141	-1.139	55.184	10078	-0.1	77.588
10001	-0.491	55.194	10039	-0.322	77.788
10544	-1.13	55.865	10600	0.229	79.132
10000	-0.162	56.174	10019	0.165	80.078
10500	-0.117	56.525	10058	0.243	80.186
10082	-1.136	56.627	10117	0.19	80.226
10522	-0.88	57.005	10581	0.301	80.388
10604	-0.926	57.234	10620	0.685	80.499
10062	-1.018	57.869	10561	-0.026	80.75
10585	-0.716	58.365	10517	-0.025	80.873
10121	-0.731	58.531	10539	-0.001	81.565
10565	-0.148	58.847	10136	0.042	82.321
10023	-0.826	59.627	10038	0.693	82.595
10101	-0.002	59.787	10097	-0.017	82.651
10140	-0.08	60.07	10077	-0.222	83.543
10624	-1.12	60.444	10018	-0.198	85.194
10543	-0.06	60.793	10516	0.994	85.568
10042	-0.718	60.979	10560	1.022	85.861
10521	-0.005	61.465	10599	1.447	85.958
10081	0.129	61.831	10057	-0.316	86.168
10603	0.165	62.397	10619	0.655	86.232
10061	0.093	63.321	10538	0.94	86.495
10022	0.015	64.404	10116	1.174	86.908
10564	-0.99	64.458	10580	1.221	87.126
10584	-0.876	64.644	10037	-0.232	88.16
10623	-0.469	64.708	10096	0.688	88.39
10120	-1.071	64.775	10135	0.965	88.449
10100	-1.105	65.491	10076	0.455	89.213

10515	-0.008	90.125
10559	-0.029	90.641
10017	0.025	90.826
10537	-0.035	90.973
10598	0.147	91.353
10115	-0.047	91.945
10579	0.135	92.142
10056	-0.113	92.536
10618	-0.035	92.992
10095	-0.227	93.024
10134	-0.053	93.39
10075	-0.164	93.529
10036	-0.542	94.399
10016	-0.324	94.728
10514	-0.519	95.769
10558	-0.659	96.426
10536	-0.597	96.591
10055	-0.019	97.043
10617	-0.222	97.235
10597	-1.01	97.516
10114	-1.162	97.935
10578	-0.946	98.161
10035	-0.221	98.845
10094	-0.962	99.136
10074	-0.835	99.407
10513	0.022	99.859
10133	-0.775	99.864
10015	-0.805	100.273
10557	-0.045	100.681
10535	-0.066	100.699
10596	-0.758	101.642
10113	-0.822	102.073
10577	-0.831	102.172
10616	-1.383	102.365
10054	-0.77	103.025
10034	-1.333	104.131
10093	0.059	104.272
10073	0.026	104.374
10512	-0.855	104.729
10014	-0.18	104.87
10132	-0.085	105.021
10534	-0.98	105.307
10556	-1.023	105.413
10615	-0.856	106.899
10595	-1.217	107.069
10576	-1.242	107.341
10112	-1.181	107.449
10053	-0.173	108.637

APPENDIX C

TEST RESULTS FOR GLOBAL POSITIONING SYSTEM.

PART A - TRACKING TEST RESULTS FOR GLOBAL POSITIONING SYSTEM AT 10km/hr

PART B - TRACKING TEST RESULTS FOR GLOBAL POSITIONING SYSTEM AT 20km/hr

PART A - TRACKING TEST RESULTS FOR GLOBAL POSITIONING SYSTEM AT 10km/hr

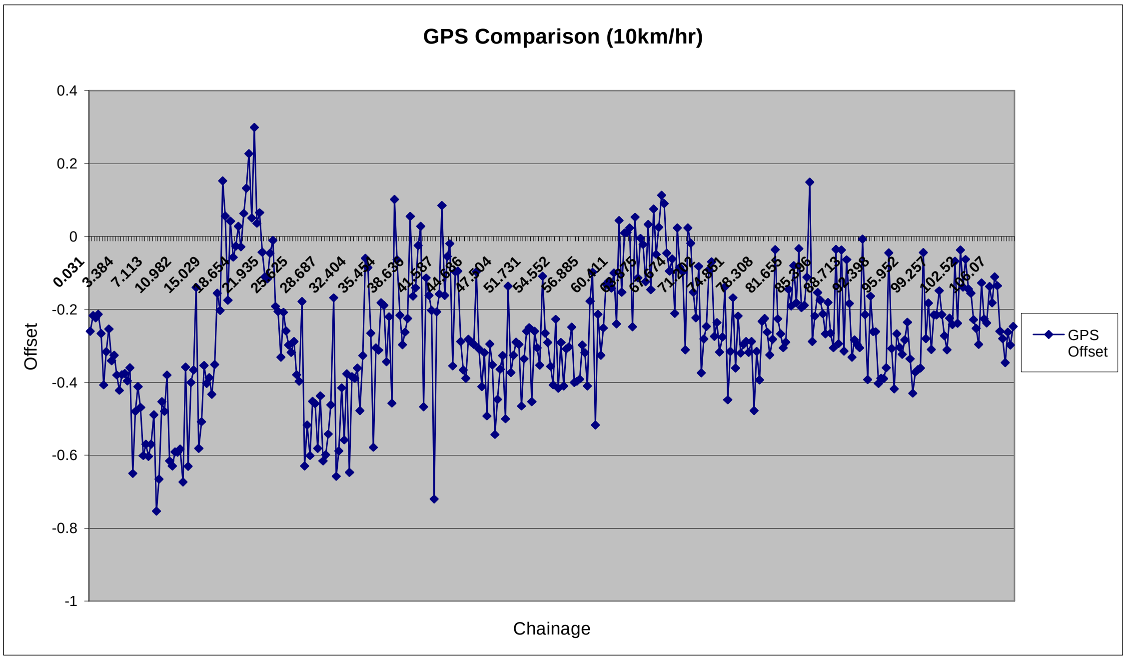

Figure C.1: GPS offsets from the control line at 10km/hr.

Table C.1: Point data of differences between GPS measurements and control line at 10km/hr.

Point Number	Offset (m)	Chainage (m)	Point Number	Offset (m)	Chainage (m)
9644(2)	-0.26	0.031	9639(2)	-0.175	17.219
9611(2)	-0.217	0.032	9546(2)	0.042	18.236
9141(2)	-0.223	0.273	9580(2)	-0.057	18.583
9083(2)	-0.213	0.575	9606(2)	-0.027	18.654
9551(2)	-0.266	1.1	9512(2)	0.028	18.681
9053(2)	-0.407	1.347	9048(2)	-0.029	19.363
9517(2)	-0.316	1.67	9078(2)	0.063	19.5
9113(2)	-0.254	2.079	9014(2)	0.132	19.677
9171(2)	-0.341	2.103	9108(2)	0.227	20.063
9019(2)	-0.326	2.988	9638(2)	0.051	20.343
9610(2)	-0.38	3.315	9167(2)	0.299	20.709
9643(2)	-0.422	3.384	9511(2)	0.036	21.309
9584(2)	-0.379	3.385	9545(2)	0.065	21.445
9550(2)	-0.376	4.369	9579(2)	-0.043	21.727
9082(2)	-0.396	4.381	9605(2)	-0.111	21.935
9140(2)	-0.36	4.432	9047(2)	-0.116	22.631
9052(2)	-0.65	4.868	9077(2)	-0.046	22.896
9516(2)	-0.48	5.084	9013(2)	-0.011	23.018
9112(2)	-0.412	5.813	9637(2)	-0.192	23.169
9018(2)	-0.469	6.383	9137(2)	-0.206	23.492
9642(2)	-0.601	6.834	9107(2)	-0.331	23.496
9609(2)	-0.57	6.995	9166(2)	-0.208	24.005
9583(2)	-0.603	7.113	9578(2)	-0.259	24.258
9549(2)	-0.57	7.761	9510(2)	-0.298	24.426
9081(2)	-0.489	8.268	9544(2)	-0.318	24.443
9051(2)	-0.753	8.489	9012(2)	-0.288	25.625
9515(2)	-0.665	8.51	9046(2)	-0.379	25.755
9139(2)	-0.453	8.564	9636(2)	-0.397	25.924
9170(2)	-0.48	9.188	9076(2)	-0.178	26.199
9111(2)	-0.38	9.545	9106(2)	-0.629	26.377
9017(2)	-0.616	9.828	9136(2)	-0.517	26.58
9641(2)	-0.629	10.314	9165(2)	-0.601	26.984
9582(2)	-0.591	10.492	9577(2)	-0.452	27.129
9608(2)	-0.592	10.982	9509(2)	-0.458	27.26
9548(2)	-0.583	11.252	9543(2)	-0.581	27.327
9514(2)	-0.673	12.041	9011(2)	-0.437	28.409
9080(2)	-0.358	12.118	9045(2)	-0.616	28.687
9050(2)	-0.63	12.214	9105(2)	-0.599	29.221
9138(2)	-0.4	12.699	9135(2)	-0.542	29.61
9169(2)	-0.366	13.208	9576(2)	-0.462	29.762
9110(2)	-0.14	13.315	9075(2)	-0.168	29.816
9016(2)	-0.581	13.389	9164(2)	-0.658	29.85
9640(2)	-0.508	13.835	9604(2)	-0.588	29.955
9547(2)	-0.354	14.791	9508(2)	-0.415	30.102
9581(2)	-0.403	15.029	9542(2)	-0.558	30.119
9607(2)	-0.387	15.33	9635(2)	-0.377	31.044
9513(2)	-0.433	15.496	9044(2)	-0.647	31.542
9049(2)	-0.351	15.89	9104(2)	-0.385	32.404
9079(2)	-0.156	15.896	9575(2)	-0.389	32.47
9015(2)	-0.203	16.787	9134(2)	-0.361	32.681
9109(2)	0.152	16.921	9163(2)	-0.478	32.807
9168(2)	0.056	17.05	9541(2)	-0.327	32.994

