Australia's Changing Surveying Infrastructure from Marks in the Ground to Virtual Reference Stations

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ABSTRACT

Around the world, surveying infrastructure is moving from being based on networks of marks in the ground to increasing reliance on networks of permanently running GPS base stations. The latest developments see GPS data being made available for real time positioning or for Internet based post processing; all with centimetre accuracy. This paper examines the implications of this increasingly *virtual* nature of our surveying infrastructure, drawing on recent developments and experiences in Australia.

The first part of this paper outlines a GPS network established over the south east corner of the Australian State of Queensland. That network uses the Virtual Reference Station (VRS) concept from Trimble. The network can deliver corrections via the mobile phone network; enabling roving receivers to be positioned anywhere inside the network in real time and with accuracy better than a few centimetres.

The second part of this paper examines the implications of VRS and other approaches, including on-line processing of GPS data via the Internet. Some of the questions that arise include:

- What is the most appropriate approach for a given set of circumstances?
- What are the implications of absolute vs relative positioning in terms of accuracy of the resulting positions?
- What are the implications for maintenance of the geodetic datum in all its dimensions?
- What new opportunities arise from being able to deliver (and perhaps receive) positions in real time?

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1. THE VIRTUAL REFERENCE STATION CONCEPT

The Virtual Reference Station (VRS) concept from Trimble is an extension of the real time kinematic (RTK) technique. With RTK, one can establish a reference station at a known point and broadcast the data from the reference receiver to roving receivers. Processing at each roving receiver combines the reference and rover data. Only a few tens of seconds of data are typically required to fix the ambiguities associated with the GPS phase data observable and compute a GPS baseline. The ability of RTK to yield centimetre accuracy in real time is further revolutionising the productivity achievable with GPS.

VRS takes the productivity increase a step further by overcoming three main limitations of the current RTK technique. Firstly, operators no longer need to establish and run a GPS receiver and radio at their own reference station every time they want to work. Secondly, the use of mobile phone technology overcomes the limitation of the range of radio communications. Thirdly, multiple reference stations increase the redundancy and thus the confidence in the resulting rover positions.

The VRS concept involves permanently running GPS reference stations, at spacings up to 70km. They feed their GPS data to a central processing computer via a computer network. The central processing computer uses the reference station data to model spatial errors that limit GPS accuracy and generate appropriate corrections. From the user's perspective, a roving receiver makes a mobile phone call, supplying its approximate GPS position and requesting corrections. The central processing computer then generates corrections as though there was a reference station at the coordinates of the rover's approximate position and the rover is positioned relative to that *virtual reference station*.

For more information on the technical background to VRS see Vollath et al (2000a), Vollath et al (2000b) and Trimble (2000).

2. THE AUSTRALIAN VRS PILOT PROJECT

The Department of Natural Resources and Mines (NR&M) is responsible for the surveying and geodetic infrastructure of the Australian State of Queensland. Given the potential of VRS, NR&M approached Trimble Australia and its local agent, Ultimate Positioning, to establish a pilot project (see Higgins, 2001a, Higgins and Talbot, 2001 and Higgins, 2001b). The location for the pilot VRS network is shown in Figure 1.

