Toitu te whenua
Land Information New Zealand

Options for Automated Processing of GPS Continuous Tracking Data

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Contents

Foreword

Land Information New Zealand (LINZ) (Toitu te Whenua) was established in July 1996. It is a government department with roles and responsibilities in the following key areas:

Regulatory Responsibilities	**LINZ Regulatory Groups**
National spatial reference system and cadastral survey infrastructure	Office of the Surveyor-General
Topographic and hydrographic information	National Topographic/Hydrographic Authority
Land Titles	Office of the Registrar-General of Land
Crown Property and setting rules for rating valuations	Property Regulatory Group

The main role of the department is a regulatory one, to set guidelines and standards and manage contracts for carrying out the day to day business associated with each of the key areas.

LINZ also offers a range of services to customers related to land titles, survey plans and associated spatial data and Crown property. Survey and Title services are carried out by the Operations Group based in LINZ processing centres throughout New Zealand.

LINZ overarching objective is to be recognised as a world leader in providing land and seabed information services.

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OPTIONS FOR AUTOMATED PROCESSING OF GPS CONTINUOUS TRACKING DATA

1 Introduction

In 2001 Land Information New Zealand, in partnership with the Institute of Geological and Nuclear Sciences (GNS), commenced development of an Active Control Network of continuous tracking Global Positioning System (GPS) stations across New Zealand. Phase one of the development of the New Zealand Active Control Network (**PositioNZ**), the implementation of fifteen permanent tracking or Zero Order stations in the North Island is due for completion by June 2003, with completion of the total network due by the middle of 2005.

Phase one allows for the provision of 30-second RINEX data from each continuous tracking station. One-hour RINEX files are up-loaded from each station hourly and a 24-hour file each day. This data is then made available via the LINZ Internet site to users free of charge.

The Surveyor-General had a milestone (2j) to 'investigate options for automated processing to monitor data from the GPS continuous tracking network by 31 March 2003'. This report addresses this milestone and considers future enhancements to the **PositioNZ** network, in particular the various options for automated and real time processing of GPS data from the network, and makes recommendations for future development.

2 Abbreviated Terms

GPS	**G**lobal **P**ositioning **S**ystem
IGS	**I**nternational **G**PS **S**ervice
NZGD2000	New **Z**ealand **G**eodetic **D**atum **2000**
RINEX	**R**eceiver **In**dependent **Ex**change format for GPS data
RTD	**R**eal **T**ime **D**ifferential GPS processing
RTK	**R**eal **T**ime **K**inematic GPS surveying
VRS	**V**irtual **R**eference **S**ystem

3 Summary of Recommendations

Recommendation 1 (see section 5.2)*. Submit data from additional* **PositioNZ** *stations to the IGS so that they are used in AUSPOS solutions. As a minimum stations in Wellington and Dunedin should be submitted to the IGS.*

Recommendation 2 (see section 5.2)*. Continue discussions with Geosciences Australia to integrate the NZ velocity model into AUSPOS to enable NZGD2000 coordinates to be generated across New Zealand. (Note. As a prerequisite to this the NZ velocity model needs to be documented and utilities developed to support this application).*

Recommendation 3 (see section 5.2)*. Investigate the requirements and costs for setting up a New Zealand automated post-processing centre.*

Recommendation 4 (see section 5.3)*. LINZ should not allow multiple real time processing facilities (such as RTK) to operation from a* **PositioNZ** *station.*

Recommendation 5 (see section 5.3)*. LINZ should investigate further the additional costs of providing 1-second data to a central processing computer from where multiple third party users may access the data to use for their applications. Where appropriate and cost effective, LINZ should provide this data via a central processing computer at the cost of delivery.*

Recommendation 6 (see section 5.4). *LINZ should continue to investigate the use and application of the RTD real time positioning system with GNS.*

4 Background

A national geodetic system, and its associated national survey control system, are fundamental components of a nation's infrastructure. The unique property of the geodetic system is its ability to integrate multiple geographically-dependant data sources into a single geographic reference frame. This forms the underlying spatial infrastructure to enable LINZ meet its outcomes and statutory requirements under the Cadastral Survey Act 2002. The primary mandate for a geodetic system comes from the Cadastral Survey Act that has a key element:

> *'to provide for a national geodetic system and a national survey control system to be maintained'*

This provides a system used to determine the position of points, features and boundaries in cadastral surveys, other surveys and land information systems.