9010(2)	-0.06	33.078	9629(2)	-0.29	50.154
9074(2)	-0.085	33.215	9536(2)	-0.296	50.962
9634(2)	-0.265	34.369	9038(2)	-0.465	50.983
9043(2)	-0.578	34.402	9188(2)	-0.336	51
9507(2)	-0.305	34.937	9569(2)	-0.26	51.731
9574(2)	-0.312	35.308	9069(2)	-0.25	51.997
9103(2)	-0.182	35.454	9004(2)	-0.453	52.325
9133(2)	-0.189	35.89	9502(2)	-0.26	52.658
9162(2)	-0.344	35.896	9599(2)	-0.305	52.923
9540(2)	-0.22	35.99	9657(2)	-0.353	53.387
9603(2)	-0.457	36.114	9098(2)	-0.109	53.49
9009(2)	0.102	36.282	9157(2)	-0.265	53.719
9073(2)	-0.064	36.379	9628(2)	-0.291	53.823
9633(2)	-0.216	37.17	9128(2)	-0.356	54.345
9042(2)	-0.297	37.415	9037(2)	-0.407	54.457
9506(2)	-0.262	38.067	9535(2)	-0.227	54.552
9573(2)	-0.225	38.328	9187(2)	-0.416	54.668
9102(2)	0.055	38.636	9501(2)	-0.291	54.687
9539(2)	-0.164	38.993	9003(2)	-0.41	54.874
9161(2)	-0.141	39.066	9500(2)	-0.308	55.228
9132(2)	-0.025	39.157	9068(2)	-0.303	55.619
9008(2)	0.028	39.49	9568(2)	-0.249	55.686
9602(2)	-0.467	39.536	9002(2)	-0.4	56.254
9632(2)	-0.114	40.107	9001(2)	-0.397	56.703
9072(2)	-0.162	40.25	9000(2)	-0.391	56.753
9041(2)	-0.203	40.573	9598(2)	-0.298	56.757
9191(2)	-0.72	40.727	9656(2)	-0.319	56.885
9505(2)	-0.207	41.423	9627(2)	-0.41	57.39
9572(2)	-0.158	41.587	9534(2)	-0.177	57.505
9101(2)	0.085	41.981	9097(2)	-0.098	57.625
9538(2)	-0.162	42.143	9186(2)	-0.517	57.931
9160(2)	-0.055	42.494	9156(2)	-0.213	57.937
9131(2)	-0.02	42.63	9036(2)	-0.326	57.948
9601(2)	-0.355	42.81	9127(2)	-0.251	58.355
9007(2)	-0.097	42.827	9567(2)	-0.131	58.926
9631(2)	-0.095	43.283	9067(2)	-0.123	60.016
9190(2)	-0.288	43.789	9597(2)	-0.142	60.222
9071(2)	-0.366	43.962	9655(2)	-0.1	60.411
9040(2)	-0.389	44.132	9626(2)	-0.24	60.92
9537(2)	-0.282	44.686	9533(2)	0.044	61.16
9571(2)	-0.289	44.956	9035(2)	-0.153	61.414
9504(2)	-0.296	45.15	9155(2)	0.01	61.711
9100(2)	-0.097	45.409	9096(2)	0.011	61.741
9159(2)	-0.308	46.014	9126(2)	0.023	61.872
9006(2)	-0.412	46.054	9185(2)	-0.248	61.921
9130(2)	-0.319	46.126	9566(2)	0.053	62.824
9600(2)	-0.492	46.206	9596(2)	-0.114	63.557
9630(2)	-0.295	46.611	9066(2)	-0.005	63.871
9189(2)	-0.352	47.356	9654(2)	-0.022	63.875
9039(2)	-0.543	47.494	9625(2)	-0.124	64.31
9070(2)	-0.447	47.504	9532(2)	0.033	64.39
9570(2)	-0.364	48.488	9034(2)	-0.146	64.722
9503(2)	-0.327	48.77	9154(2)	0.075	65.353
9005(2)	-0.5	49.251	9184(2)	-0.049	65.445
9099(2)	-0.136	49.503	9095(2)	0.025	65.659
9129(2)	-0.373	49.52	9125(2)	0.113	65.96
9158(2)	-0.326	49.82	9565(2)	0.09	66.235

9531(2)	-0.046	67.555	9559(2)	-0.154	85.396
9065(2)	-0.095	67.59	9525(2)	-0.175	86.088
9624(2)	-0.062	67.674	9650(2)	-0.212	86.312
9033(2)	-0.211	67.972	9590(2)	-0.267	86.404
9153(2)	0.023	69.088	9148(2)	-0.181	86.464
9183(2)	-0.084	69.107	9178(2)	-0.265	86.49
9094(2)	-0.097	69.149	9027(2)	-0.305	86.612
9595(2)	-0.311	69.328	9119(2)	-0.035	87.225
9564(2)	0.023	69.656	9618(2)	-0.294	87.276
9124(2)	-0.019	69.758	9089(2)	-0.037	87.462
9653(2)	-0.153	70.406	9059(2)	-0.314	87.916
9530(2)	-0.223	70.691	9558(2)	-0.064	88.713
9623(2)	-0.082	71.106	9524(2)	-0.184	88.942
9032(2)	-0.374	71.202	9026(2)	-0.331	89.476
9064(2)	-0.281	71.257	9147(2)	-0.284	89.503
9182(2)	-0.247	72.744	9177(2)	-0.296	89.75
9152(2)	-0.091	72.769	9617(2)	-0.305	90.243
9563(2)	-0.07	72.964	9118(2)	-0.007	90.74
9093(2)	-0.274	73.244	9088(2)	-0.214	91.01
9123(2)	-0.236	73.461	9058(2)	-0.392	91.375
9594(2)	-0.317	73.518	9557(2)	-0.164	91.472
9529(2)	-0.276	73.778	9523(2)	-0.261	91.845
9622(2)	-0.138	74.509	9649(2)	-0.261	92.398
9031(2)	-0.448	74.732	9146(2)	-0.403	92.668
9063(2)	-0.315	74.851	9025(2)	-0.389	93.056
9562(2)	-0.168	76.178	9176(2)	-0.39	93.202
9181(2)	-0.361	76.355	9616(2)	-0.36	93.297
9151(2)	-0.218	76.393	9117(2)	-0.045	93.915
9528(2)	-0.32	76.826	9556(2)	-0.307	94.505
9593(2)	-0.296	76.826	9057(2)	-0.418	94.601
9092(2)	-0.288	76.897	9087(2)	-0.267	94.649
9122(2)	-0.318	77.103	9522(2)	-0.304	95.099
9652(2)	-0.288	77.133	9145(2)	-0.323	95.946
9030(2)	-0.478	77.573	9648(2)	-0.284	95.952
9621(2)	-0.315	78.196	9024(2)	-0.235	96.155
9062(2)	-0.393	78.308	9615(2)	-0.336	96.398
9561(2)	-0.233	79.356	9175(2)	-0.43	96.731
9150(2)	-0.225	79.558	9589(2)	-0.372	96.969
9527(2)	-0.262	79.601	9555(2)	-0.365	97.598
9180(2)	-0.325	79.86	9056(2)	-0.361	97.94
9592(2)	-0.282	80.13	9116(2)	-0.044	97.953
9091(2)	-0.036	80.461	9521(2)	-0.28	98.14
9121(2)	-0.226	80.632	9086(2)	-0.183	98.418
9651(2)	-0.267	80.689	9588(2)	-0.31	98.887
9029(2)	-0.305	80.713	9647(2)	-0.215	99.257
9620(2)	-0.29	81.082	9144(2)	-0.215	99.271
9061(2)	-0.145	81.655	9023(2)	-0.149	99.335
9560(2)	-0.191	82.417	9614(2)	-0.214	99.583
9526(2)	-0.08	82.899	9174(2)	-0.272	100.673
9179(2)	-0.182	83.196	9554(2)	-0.311	100.935
9149(2)	-0.033	83.243	9520(2)	-0.224	101.219
9591(2)	-0.195	83.291	9055(2)	-0.242	101.301
9028(2)	-0.189	83.669	9115(2)	-0.068	101.586
9120(2)	-0.112	83.893	9587(2)	-0.238	102.119
9090(2)	0.149	83.973	9085(2)	-0.037	102.211
9619(2)	-0.288	84.318	9022(2)	-0.139	102.523
9060(2)	-0.218	84.816	9646(2)	-0.063	102.599