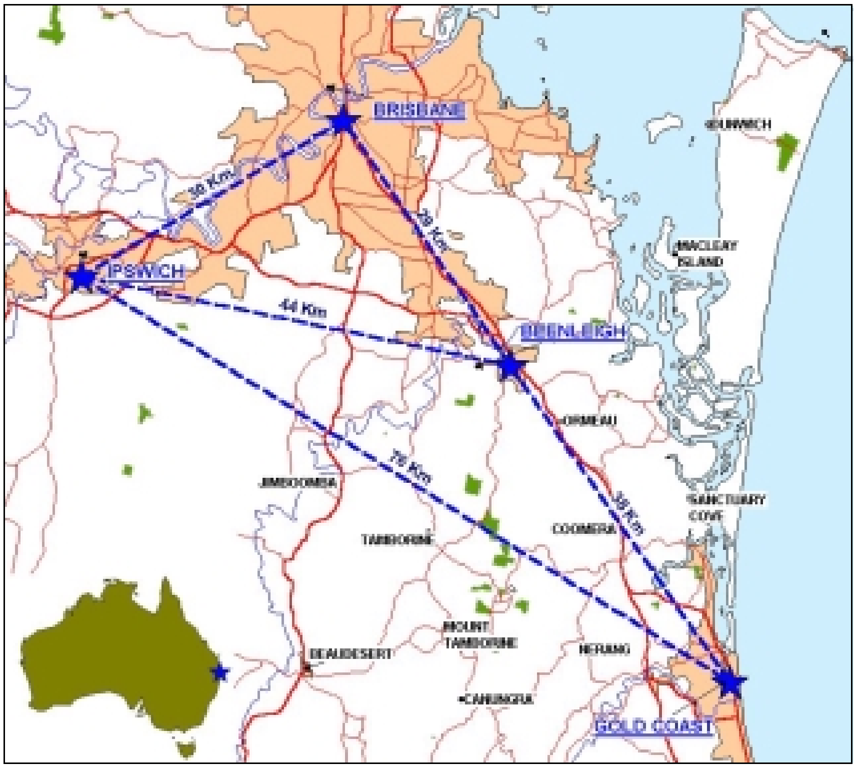

Figure 1 Location of VRS Base Stations for the Pilot Project

3. GOALS OF THE VRS PILOT PROJECT

3.1 Goal 1: Establishing and Running the VRS Network

The project successfully investigated the technical and financial aspects of:

- Establishing Stations on NR&M Buildings
- Connections between network base stations using WAN.
- Connection of the GPS Network Control Centre to the mobile phone network.

For the GPS component, Trimble equipment was used at all sites. The Beenleigh site used the newly released 5700 receiver and Zephyr Geodetic antenna. 4700 receivers and choke ring antennae were used at the other sites.

3.2 Goal 2: GPS Rovers within a VRS Network

The project also investigated the technical and financial aspects of running GPS rovers within a VRS network.

3.2.1 Results from Preliminary VRS Testing

In the testing reported in this paper, a given station was occupied with VRS multiple times and/or with multiple initialisations. After initialisation, 60 seconds of data was recorded for each occupation at a given station. The homogeneity of the existing geodetic network in the

Geocentric Datum of Australia enabled comparison to high quality three-dimensional coordinates (including consistent ellipsoidal height). Another critical point that was noted was the time taken to initialise.

For this preliminary testing many aspects of the network and software were still being tested and tuned and there was a deliberate effort to test at the limits of the system. Additional characteristics of this testing were:

- 115 occupations over 2 weeks; reduced to 106 after outlier rejection
- 6 control stations were used; 3 inside network and 3 outside.
- 52 of the occupations were while Beenleig1h was in the network as a base.
- 63 were with Beenleigh as a rover and all rovers using the large surrounding triangle.
- Given that, nearest base ranged 8 to 30km from new stations, with an average of 18km.

Table 1 Results from Preliminary Testing with 6 Stations

	Horizontal Distance	**Absolute Height**	**3D Vector**
Mean	0.032m	0.040m	0.054m
0.01 + X ppm	1.4	2.0	2.9
Standard Deviation	0.014m	0.031m	0.029m

3.2.2 VRS Initialisation Testing

For the preliminary testing above, the average initialisation time was 2 minutes and all reported occupations were less than 5 minutes. There were other occupations where initialisation time was more than 5 minutes and the initialisation was restarted. Many of those occurrences were while experimenting with various hardware or software configurations.

There are many variables that can affect initialisation time during the type of field-testing outlined in the previous section. These include time dependent variables such as number of satellites and their geometry as well as site dependent variables such as multipath conditions, RF interference and GSM signal strength. Therefore, a more rigorous test of initialisation time was conducted by running Beenleigh as though it was a rover and with the VRS corrections being generated using the large surrounding triangle. The receiver was set to initialise, record for 5 seconds, then re-initialise and repeat this process for 15 hours.