Active control networks, such as the **PositioNZ** network, are used internationally and to an increasing extent in New Zealand, to support the geodetic infrastructure in the following ways:

- They provide greater confidence in the geometry and performance of national geodetic datums (eg New Zealand Geodetic Datum 2000 - NZGD2000) through continuously collecting and analysing data;
- They enable significant gains in the way that the datum (through geodetic control) can be developed and maintained through new survey control being surveyed directly into the high level of the datum (eg Zero Order 2000 network rather than establishing intermediate lower order stations);
- They potentially allow connection of local surveys, eg. cadastral surveys, into the high integrity spatial infrastructure (eg. Zero Order 2000 network) to enable seamless and spatially consistent data sets to be developed, and additionally these surveys may also contribute to the local geodetic framework;
- Future improvements in the processing of longer GPS baselines will allow greater efficiencies in the design of the geodetic network (in particular – reduced density of marks and reduced physical maintenance costs) and the way that surveys can be carried out;
- They will lead to an enhancement of the spatial infrastructure that benefits all users through simplifying the integration of spatial data sets within New Zealand; and
- Improve the connection between the New Zealand geodetic system and the international geodetic framework and reference system.

Other positioning applications supported by these stations can include:

- Continuous monitoring of the movement of large engineering structures such as bridges or dams for public safety;
- Acting as the basis for air and sea transport safety including precision airport approach; and
- Supporting law enforcement by providing proof of the integrity of evidence based on GPS positions.

In addition, such networks are used for scientific and environmental studies including the following:

- Continuous monitoring of crustal deformation;
- Continuous monitoring of the atmosphere for weather forecasting and climate research; and
- In association with other sensors, they contribute to studies of ocean circulation patterns, which, in turn contributes to vertical reference systems, climate research and marine resource management.

LINZ would receive the following direct and indirect benefits from an active control network of GPS tracking stations:

- High quality data available for periodic monitoring and maintenance of the relationship between NZGD2000 and the international reference systems on which it is based;

- Data on deformation in New Zealand to allow periodic update of the velocity model on which NZGD2000 is based;
- Data available for periodic monitoring and maintenance of the high order (Zero and 1st Order 2000) networks without the cost of field survey. Note that episodic campaigns currently require field survey;
- Data available to LINZ geodetic contractors to improve the efficiency of field survey for lower order (2nd, 3rd, 4th, & 5th Order 2000) surveys;
- Data available to LINZ topographic and hydrographic contractors to improve the efficiency of connecting topographic and hydrographic data to the spatial infrastructure;
- Data available to cadastral surveyors to increase compatibility of their surveys with **Land*online*** survey-accurate boundary coordinates;
- Contributions to the geodetic infrastructure from other non-geodetic agencies interested in GPS tracking;
- Coordination of the network design and deployment of GPS stations by a range of government, scientific and commercial agencies (provides the ability to share costs and complimentary expertise);
- Development of a system that will allow improved prioritisation of maintenance of conventional geodetic stations and beacons as GPS becomes increasingly used for cadastral and other surveys; and
- Capability to implement a system for continuously determining and recording the integrity of the GPS system in general and specific satellite signals and data in particular.

The implementation of phase one of the **PositioNZ** network allows for the provision of RINEX data which allows post processing of data from GPS roving receivers, generally within 24 hours of observation. This system requires users to download GPS data from the permanent tracking (base) stations via the LINZ Internet site and then use their software to post-process the data. Such a system suffers the following limitations:

- There is a time lag of up to 24 hours before data from a roving receiver can be processed;
- It requires the user to have access to specialised GPS processing software; and
- The system is designed to use static data. The minimum amount of static data required is dependent on the distance from a base station and accuracy required, but can vary from a few minutes to 24 hours of data to enable an accurate position to be determined.