9143(2)	-0.144	102.623
9613(2)	-0.156	102.811
9173(2)	-0.228	103.944
9553(2)	-0.252	104.027
9519(2)	-0.296	104.348
9114(2)	-0.127	104.806
9586(2)	-0.226	105.583
9021(2)	-0.237	105.779
9645(2)	-0.137	105.99
9142(2)	-0.182	106.07
9084(2)	-0.111	106.076
9612(2)	-0.135	106.1
9552(2)	-0.26	106.93
9054(2)	-0.28	107.208
9518(2)	-0.346	107.691
9172(2)	-0.262	107.728
9020(2)	-0.298	109.088
9585(2)	-0.247	109.177

PART B - TRACKING TEST RESULTS FOR GLOBAL POSITIONING SYSTEM AT 20km/hr

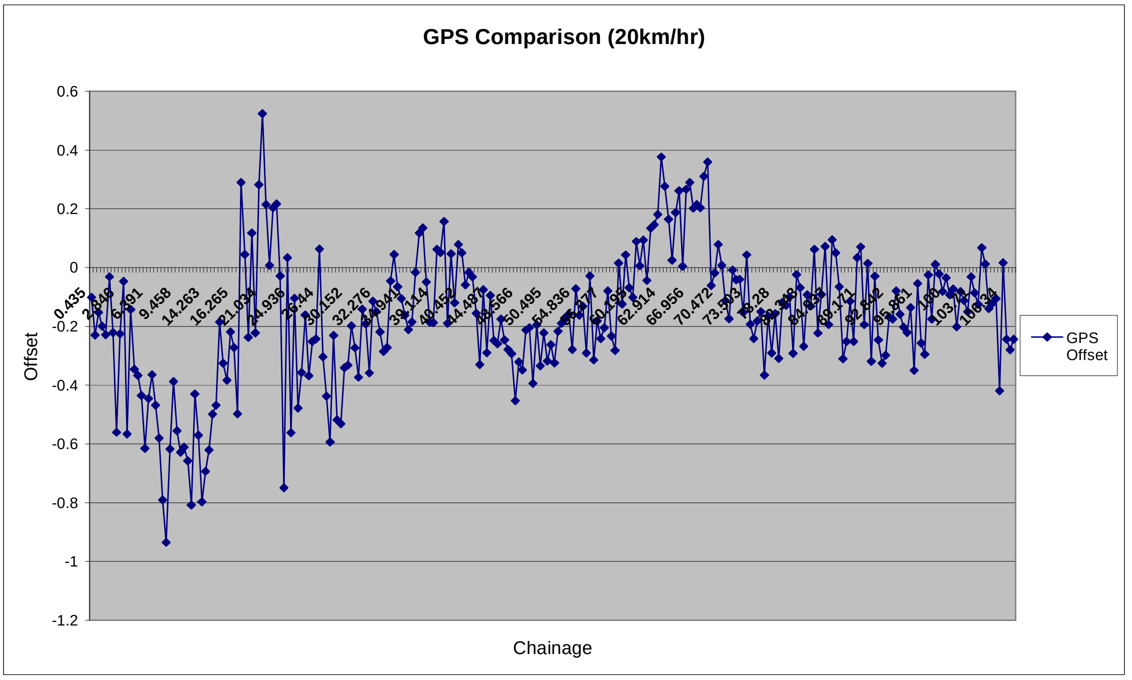

Figure C.1: GPS offsets from the control line at 20km/hr.

Table C.1: Point data of differences between GPS measurements and control line at 20km/hr.

Point Number	Offset (m)	Chainage (m)			
10512(2)	-0.101	0.435	10508(2)	0.217	21.654
10555(2)	-0.23	0.47	10126(2)	-0.028	22.084
10110(2)	-0.152	0.591	10106(2)	-0.749	23.316
10052(2)	-0.199	0.718	10048(2)	0.034	24.453
10533(2)	-0.228	0.821	10028(2)	-0.562	24.936
10071(2)	-0.031	1.116	10571(2)	-0.104	25.071
10592(2)	-0.221	2.144	10067(2)	-0.478	25.218
10032(2)	-0.56	2.564	10550(2)	-0.357	25.334
10575(2)	-0.225	2.846	10588(2)	-0.161	25.545
10090(2)	-0.047	2.948	10601(2)	-0.368	25.869
10011(2)	-0.566	3.164	10086(2)	-0.251	26.097
10129(2)	-0.143	3.232	10507(2)	-0.243	26.213
10605(2)	-0.346	4.293	10529(2)	0.063	26.44
10554(2)	-0.367	5.197	10125(2)	-0.304	27.057
10511(2)	-0.436	5.895	10007(2)	-0.438	27.388
10532(2)	-0.615	6.053	10105(2)	-0.593	27.93
10109(2)	-0.446	6.391	10047(2)	-0.231	29.202
10070(2)	-0.364	7.282	10027(2)	-0.518	29.52
10051(2)	-0.468	7.4	10549(2)	-0.532	29.858
10591(2)	-0.58	7.57	10066(2)	-0.341	29.919
10031(2)	-0.791	8.593	10570(2)	-0.332	30.152
10010(2)	-0.935	8.61	10587(2)	-0.198	30.235
10574(2)	-0.617	8.7	10600(2)	-0.273	30.242
10089(2)	-0.388	9.114	10506(2)	-0.373	30.549
10128(2)	-0.555	9.458	10528(2)	-0.141	30.895
10604(2)	-0.628	10.167	10085(2)	-0.191	30.923
10553(2)	-0.611	11.104	10006(2)	-0.359	31.061
10510(2)	-0.657	11.399	10124(2)	-0.114	31.888
10108(2)	-0.808	12.423	10104(2)	-0.15	32.276
10050(2)	-0.43	12.964	10046(2)	-0.219	33.493
10069(2)	-0.57	13.805	10548(2)	-0.286	34.07
10030(2)	-0.797	14.117	10026(2)	-0.272	34.244
10009(2)	-0.693	14.263	10065(2)	-0.046	34.77
10590(2)	-0.621	14.552	10599(2)	0.044	34.882
10573(2)	-0.499	14.777	10586(2)	-0.065	34.898
10127(2)	-0.469	15.183	10569(2)	-0.106	34.917
10088(2)	-0.185	15.309	10527(2)	-0.162	34.941
10552(2)	-0.326	15.954	10505(2)	-0.211	34.993
10603(2)	-0.383	16.051	10005(2)	-0.185	35.721
10509(2)	-0.219	16.212	10084(2)	-0.016	35.901
10531(2)	-0.272	16.265	10123(2)	0.117	37.012
10107(2)	-0.498	18.423	10103(2)	0.135	37.901
10049(2)	0.29	18.719	10547(2)	-0.049	38.489
10008(2)	0.044	19.015	10045(2)	-0.186	38.832
10068(2)	-0.237	19.3	10025(2)	-0.187	39.114
10589(2)	0.117	19.921	10504(2)	0.062	39.22
10029(2)	-0.222	20.255	10585(2)	0.051	39.669
10572(2)	0.282	20.496	10598(2)	0.157	39.793
10530(2)	0.524	21.034	10526(2)	-0.19	39.919
10087(2)	0.215	21.09	10568(2)	0.047	39.994
10602(2)	0.008	21.311	10004(2)	-0.12	40.031
10551(2)	0.204	21.399	10064(2)	0.079	40.279