- With 5 or more satellites there were 510 initialisations taking an average of 1.7 minutes.
- With 7 or more satellites there were 426 initialisations taking an average of 1.3 minutes.

3.2.3 Ipswich City Council VRS Testing

An operational test was conducted in conjunction with Ipswich City Council (ICC) to observe 36 survey marks north east of Ipswich with all stations just outside the triangle, by 3 to 10km. The direct distance to the Ipswich reference station ranged from 5.7 to 12km. On those marks where fast static was also observed, a total of 93 occupations were made using VRS. 10 occupations were rejected as outliers and for the remaining 83 occupations:

- The mean longitude residual was 0.001m with a standard deviation of 0.013m
- The mean latitude residual was 0.001m with a standard deviation of 0.014m
- The mean ellipsoidal height residual was 0.015m with a standard deviation of 0.036m

While the ICC surveyors had previously rented GPS equipment for fast static work, none had used Trimble equipment before. They were given a brief written procedure and 20 minutes of instruction on VRS. Even so, both ICC parties occupied all 36 marks in 8 working hours.

It should be noted that there were 4 stations where initialisation time was significantly worse than normal. It was found that they were where the GSM signal coverage map showed that it was not suitable for a handheld mobile phone and recommended a vehicle mounted phone with external antenna.

Despite this, for all occupations by all parties, 50% of initialisation times were less than 50 seconds and 95% were less than 130 seconds. In terms of productivity, travelling time between the stations (at an average density of 700m) was the major limiting factor, rather than initialisation time.

3.3 Goal 3: Business Viability

As well as the technical aspects, the project investigated the business viability of VRS. A detailed business case has been produced with assistance from an external accounting and business development firm. Involving key players in government and industry in the fields of surveying, earth moving, mining and agriculture facilitated sound assessment. The business case identified establishment and running costs, potential users and applications, risk management issues, charging models and potential revenue streams. NR&M management has now approved the business case and work has begun on the transition from the pilot to a commercial VRS service in South East Queensland.

4. GPS BASE STATION APPROACHES OTHER THAN VRS

The implications for survey infrastructure from GPS base station approaches like VRS will be investigated in remainder of this paper. However, it is first necessary to realise that there are approaches other than VRS that are also useful in certain situations. Two other examples will be used.

The first example, that can significantly impact how survey infrastructure should be approached in certain situations, is the on-line processing service offered by the Australian Federal Government and known as AUSPOS (see Dawson et al, 2001). As a brief description for the purpose of this paper; the service is free and uses data from the worldwide set of base stations run under the auspices of the International GPS Service (IGS). A user simply gathers data with a single GPS receiver (of suitable quality) and submits it to the AUSPOS web site where the data is post processed, after which results are emailed back to the user. The achievable accuracy depends on the amount of data gathered and submitted by the user. The minimum observation time from which AUSPOS will accept data is 1 hour. The expected accuracy from the minimum recommended observation time of 6 hours is 1cm horizontal and 2cm vertical.

Another example of a base station approach is the network of permanent GPS base stations in the Australian state of Victoria known as GPSNet (see Hale and Mowlam, 2001). The network has the capability to support varying approaches. In its basic form, GPSNet supports users doing their own post processing of their GPS rover data to obtain centimetre accuracy. However, it also has the potential to be augmented to enable single station RTK and, in areas with sufficient station density, to enable VRS.

5. IMPLICATIONS OF INCREASINGLY VIRTUAL INFRASTRUCTURE

The paper now examines the implications of these base station approaches and the trend to an increasingly virtual surveying infrastructure. The questions that arise are especially relevant for agencies responsible for supplying and maintaining the surveying infrastructure. However, such questions are also of interest to the users of the infrastructure. Some of the questions lead to problems that will need to be addressed while some are opportunities that arise from being able to deliver the infrastructure in new and timelier ways.