To fully realise the advantages of the **PositioNZ** network it was envisaged that a number of enhancements would be considered such as the provision of a facility to allow **automated post processing** of data and/or the ability for **real time processing** of data from the network. **Automated post processing** of data is the ability to submit via the Internet a GPS dataset collected from a roving receiver where it is automatically processed with **PositioNZ** data. Several such systems already operate in a number of countries including the USA and Australia. **Real time processing** of GPS data is the ability to obtain at the roving receiver corrections from the permanent base stations. This enables the corrections to be applied at the roving receiver to enable accurate positions to be determined in real time.

5 Options

Four options are considered for automated and real time processing of GPS data from the Active Control Network:

- Do nothing and continue to only support post processing of GPS data;
- Provide an automated post processing capability;
- Real time processing facility provided by a third party; and
- Provision of real time processing by LINZ.

5.1 *Option 1 - Do Nothing*

Option one is to continue to only provide data for post processing of GPS observations by users. This requires users to have software and expertise to preform the processing, often 24 hours after the data has been collected. This has the potential for inconsistent solutions to be determined if non-identical procedures are not followed, ie deficient processing models are used. It requires a significant level of manual intervention in processes that have been demonstrated overseas as capable of being readily automated. This includes manual effort by LINZ geodetic contractors who charge accordingly for the time, expertise and software required to complete LINZ contracts. These contracts also require manual effort by LINZ staff to audit or validate the processing undertaken by geodetic contractors.

There will be specialised users who will want access to the raw data and LINZ will continue with the present system of providing data for post processing. However this option does not realise the full potential of the **PositioNZ** network to benefit users as discussed below and thus will not be considered further here.

5.2 *Option 2 – Automated Post Processing*

Automated post processing of GPS data is the ability to take a GPS data set from a roving receiver and submit it by email to a processing centre where it is automatically processed with data from the nearest surrounding continuous tracking or **PositioNZ** stations. From the time of submitting the data, it can take 15 minutes to 1 hour to process the data and email the results back to the user. Such a system would use the 30-second RINEX files currently generated by the **PositioNZ** network.

Advantages of such an automated post processing system are:

- Users can complete a survey with only one GPS receiver with no other specialised equipment (normally a minimum of two receivers are required);
- A user can generate accurate positions without the need for specialised GPS processing software;

- Solutions will be in the official coordinate system ie NZGD2000 and have the national velocity model and other processing correction models correctly applied;
- The system is simple to use for users (no specialised processing knowledge is required); and
- The system utilises existing technology ie the Internet.

Disadvantages of the system are:

- Positions are not generated in real time, however positions can be generated generally within about 24 hours of observation and the high accuracy (eg sub cm) solutions generated after about 2 weeks with precise ephemeris; and
- The need to collect static data for a long period of time (at least a few hours and 24 hours may be recommended for higher accuracy).

Implementation of an automated processing system could be carried out by LINZ and would require specialised computer hardware and software. However a number of organisations already provide such services using global and national GPS networks. One of these existing services could incorporate the **PositioNZ** stations and provide a facility to generate New Zealand Geodetic Datum 2000 (NZGD2000) coordinates. The use of an existing service would greatly reduce the setup and running costs for the provision of such a service.

Geosciences Australia provides the AUSPOS on-line GPS processing service. This system uses data from International GPS Service (IGS) GPS sites and as such already incorporates the New Zealand GPS stations, Auckland and Chatham Islands. Any other **PositioNZ** stations submitted to the IGS would be automatically used by AUSPOS.

Discussions with Geosciences Australia indicate that they could incorporate the New Zealand velocity model into AUSPOS to enable NZGD2000 coordinates to be generated across New Zealand. This would provide a low cost option for automatically post processing GPS data that could be implemented quickly and cheaply. However it would rely on an outside organisation providing the service which could increase risk for service provision should that organisation restructure or have a change in priorities which would be outside New Zealand control. Additional **PositioNZ** stations submitted to the IGS would enhance the service.