10083(2)	0.05	40.452	10614(2)	0.277	64.825
10122(2)	-0.059	42.405	10060(2)	0.165	64.886
10102(2)	-0.016	43.382	10521(2)	0.025	64.888
10618(2)	-0.032	43.799	10542(2)	0.187	65.603
10546(2)	-0.156	43.837	10118(2)	0.261	65.758
10044(2)	-0.33	44.178	10020(2)	0.005	66.312
10503(2)	-0.075	44.189	10137(2)	0.266	66.536
10024(2)	-0.29	44.282	10594(2)	0.29	66.956
10597(2)	-0.095	44.487	10098(2)	0.202	67.263
10003(2)	-0.249	44.563	10040(2)	0.215	67.757
10525(2)	-0.259	44.705	10079(2)	0.204	67.848
10063(2)	-0.176	45.319	10563(2)	0.311	68.499
10584(2)	-0.246	45.365	10580(2)	0.359	68.91
10567(2)	-0.279	45.449	10520(2)	-0.061	69.88
10082(2)	-0.293	45.838	10059(2)	-0.018	70.446
10121(2)	-0.453	47.951	10613(2)	0.079	70.472
10545(2)	-0.321	48.566	10541(2)	0.007	71.002
10002(2)	-0.348	48.983	10117(2)	-0.113	71.546
10617(2)	-0.213	49.132	10019(2)	-0.174	71.709
10101(2)	-0.204	49.166	10097(2)	-0.008	72.486
10023(2)	-0.394	49.173	10136(2)	-0.041	72.743
10524(2)	-0.195	49.721	10562(2)	-0.04	73.426
10043(2)	-0.334	50.043	10078(2)	-0.153	73.437
10583(2)	-0.222	50.437	10579(2)	0.043	73.503
10140(2)	-0.318	50.495	10039(2)	-0.193	74.152
10502(2)	-0.262	51.146	10612(2)	-0.241	75.378
10566(2)	-0.324	51.224	10519(2)	-0.182	75.697
10062(2)	-0.217	51.531	10540(2)	-0.15	76.152
10001(2)	-0.19	52.719	10058(2)	-0.366	76.841
10616(2)	-0.176	53.671	10018(2)	-0.165	77.049
10120(2)	-0.159	53.826	10116(2)	-0.291	77.069
10544(2)	-0.279	54.629	10135(2)	-0.157	78.28
10523(2)	-0.072	54.836	10077(2)	-0.309	78.768
10501(2)	-0.163	54.913	10096(2)	-0.118	79.209
10100(2)	-0.132	55.22	10518(2)	-0.128	79.423
10022(2)	-0.291	55.228	10561(2)	-0.1	79.665
10596(2)	-0.028	55.305	10038(2)	-0.292	79.696
10139(2)	-0.314	55.372	10539(2)	-0.024	81.041
10000(2)	-0.182	55.68	10611(2)	-0.069	81.689
10042(2)	-0.242	56.202	10057(2)	-0.268	82.343
10081(2)	-0.205	56.277	10115(2)	-0.093	82.357
10582(2)	-0.08	56.293	10017(2)	-0.131	82.606
10565(2)	-0.233	57.051	10134(2)	0.062	83.115
10061(2)	-0.282	57.943	10076(2)	-0.223	83.803
10500(2)	0.015	58.549	10095(2)	-0.091	84.441
10615(2)	-0.124	58.91	10560(2)	0.072	84.649
10119(2)	0.043	59.824	10037(2)	-0.194	84.858
10522(2)	-0.068	59.903	10517(2)	0.095	84.937
10543(2)	-0.101	60.195	10538(2)	0.05	85.702
10595(2)	0.089	60.611	10610(2)	-0.066	86.753
10138(2)	0.006	60.939	10056(2)	-0.31	86.954
10099(2)	0.094	61.336	10016(2)	-0.251	87.311
10021(2)	-0.044	61.408	10114(2)	-0.114	88.043
10080(2)	0.134	62.135	10075(2)	-0.252	88.223
10041(2)	0.146	62.373	10559(2)	0.034	89.101
10564(2)	0.181	62.813	10133(2)	0.07	89.171
10581(2)	0.376	62.914	10094(2)	-0.194	89.585

10516(2)	0.014	89.618
10036(2)	-0.319	89.981
10537(2)	-0.029	90.456
10609(2)	-0.246	91.926
10015(2)	-0.326	92.096
10113(2)	-0.299	92.771
10055(2)	-0.168	92.842
10074(2)	-0.175	93.803
10132(2)	-0.08	94.265
10515(2)	-0.159	94.353
10558(2)	-0.203	94.546
10093(2)	-0.221	94.962
10536(2)	-0.136	95.245
10035(2)	-0.35	95.278
10578(2)	-0.054	95.861
10608(2)	-0.257	96.663
10014(2)	-0.295	97.002
10054(2)	-0.025	98.475
10112(2)	-0.176	98.729
10073(2)	0.011	99.18
10514(2)	-0.022	99.313
10557(2)	-0.081	99.602
10092(2)	-0.035	100
10535(2)	-0.092	100.155
10131(2)	-0.073	100.675
10034(2)	-0.202	100.783
10577(2)	-0.081	101.233
10013(2)	-0.113	102.034
10607(2)	-0.15	102.558
10053(2)	-0.031	103.625
10111(2)	-0.086	103.714
10556(2)	-0.125	104.162
10513(2)	0.067	104.413
10072(2)	0.012	104.638
10534(2)	-0.139	105.051
10593(2)	-0.122	105.704
10130(2)	-0.106	105.949
10033(2)	-0.419	106.284
10091(2)	0.016	106.344
10576(2)	-0.244	106.66
10012(2)	-0.28	107.257
10606(2)	-0.244	108.069

APPENDIX D

TEST RESULTS FOR ROBOTIC TOTAL STATION AND GLOBAL POSITIONING SYSTEM.