6. THE MOST APPROPRIATE APPROACH

What is the most appropriate approach for a given set of circumstances?

In some circumstances, the AUSPOS on-line processing may offer a viable alternative to the traditional approach of connecting to the local geodetic network. From a user's perspective, the decision on which approach to use will be based on efficiency.

The AUSPOS on-line processing service will deliver the geodetic datum with sufficient accuracy for most types of projects, given sufficient GPS occupation time on the new stations. The alternative is the traditional approach of using GPS to connect to sufficient marks in the local geodetic network. In remote areas, it is not viable to supply a geodetic network with a high density of ground marks. For example, in remote areas of Queensland, high quality GPS derived ground marks are at a nominal density of 75 to 100km. In such areas, connecting to two or three marks will require significant field time for travel and for GPS baseline observation time. The total time may amount to a day or more. The number of GPS receivers available may also be a limitation. In many cases a 12 to 15 hour occupation time, say overnight, processed with the AUSPOS on-line approach may give a comparable result and be an attractive logistical alternative to using ground mark infrastructure.

At the other end of the scale are high activity areas where the infrastructure must deliver the geodetic datum in real time or with post processing of GPS occupation times measured in minutes rather than hours. Currently, users typically establish temporary RTK base stations or use the fast static technique and require geodetic networks with densities ranging from 5 to 25km. Given that users often tend to be clustered in areas of development, a significant percentage of users could also be serviced by well placed permanent GPS base stations supporting fast static post processing. The current configuration of the Victorian GPSNet is an example of an approach that can offer a viable alternative to ground mark infrastructure for many applications.

In high activity areas, a permanent RTK service can become viable. This approach can be as simple as servicing a radius around a single base station (for example in a regional city). In other cases the number of users and physical size of the area may justify the establishment costs of a networked RTK approach, such as VRS.

Even with all these new options, there will be areas where none is viable. In those cases, it may be most efficient to run individual GPS surveys that continue to rely on traditional geodetic ground marks. These will typically be those areas that are less remote but still rural in nature and where survey activity is only occasional.

Even in areas where these new options are viable, suppliers of the infrastructure will still need to consider whether ground mark infrastructure can be totally replaced. There may still be a need for a transition period when the infrastructure continues to support users who may be slower to take up these new techniques.

7. ABSOLUTE VS RELATIVE ACCURACY

What are the implications of absolute vs relative positioning in terms of accuracy of the resulting positions?

Approaches to surveys based on GPS base stations lead to what can be thought of as *absolute* positions within that particular network. Questions then arise about the accuracy of new stations relative to nearby stations. Those nearby stations may be established using the same technique or they may be previously existing geodetic network stations.

Existing geodetic stations tend to have good relative accuracy within their network. However, when comparing to a position from AUSPOS one needs to consider the full propagation of error through a hierarchy of geodetic networks back to the IGS stations used in the AUSPOS solution. For example, for the Queensland 100km GPS network, the relative accuracy is typically better than 5cm. However, taking into account its connection to the 500km network and its connection to the IGS stations may give a total uncertainty larger than 10cm.

In the case of VRS, each initialisation has an accuracy of 1 to 3 cm (horizontal). That needs to be considered when comparing positions derived from different initialisations. On the other hand, it must be remembered that a set of positions derived under the same initialisation may have internal relative accuracy better than the absolute accuracy of the set as a whole.

Such issues will vary on a case-by-case basis and need careful consideration to ensure the final positions have sufficient absolute and relative accuracy to meet the requirements of the project.

From a broader perspective, this increased mixing of absolute and relative positions will have implications for the management of spatial data generally. For example, this has been recognised in spatial data standards currently emerging in Australia, which provide better ways of stating accuracy.

8. IMPLICATIONS FOR MAINTENANCE OF THE GEODETIC DATUM IN ALL ITS DIMENSIONS

What are the implications for maintenance of the geodetic datum, in all its dimensions?