> ***Recommendation 1****. Submit additional* ***PositioNZ*** *stations to the IGS so that they are used in AUSPOS solutions. As a minimum stations in Wellington and Dunedin should be submitted to the IGS.*
>
> ***Recommendation 2****. Continue discussions with Geosciences Australia to integrate the NZ velocity model into AUSPOS to enable NZGD2000 coordinates to be generated across New Zealand. (Note. As a prerequisite to this the NZ velocity model needs to be documented and utilities developed to support this application).*

***Recommendation 3**. Investigate the requirements and costs for setting up a New Zealand automated post-processing centre.*

5.3 *Option 3 – Real Time Processing Facility Provided by a Third Party*

Unlike post processing which defines positions after the event using lots of data, real time processing allows the generation of accurate positions using short term or single epoch GPS observations in real time. The advantage of this system is the ability to generate accurate positions quickly and in real time. This option considers the options for third parties to access data from the **PositioNZ** network to provide a real time processing capability.

5.3.1 *Option 3A – Real Time Broadcast Corrections (Real Time Kinematic)*

This first option considers the provision of real time broadcast corrections from **PositioNZ** stations.

GPS observations suffer from systematic errors introduced into the raw data. Real Time Kinematic (RTK) systems consist of broadcasting (generally every second), either free to air or at a cost, corrections for these systemic errors from a GPS base station (eg a **PositioNZ** station) to GPS roving receivers. The roving receiver receives the corrections and applies these to the data to generate real time corrected positions of points. Such a system would require either a radio transmitter to be located at the permanent tracking station or a cell phone switchboard to transmit the correction data in real time to the roving receiver. The rovers require either a radio or cell phone modem to receive the corrections. Due to the effects of the atmosphere which create random errors in the raw data, RTK systems only work within a radius of about 10-15km from a base station and so such a system would not provide national coverage. The expected horizontal positional accuracy is 1-2cm. The biggest advantage of such a system is the ability to quickly generate cm accuracy positions in real time. The disadvantages include:

- The need for specialised GPS and transmitting equipment;
- Radio or cell phone reception from the base station which is often restricted due to line of sight; and
- A system that only operates over a radius of up to 15km from base stations.

Several private sector companies have expressed an interest in using the **PositioNZ** stations for this option. These companies would provide the necessary equipment at one or more permanent tracking sites and would plan on selling the data. One trial is underway at the Gisborne **PositioNZ** station. It is unlikely that any one such party would provide coverage at all sites, rather they would tend to concentrate their efforts on areas of high population density or activity where such a system would be commercially viable.

If this option were adopted, the addition of a transmitter at a permanent tracking station would increase overheads, notably higher power requirements for the transmitter and higher maintenance costs. This would be compounded if additional transmitters were set up, ie multiple third parties had an interest in each site. This would be a particular problem at remote sites where power is provided by solar panels and where radio and/or cell phone coverage may not be good. While development of such a system(s) would make greater use of the **PositioNZ** network, development would also provide logistical problems for LINZ and GNS. Notably, if LINZ allowed only one third party to implement such systems to minimise power and maintenance concerns this could be seen as providing a monopoly situation or government subsidising one party. Alternatively, if there were multiple third parties this would result in LINZ or GNS needing to manage multiple small contracts.

In summary, to provide this type of development of the **PositioNZ** network would have the following limitations:

- Additional logistical issues such as higher power and maintenance requirements, and the need to manage multiple contracts;
- By minimising logistical issues and allowing access by only one party to each station this could lead to a monopoly situation or be seen as a government subsidy;
- It could lead to a fragmentation of the system with a number of operators using parts of the whole network; and
- This option would lead to additional administrative costs if a number of additional parties were involved.

Accordingly, this is not considered to be a workable option and a more viable option is discussed under Option 3B that could still satisfy third party user requirements.

5.3.2 *Option 3B - LINZ Provide One Second Data to a Central Processing Computer*

A variation on option 3A above is for LINZ to provide the facility to download one-second data in real time from each **PositioNZ** station to a central processing computer. The data can then be distributed to, or accessed by, a number of users including by one or more third parties for RTK type operations. This would overcome many of the logistical issues discussed in Option 3A.