PART A – DYNAMIC TRACKING COMPARISON TEST RESULTS FOR ROBOTIC TOTAL STATION AND GLOBAL POSITIONING SYSTEM AT 10km/hr

PART B - DYNAMIC TRACKING COMPARISON TEST RESULTS FOR ROBOTIC TOTAL STATION AND GLOBAL POSITIONING SYSTEM AT 20km/hr

PART A – DYNAMIC TRACKING COMPARISON TEST RESULTS FOR ROBOTIC TOTAL STATION AND GLOBAL POSITIONING SYSTEM AT 10km/hr

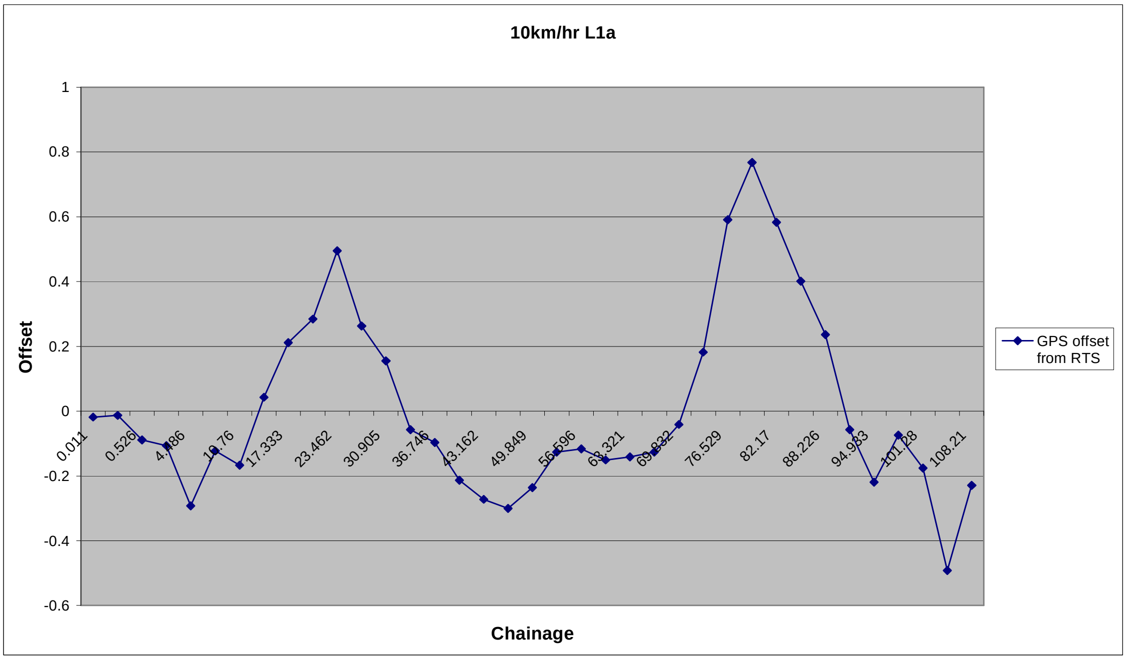

Figure D.1: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

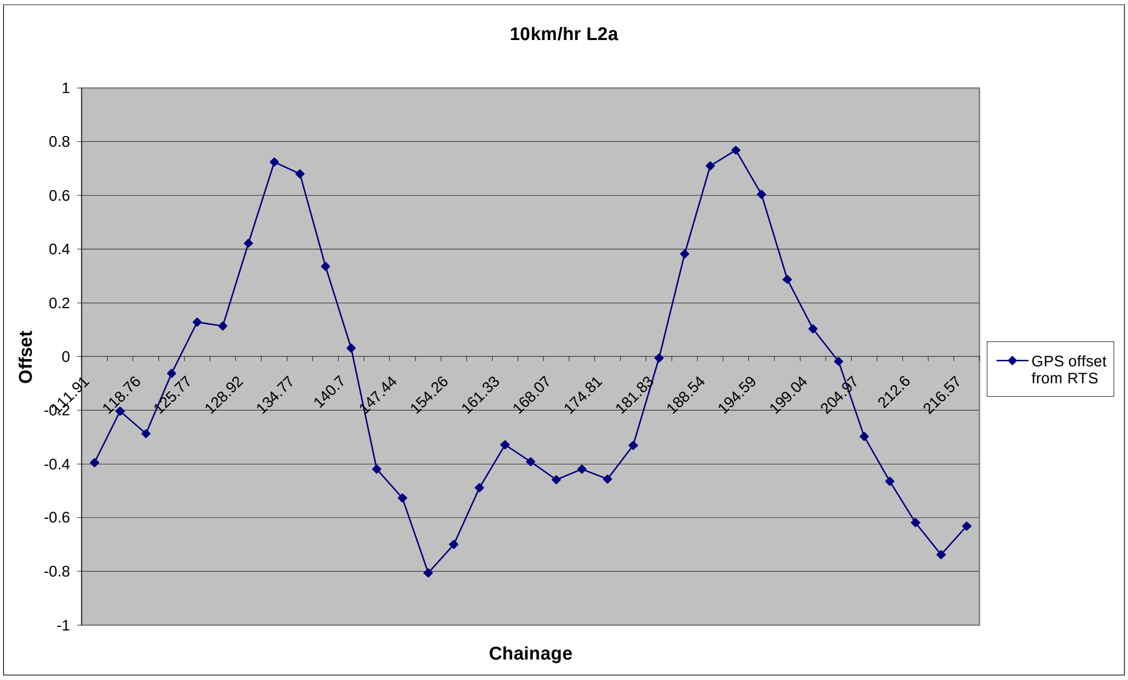