The absolute nature of these base station techniques raises possibilities for differences in how the datum is realised in an area. Such differences in realisation can arise at either the reference or rover stations. For horizontal coordinates in Australia, the impact of this issue is lessened by the high accuracy and homogeneity of the Geocentric Datum of Australia (GDA).

AUSPOS computes in the latest version of the International Terrestrial Reference Frame (ITRF) and at the current absolute position of the tectonic plate. When the user's position falls in Australia, it is then transformed back to GDA94 (in space and time) based on knowledge of the reference station positions in both frames. That process deals with the transformation at better than the typical noise in the resulting position of the user's receiver.

A similar issue can arise with VRS networks; albeit at a different scale. The coordinates of the physical VRS reference stations need to be consistent at the 1cm level if the VRS software is to model the GPS errors well enough to provide centimetre accuracy corrections to rovers. In the case of the South East Queensland pilot VRS network there was a distortion in the underlying GDA network of 3cm in the 50km of longitude covered by the VRS network. While 3cm is well within the working error of the underlying geodetic network (less than 1 part per million) it is larger than desirable for generating optimal VRS corrections. To get full accuracy and reliability from the VRS network it was necessary to use improved reference station coordinates. At the Ipswich station, that effectively created a variation on the published GDA94 datum in that area, albeit at only the centimetre level. This would be a much more significant issue if the underlying network had larger distortions than is typical of GDA94, as would be the case for establishing VRS in many other areas of the world. Because VRS works on knowing the location of the rover, it is possible to model any such distortion across the VRS network coverage and correct the position of the virtual reference station before it is broadcast to the rover.

As a general comment then, these datum definition issues can be minimised if the service provider considers them carefully. The issue of absolute vs relative accuracy affecting the roving receivers (outlined in the previous section) is likely to be a greater cause of variations with the horizontal datum in an area.

However, it is important to note that all of the above comments about accuracy and about realisation of the datum are much more manageable for horizontal coordinates than for orthometric heights. Variations in the horizontal tend to be geometric in nature and can be managed through a combination of careful selection of reference station coordinates and/or parameters in the processing. On the other hand, variations in orthometric height are more dependent on physical factors that can vary across the network coverage area in a way that is less predictable than for horizontal.

At the national scale covered by AUSPOS, the variation between the standard AUSGEOID98 model and the base of the Australian Height Datum (AHD) can amount to more than 1m. Even at the scale of the South East Queensland VRS network, the variation can be greater than 0.2m. The best way to account for this is to create a model of the residual variation surface and add it to the geoid model.

In the case of VRS, such a model could be applied to the height of the virtual reference station or the roving receivers could apply it to their computed positions (but not both). In South East Queensland, the underlying geodetic network has a large sample of stations that have both orthometric height and ellipsoidal heights derived from static and fast static GPS observations. That facilitates development of a model of the residual variation.

For AUSPOS a model of this residual variation is required for the whole country. While some work has begun on this, with coordination through the Inter-Governmental Committee on Surveying and Mapping, it will be some time before it will have national coverage. Once such a model is available it could be applied to the user receiver's position as a step in the AUSPOS processing, similar to the transformation between ITRF and GDA. However, until then, users must be aware that the heights above the geoid that come from AUSPOS may vary from local AHD by more than 1m.

In terms of the fourth dimension, time, base station approaches bring an advantage by enabling constant monitoring of the stability of the reference frame. The issue of stability, when viewed internal to Australia (ie within the frame of GDA94) relates to the physical stability of the reference station monuments and to their relative positions. When viewed external to Australia, stability relates to issues such as plate tectonics. The fact that this monitoring of stability can be built into the process is an improvement over ground mark based geodetic networks where any movements go unnoticed until the network, or parts of the network are remeasured from time to time.

9. NEW OPPORTUNITIES

What new opportunities arise from being able to deliver (and perhaps receive) positions in real time?