However this system introduces a new limitation related to the ability to provide the data in real time. Because of the remoteness of some sites and communication systems currently employed it is anticipated that a delay of 2-5 seconds is expected with some of the data unless expensive communication, ie satellite links, are provided at these site. This would allow the data to be used for real time point positioning of static or slow moving platforms (eg for cadastral or geodetic survey) but not for fast moving platforms, ie cars. Real time data with a latency of 2-5 seconds would meet all LINZ requirements and most private sector requirements. It would also allow the development of the options discussed under Option 4 below.

This option would require modification to the existing **PositioNZ** stations to enable real time recording and transmitting of 1-second data. The costs to provide this facility may be high for some stations and these will need to be fully evaluated. It may be appropriate to only provide the 1-second data from a subset of the total network.

5.3.3 *Summary and Recommendations*

To allow third party provider's access to data sufficient for real time applications the most viable option that is likely to cause least disruption to LINZ and GNS is to provide transmitted 1-second data from **PositioNZ** stations to a central processing computer from where it can be accessed by third parties. Users of the data would be expected to pay some cost towards the costs of delivery of the data.

> ***Recommendation 4****. LINZ should not allow multiple real time processing facilities (such as RTK) to operation from a* ***PositioNZ*** *station.*

> ***Recommendation 5****. LINZ should investigate further the additional costs of providing 1-second data to a central processing computer from where multiple third party users may access the data to use for their applications. Where appropriate and cost effective, LINZ should provide this data via a central processing computer at the cost of delivery.*

5.4 *Option 4 – Options for Using Real Time Data*

If 1-second data is provided to a central processing computer there are a number of options that could be considered to further process and enhance the data and provide a real time processing capability. One option is to provide an RTK capability as detailed in Option 2 by accessing data from the central processing computer. This suffers a number of technical limitations as detailed in Option 2 and therefore won't be discussed further here. Option 4 considers two further options should Option 3B above be implemented.

5.4.1 *Option 4C – Trimble's Virtual Reference Station Network*

High accuracy RTK methods suffer from a number of limitations as discussed above. In particular:

- The need to use specialised transmitting and receiving equipment;
- Its use is constrained by the effects of the atmosphere which creates systematic errors in the raw data; and
- This latter effect limits the distance from a base station over which the system can be used.

Trimble's Virtual Reference Station (VRS) technology overcomes these limitations with high accuracy RTK by utilising data from a network of continuous tracking stations to model the error sources within the network, including the effects of the atmosphere. This system significantly reduces the errors to improve reliability and operating range. All reference stations provide 1-second data in real time to a control centre where the data are processed. Corrections are transmitted via cellular modems to rover receivers within the network area - in a similar manner to RTK. The system can operate using reference stations spaced at 50 - 70km, significantly increasing the range over which roving receivers can operate relative to an RTK system. The expected horizontal positional accuracy is 1-2cm. Such a system requires 1-second data from the base stations as detailed in option 3B above.

The requirements for a VRS network are:

- Base stations at a spacing of 50-70 km over the areas to be covered;
- One second data in real time to a processing centre (for most applications 5 second latency is adequate however for applications such as fast moving platforms < 1 sec latency is required;
- Specialised VRS processing software ($100k +);
- High spec computer to compute the corrections and service the large number of users that could use the system;
- A Telephone exchange with multi lines to service users; and
- Cell phone coverage for the user to operate.

The advantages of a VRS system are:

- Increased range over which roving receivers can operate relative to reference stations;
- No specialised equipment required by the field users compared with normal RTK requirements (eg rover receiver and cell phone); and
- Real time positioning capability which would increase efficiency for geodetic contractors.