Figure D.2: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

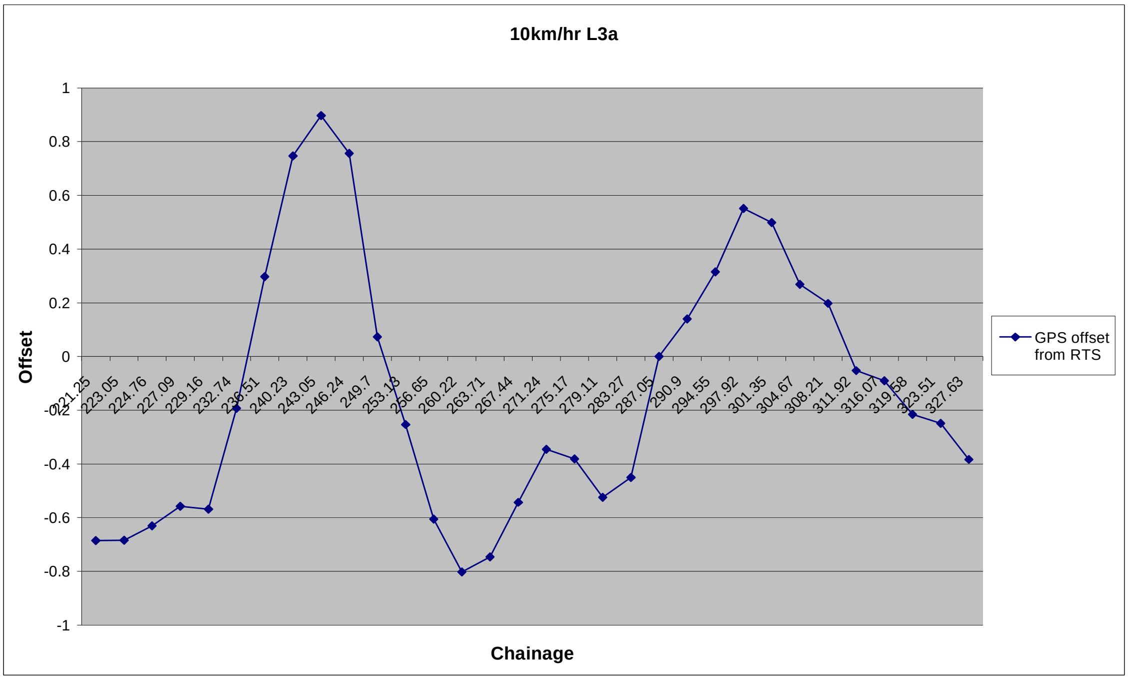

Figure D.3: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

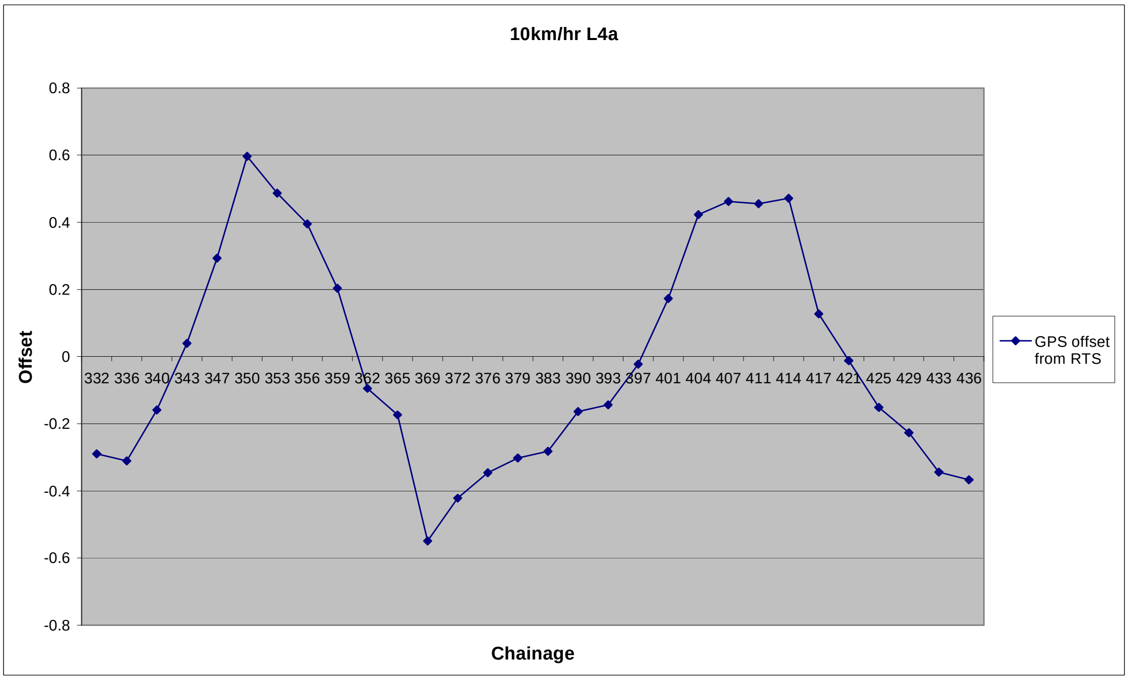

Figure D.4: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

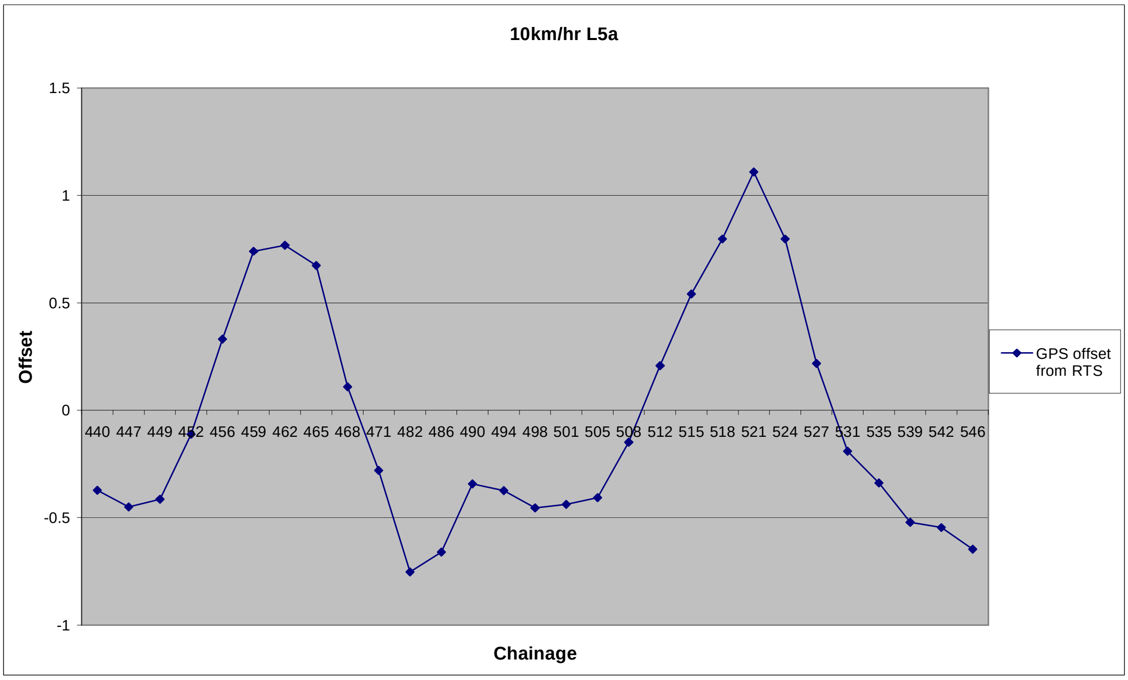

Figure D.5: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

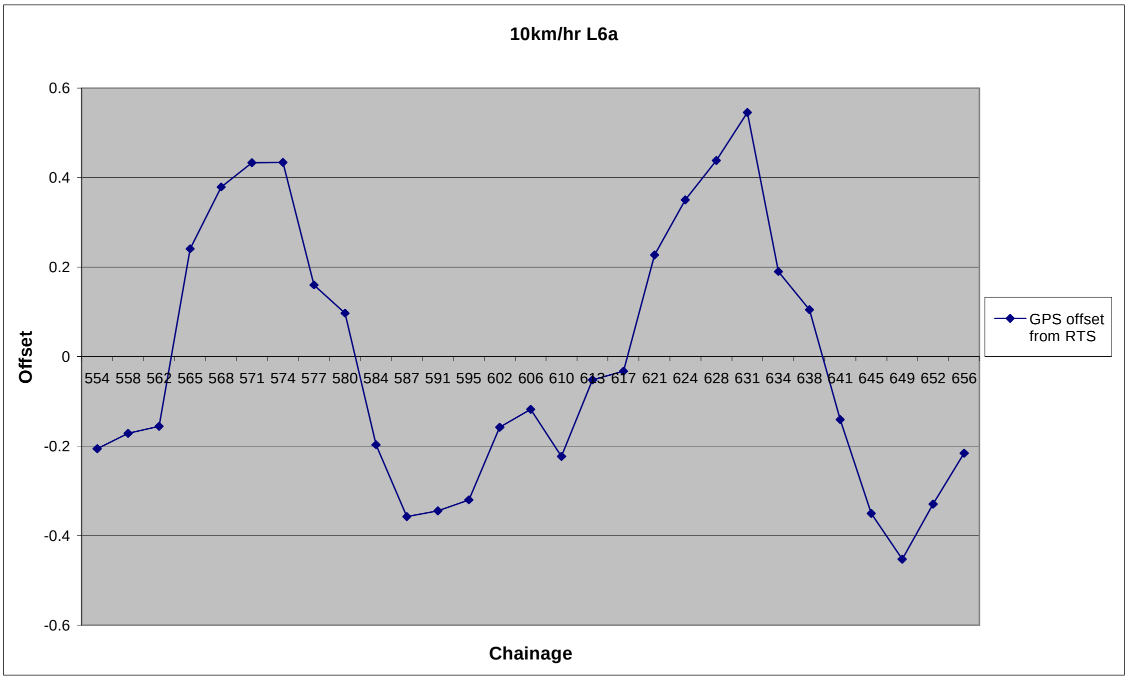

Figure D.6: Comparison between RTS and GPS Dynamic Tracking measurements at 10km/hr.