The virtual approaches to infrastructure afforded by GPS bases stations will raise issues like those outlined above and they will need careful consideration. However, it must be remembered that these new approaches also bring many new opportunities. The most obvious ones are the efficiency they bring to the delivery of surveying infrastructure but, in the broader context, they also facilitate new areas of business.

Systems such as VRS bring the ability to deliver the geodetic datum with centimetre accuracy directly to users in real time. While survey efficiency is an obvious beneficiary, the real pay offs come in machine control applications such as earth moving, mining and precision agriculture. In those applications, operating costs are high and any improvement in efficiency can bring significant cost savings.

Looking broader still, Location Based Services (LBS) are gaining momentum. These involve delivering products and services tailored for a user's location. While many of the applications do not require centimetre accuracy, availability of GPS base station services can facilitate development of enhanced applications.

In the simplest forms of LBS, the user down loads data of interest into a location-enabled terminal; such as a personal digital assistant (PDA) combined with a GPS receiver. The terminal matches data with location as required. The next step in sophistication is to add wireless communications and for a central server to broadcast data to the user terminal in real time. The highest level of sophistication comes from two-way communications where the user terminal can send its position back to the central server that then broadcasts data specifically tailored to that user's needs and location.

The use of GSM communications in VRS enables this highest level of sophistication because the roving receiver sends its location to the control centre computer every 2 seconds. Also with VRS, once the rover has initialised, the reported positions are accurate at the centimetre level. It would be possible to augment a VRS system to stream data to the users based on their location. While many LBS applications do not require centimetre accuracy, VRS may enhance opportunities in applications such as real time facilities management and maintenance.

10. CONCLUSION

Surveying infrastructure has moved from a reliance on networks of ground marks to increasing reliance on permanently running GPS base stations. The latest services include real time positioning based on the Virtual Reference Station (VRS) concept and Internet based post processing. Many implications arise from this increasingly virtual approach to the provision and use of surveying infrastructure.

Surveys using these new services will increasingly sit among the existing infrastructure based on ground marks. For users, it is important to decide on the most appropriate approach for a given set of circumstances. Usually it will come down to the most efficient approach, which often comes down to the time for a given survey using one approach or another. In some remote areas, Internet based post processing relative to distant base stations may turn out to be more efficient than surveys connected to the closer ground mark infrastructure. In many high activity areas, VRS will become viable. In the less dynamic rural and regional areas between, base station approaches may not be viable and existing ground mark infrastructure may continue to be the best way to service the occasional RTK and fast static surveys that occur.

Surveys from distant GPS base stations in and around existing networks of ground marks can lead to a mixing of varying levels of absolute and relative accuracy. Providers and users of the infrastructure need to be aware of the problems of such mixing. The effect will vary on a case-by-case basis and needs careful consideration to ensure the final positions have sufficient absolute and relative accuracy to meet the requirements of the project. There is also a need for more careful attention to and better ways of stating accuracy.

Wider use of GPS base stations will also affect realisation and maintenance of the geodetic datum in all its dimensions. Absolute vs relative accuracy issues are likely to be the most significant cause of variations with the horizontal datum in an area but local datum distortions will need consideration. Variations in the horizontal tend to be geometric in nature and can be managed through a combination of careful selection of reference station coordinates and/or parameters in the processing. However, variations in orthometric height are more dependent on physical factors that can vary across the network coverage area in a way that is less predictable than for horizontal. Services promising centimetre accuracy need to consider ways to model such vertical distortions and deliver them efficiently to the user.

While the virtual approaches to infrastructure afforded by GPS bases stations raise some problems, they will also bring new opportunities. The most obvious ones are the efficiency they bring to the delivery of surveying infrastructure. However, the greater pay-offs could be for whole new areas of business in the growing field of Location Based Services where specifically targeted information will be matched with positions being delivered and received in real time.

Discussion of all these issues is an important step in developing appropriate models for surveying infrastructure in the 21st century.

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