Disadvantages of a VRS system are:

- The proposed density of **PositioNZ** stations would not meet VRS requirements;
- High capital cost of software (this depends on the number of rover sites with access to the system;
- Ideally rover sites should lie inside the area covered by the network stations (interpolation rather than extrapolation) - otherwise modelling of the corrections becomes unreliable;
- High capital cost of a large computer with a multi phone line exchange and significant on-going running costs for this facility;
- The system is not easily scaled up as additional users require greater processing capacity (as well as additional phone lines); and
- Limited ability for the field user to provide their own quality assurance because corrections are determined remotely and broadcast to the rover.

5.4.2 *Option 3E - Geodetics Inc Real Time Differential (RTD)*

A new system currently under development by Geodetics Inc uses the ability to rapidly determine epoch by epoch positions from a number or continuously tracking base stations.

Geodetics' Epoch-by-Epoch technology provides instantaneous positioning relative to one or multiple reference stations. This option computes baselines to surrounding **PositioNZ** stations that can be analysed whereas other systems apply remotely derived corrections to the data. However, this is a similar system to VRS in that it allows remote receivers to operate over greater distances from base stations than RTK and it requires 1-second data to be transmitted to a control centre. The data is then transmitted in near real time to roving receivers using cellular modems. The principal difference from the VRS method is that the processing is decentralised at the rover receiver which computes solutions to 2 or more reference stations epoch by epoch allowing the position of the rover to be determined. This system allows centimetre-level positions to be estimated given only a single epoch of data from two or more receivers. The ability to rapidly recompute baselines makes it easy to provide quality assurance by detecting and rejecting bad data points in the field, compared to post processing or RTK positioning methods which may then result in repeat field visits to obtain data.

This system offers several advantages over VRS, notably base stations can be at a greater distance than the 50-70km required for a VRS system and roving sites do not have to be inside the area covered by the network.

Both LINZ and GNS are currently testing the viability of such a system.

Requirements of the system are:

- One second data in real time to a data warehousing centre (for most applications 5 second latency is adequate however for applications such as fast moving platforms 1-2 sec latency is required;
- Specialised software ($50k);
- Base stations ideally spaced at 100km;
- A server to receive and transmit data;
- A multi-line telephone exchange; and
- Cell phone coverage for the user to operate.

Advantages of the epoch by epoch system:

- The density of stations in the **PositioNZ** network could support this application;
- Increased range over which roving receivers can operate relative to base stations in comparison to RTK and VRS methods;
- Survey accurate positions are determined in real time providing efficiencies for geodetic contractors and surveyors;
- Able to work outside of the network;
- Less expensive software than VRS;
- Lesser processing capacity for the processing centre required compared with VRS because this centre is only receiving and transmitting data to users to carry out their own processing;

- The system is more scalable than VRS because while additional users still require additional phone lines, they do not require greater centralised processing capacity; and
- Able to carry out in-field real time quality assurance of the data avoiding possibility of repat visits.

Disadvantages of the epoch by epoch system:

- The requirement for the rover receiver to be equipped with an additional hardware device to preform the computations; and
- There is a requirement for a computer (not as high specification as VRS) with multi phone line exchange.

5.5 *Summary and Recommendations*

There are a number of real time processing systems available. Given the density of **PositioNZ** stations the RTD system appears to offer some advantages over other systems such as VRS. There is merit in LINZ continuing to work with GNS to investigating the possibilities for use and implementation of the RTD system and how it would benefit the geodetic system. The question of LINZ then developing a fully operational system would need to be addressed as a separate issue.

> ***Recommendation 6***. *LINZ should continue to investigate the use and application of the RTD real time processing system with GNS.*

6 Conclusion

There are a number of possible enhancements to the **PositioNZ** network that would significantly increase the usefulness of the New Zealand geodetic system to a wide range of users. Any such enhancements should not compromise the primary function of the network, which is to control NZGD2000 and the national survey control system and provide data to geodetic contractors and cadastral surveyors.

However, any real time capability enhancements are likely to significantly increase the efficiency with which geodetic control and cadastral surveys can be carried out as well as satisfying many third party requirements and reduce GPS base station duplication.

> The main enhancement to the active control network is seen to be the capability to provide real time 1-second data from some or all of the **PositioNZ** stations to a central processing computer from where it can be accessed for a wide range of applications.