PART B - DYNAMIC TRACKING COMPARISON TEST RESULTS FOR ROBOTIC TOTAL STATION AND GLOBAL POSITIONING SYSTEM AT 20km/hr

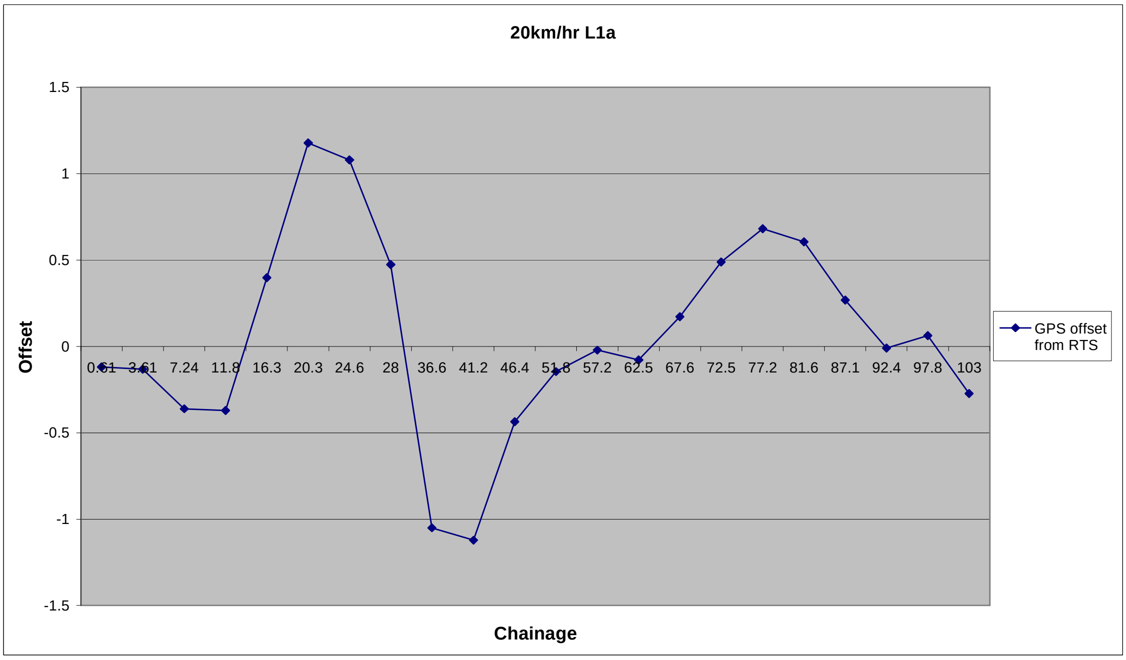

Figure D.1: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

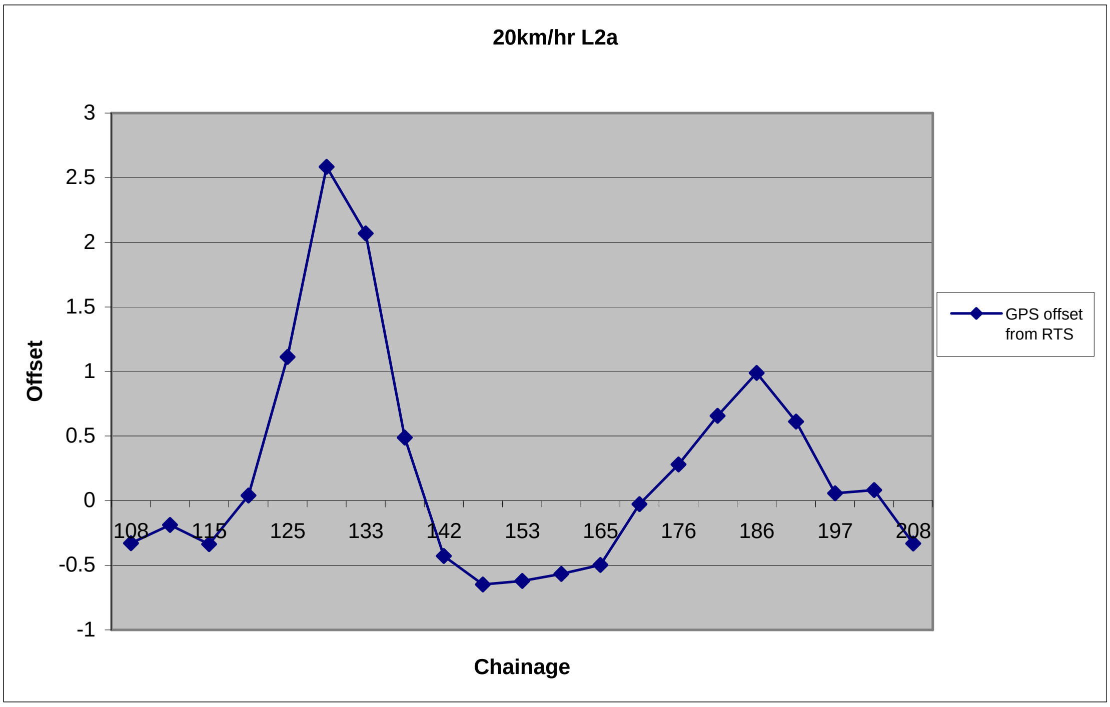

Figure D.2: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

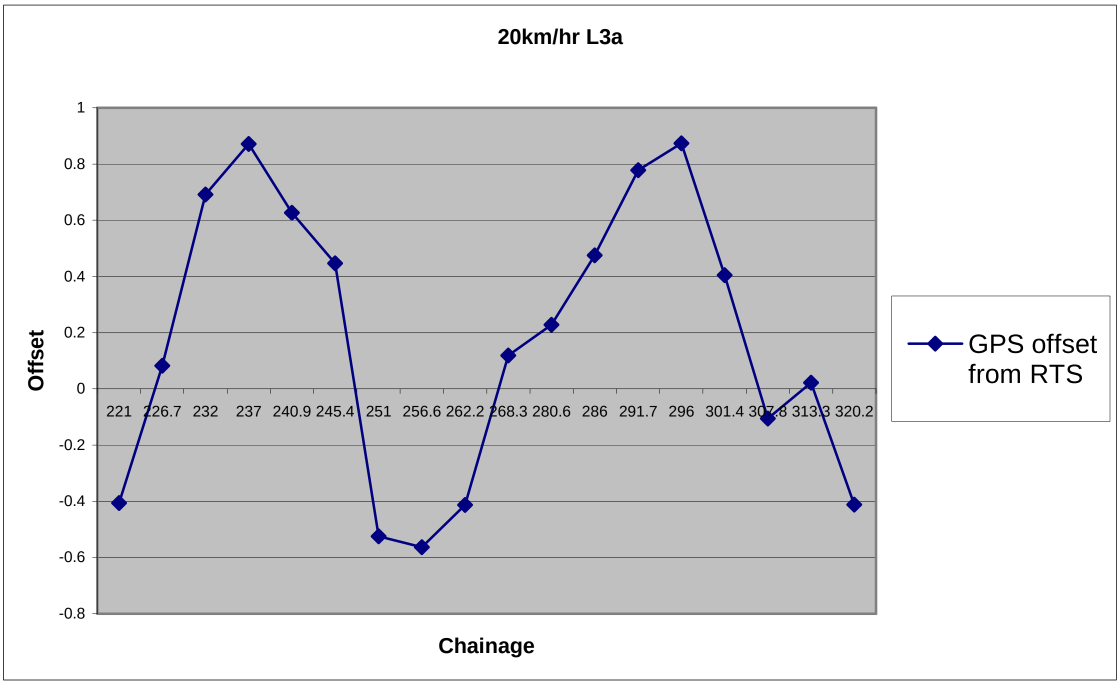

Figure D.3: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

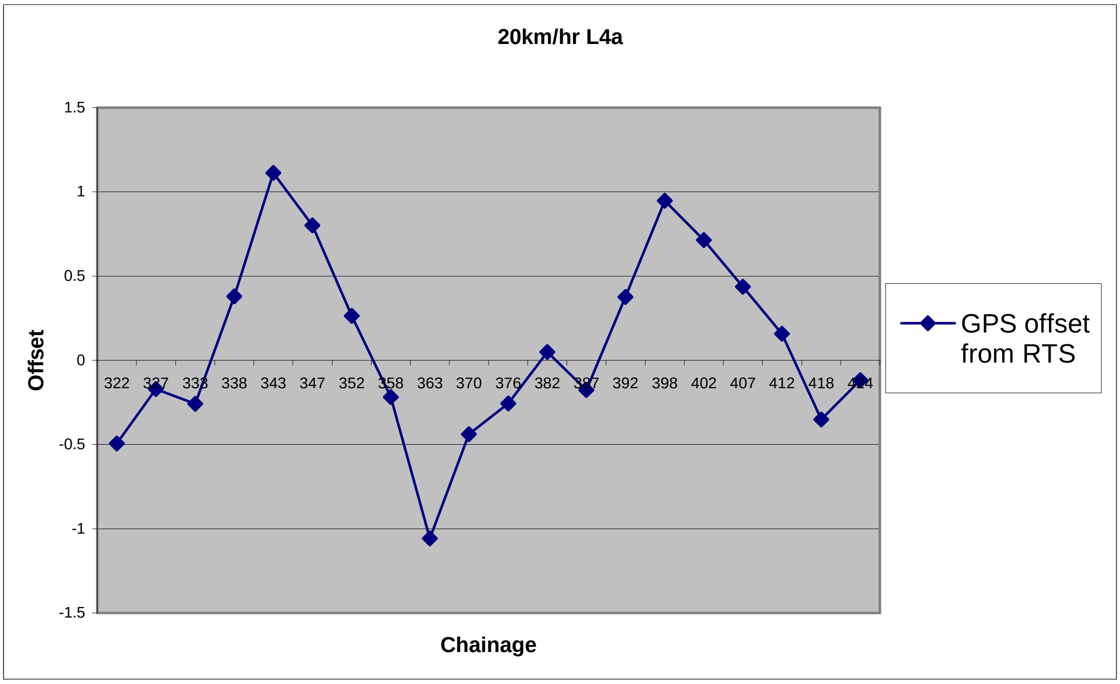

Figure D.4: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

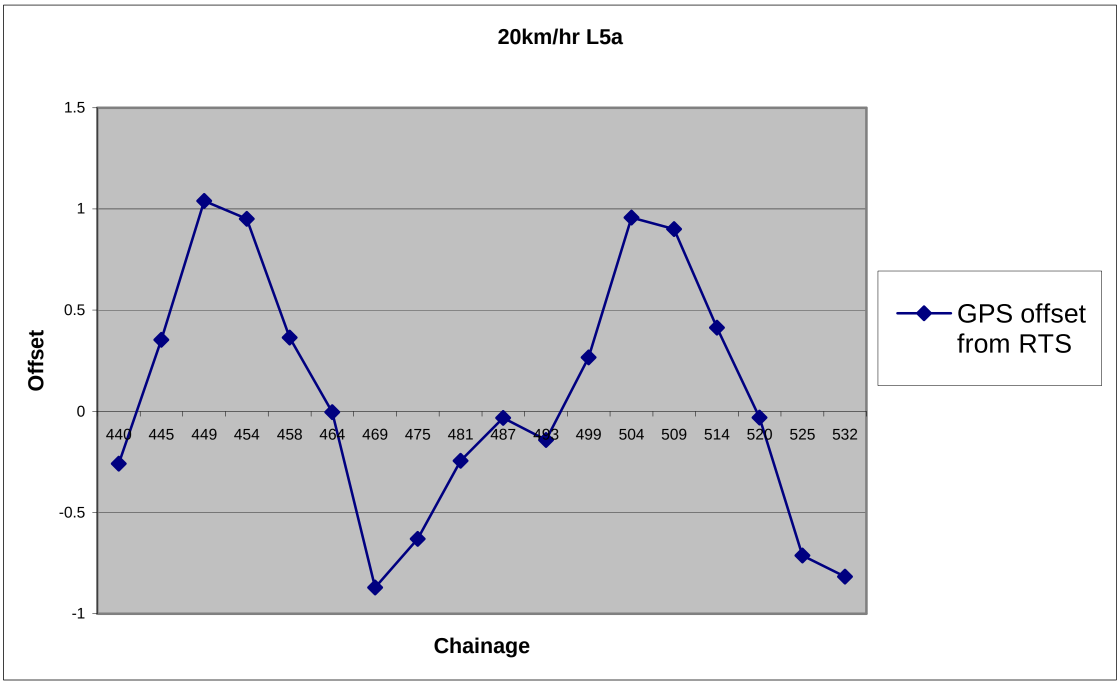

Figure D.5: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

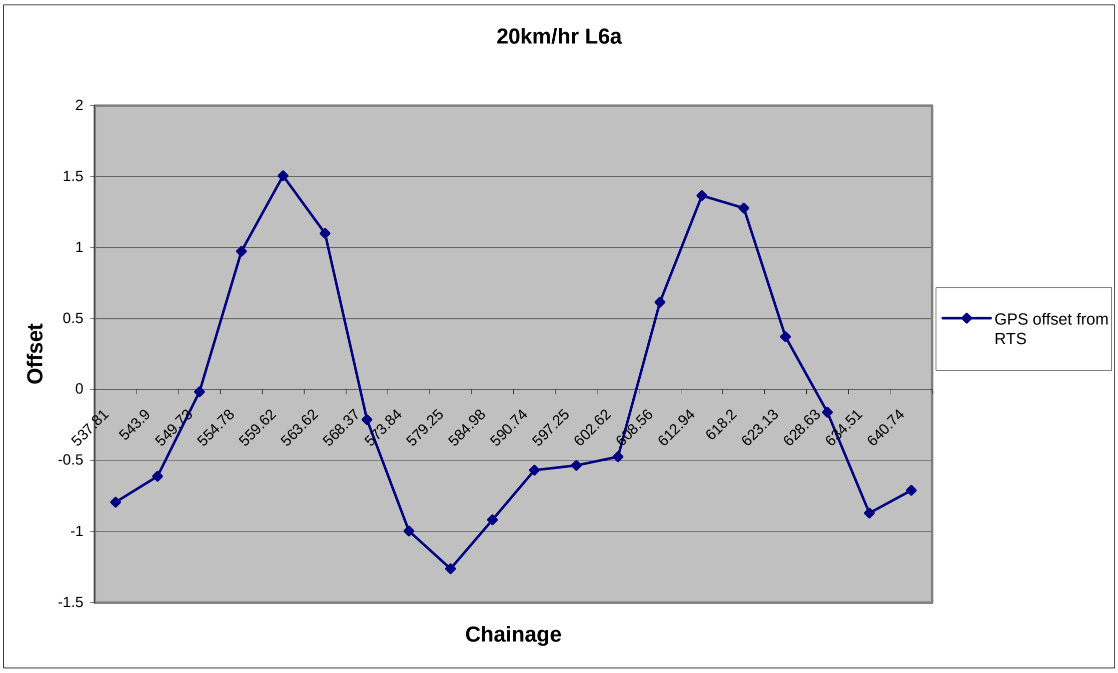

Figure D.6: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

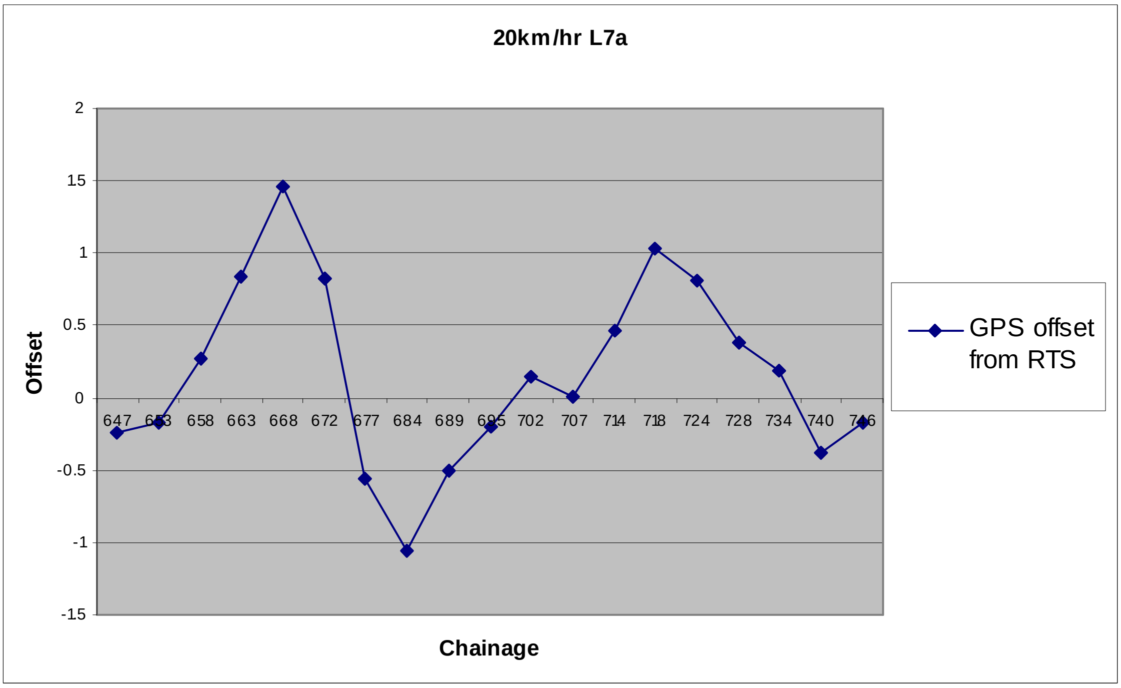

Figure D.7: Comparison between RTS and GPS Dynamic Tracking measurements at 20km/hr.

APPENDIX E

CURRENT CAMS REGULATIONS - VEHICLE TELEMETRY

C 13.8 Computers on the Grid

Unless the specific permission is first obtained from the CTD computers of any description, other than computers which are an integral part of a Car, are forbidden to be taken onto the grid by any person at any time.

C 13.11 Electronic Data – Logging, Display & Telemetry

13.11.1 All Cars must only be fitted with any of the data recording units designated in the following table:

Brand	**Model**
Motec	ADL/ADL 2
PI Research	Sigma

13.11.2 Each Car must only be fitted with one (1) data recording unit in addition to the data recording capacity of the Control ECU or any unit specifically required or approved by the CTD.

13.11.3 In addition to the sensors permitted solely as inputs to the Control ECU, and unless otherwise specified, each Car must only be fitted with one (1) of each of the sensors listed in Rules C 13.11.6 and C13.11.7 which must only perform the function stated in each of the respective Rules; and no other sensors are permitted.

13.11.4 The sensors listed in Rule C 13.11.6 and C13.11.7 are in addition to any switches, carrier detect signal for telemetry or any sensors specifically required or approved by the CTD.

13.11.5 The data gathered from the sensors listed in Rule C 13.11.6 and C13.11.7 may then be recorded, displayed or transmitted by any means permitted under these Rules.

13.11.6 Engine Sensors

The sensor listed below are the only sensors allowable in the relevant Series

Sensor	**VCS**	**DVS**
*Crankshaft position	√	√
*Throttle position	√	√
Air temperature	√	√
Coolant temperature	√	√
Coolant level	√	√
Coolant pressure	√	√
Oil pressure	√	√
Oil temperature	√	√
Fuel pressure	√	√
Fuel temperature	√	√
Fuel usage (x2)	√	√
Lambda (x2)	√	√
Manifold air pressure	√	√

*Note: Access to the crankshaft position and throttle position signals generated by the sensors which are a part of the "TEGA" data monitoring system will be made available on Cars fitted with such a system, subject to the approval of the CTD.

If these signals are used, then the relevant sensors listed in rule C13.11.6 are deleted.

13.11.7 General Sensors

The sensor listed below are the only sensors allowable in the relevant Series

Sensor	**VCS**	**DVS**
Front wheel speed – x2 (see note below)	√	√
Steering angle	√	√
Power steering pressure	√	√
Power steering temperature	√	√
Gearbox oil temperature	√	√
Diff oil temperature	√	√
G – Force – longitudinal	√	√
G – Force – lateral	√	√
G – Force – vertical	√	√
Suspension position x4	√	√
Brake light	√	√
Brake disc temperature (front & rear)	√	√
Brake line pressure (front & rear)	√	√
Cockpit temperature x2	√	√
Battery voltage	√	√
Beacon input	√	√
Brake balance bar position	√	√
Anti roll bar position (front & rear)	√	√

Please note: G – Force sensors must only be mounted to the Bodyshell.

Note: In order to provide wheel speed information for the exclusive use of display and data acquisition instruments it is permitted to fit two (2) of the non-driven wheel hub assemblies with the necessary equipment.

C 13.12 Signals to/from Cars

At any time only the following signals may be sent to or from a Car:

Signal	**Send to Car**	**Send from Car**
Any signal exclusively for television	Yes	Yes
Telemetry (transmission of data)	No	Yes
Driver voice communication	Yes	Yes
Driver visual communication	Yes	Yes

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