The Development of a Modular DGPS System

by T.J. McCall, Bach App. Sc. (Surv)

Dynamic Satellite Surveys P/L
P.O. Box 713, Yeppoon 4703 Australia
Phone 61 79 392 866, Fax 61 79 392 867

BIOGRAPHY

After general and exploration surveying work in Australia, Timothy McCall was transferred in 1982 to Taazaaia (East Africa) and observed an exteasive control network using Magnavox 1502 TRANSIT receivers. In 1989, Tim developed the Rapid Elevation Meter (a barometric levelling device), formed Dynamic Satellite Surveys with Bill Hedditch. and began performing full seismic surveys with GPS and the REM.
Tim graduated from the Queensland University of Technology in surveying and heads research and development with Dynamic Satellite Surveys, which has grown to become Australia's largest GPS service company.

ABSTRACT

This paper describes the development and implementation of a DGPS system which provides real time set out to less than one metre (2D) and provides a post processing result to less than 5cm (3D).

The core of the system is a NovAtel OEM board, interfaced to **a** radio/modem combination, all of which is addressed by a palm-top computer. The emphasis has been reliability, modular design and light-weight, to produce a portable system. to operate in very harsh environments.

A complete suite of programs have been written that take the user from initial waypoint calculation, to the final quality checks of the phase processed kinematic data and subsequent damp to any map grid. Phase processing software allows all avenues of post processing including 'On the Fly' ambiguity resolution.

The discussion describes the criteria for selection **the** OEM board and the other hardware components software design, initial field trials, modifications and final field implementation. The emphasis is mainly on the practical field aspects, and the continued development of the system which operates on Dynamic Satellite Surveys crews in Australia and the Middle East, involved in seismic, mineral exploration, and land boundary definition.

INTRODUCTION

As part of Dynamic Satellite Surveys (DSS) exploration work, there was a aced for an instrument capable of setting out to sub metre accuracy (2D) and by post processing, to achieve a result to better than 10cm (3D). In the early part of 1993, there were only two 'off the shelf instruments capable of achieving the results, however neither were completely suitable.

Through DSS operations since 1989, 'off the shelf GPS systems had shown some un-reliability in very harsh environments While these breakdowns were not unexpected, sending complete units away for repair was both expeasive and inconvenient.

It was decided our future purchases should be of modular equipment thus if breakdown does occur, it can be isolated to a single module, and **replaced** by a non-technical person. Since the most expensive and reliable part of most systems is the GPS sensor. multiple spares can be carried of all other modules at little cost.

However, there were no modular systems suitable for our application, so it was decided to build a system 'in house' from components.

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INITIAL CTITERIA

The criteria for selection of the components were - sub metre real time positioning reliability

- post process to sub decimetre
- small and light weight (for portability)
- reliability and ease of repair
- availability
- ease of use
- cost

Once it was established that the unit could achieve the results, reliability was the next most important criteria with cost being down the list.

Since real time positions were required to sub metre, the GPS system capable of this were limited to Ashtech P code, Trimble SSE and the NovAtel 951R and 2151R GPS Card. Unfortunately, neither Trimble nor Ashtech were willing to sell the core of their systems, as our development could become competition for their full systems.

The NovAtel Performance series of cards contain Narrow Correlation technology which is under NovAtel patent. While the receiver is a ten parallel channel single frequency receiver, by the use of the narrow correlation, pseudo range accuracy of 10cm are possible, thus approaching P code results.

After reading most of the papers published on the NovAtel GPS card and talking by telephone to the development team, a trip was planned to Calgary (Canada) in late May of 1993 to establish if the card was truly capable of real time sub metre positions under normal conditions rather than ideal test conditions. As NovAtel was a relative new comer to GPS, the availability and reliability criteria needed to be researched also.

INITIAL CARD TESTS

As very few NovAtel cards were in a survey production environment neither Premier GPS (NovAtels distributor) or NovAtel could recommend any company which had an existing system achieving sub metre real time, and sub decimetre post processed positions, so a system was to be put together by Premier and NovAtel for a trial on my arrival in Canada.

The system consisted of two 951R GPS cards installed in portable (lunch box style) computers with UHF radios and modems attached. The system was very rudimantary and after some initial testing problems, achieved real time positions.

The test site was a series of marks previously surveyed using static techniques by a- survey' company with quoted accuracies of a few centimetres. The sites were quite close to a main highway, and thus very prone to multi-path. Throughout the test many of the real time positions were sub metre, however a random wander was evident at each site. Due to the nature of this wander, it was considered to be a combination of multi-path at the base and the remote stations due to passing vehicles. While the NovAtel Antenna (Model 501) has a multi-path reduction feature incorporated, choke rings would be required to ensure sub-metre positions in real time, however due to time constraints, no test was made with these attached.

Since the radio link was only UHF, it dropped-out after 8km, so longer baselines could nor be checked, but no systematic errors were evident at this range.

The system showed excellent DGPS results, especially considering its crudeness. No phase data was logged by the remote computer, so the phase capability could not be checked. There -appeared to be enough evidence (in papers etc) to suppon NovAtels claims of quality phase data.

A further advantage of using this system was that the real time position was not phase added but code only, thus when post processing is performed on the phase data, it gives a somewhat independent check on the DGPS data.

THE INITIAL SYSTEM

The installation of a GPS card in a portable computer would not allow for a backpack system to be developed, so the OEM board version installed in an Evaluation kit (which I had seen in NovAtels Development section) seemed the logical alternative This evaluation kit provides power to the card, an antenna socket (TNC), two RS-232 ports and a strobe input for photogrammetric operations, all in an aluminium case (21cm x 1 Icm x 5cm).

The OEM cards have software loaded during manufacture, and require a computer to send requests or commands to the card via RS-232 (or other protocols if required The card will then respond with data. By the use of two RS-232 ports, commands can be sent (from the controlling computer) through Com1 to the card. Differential corrections can be generated out of Com2, in response to a command received through Coml. simultaneously with phase or position data flowing back to the computer via Coml Thus any computer capable of serial communications (RS-232) can address the card. This was far more suitable then the card being inserted in a slot inside a computer.

An order was placed in early June 93 for three 215IRE OEM cards inserted in evaluation kits for delivery by 1st July.

To allow adequate range of GPS, a Kenwood 7305 VHF radio was selected. The radio was capable of 5 or 25 watts (switchable). and was a standard 'off the shelf voice transceiver. As safety is a prime concern in remote locations, a radio which can be used for voice communication in an emergency was desirable. Minor modifications were performed to allow data transmission

The modem selected was a GFS Electronics (Australia) 1201 modem. This was a commercial 1200 baud modem with a good interface to radios.

Although many dataloggers were available, very few were DOS based, offer a full 80 column x 25 line display and a QWERTY keyboard. The full display was highly desirable as any utility programs could be placed directly on to the unit without modification. The Sharp PC-3100 palmtop computer offered many features including DOS 3.3 1, 80 x 25 CGA mono display, RS-232 communication, QWERTY keyboard, and two PCMCIA (type 1) card slots. The palmtop only measured 22cm x llcm x 2.5cm and weighted 0.5kg. Robusmess was unknown, however experience with a predecessor (Sharp PC 1600) had proved it very robust.

The features required in the software were a rapid static capability (operating on the NovAtel Ll frequency). ambiguities on the fly, kinematic processing after fixing ambiguities, and fixed and float static solutions. The logging software was to be one or two screens which would include the navigation data.

As NovAtel did not have any software capable of phase processing, various thild party software packages were considered. Most seemed powerful, but not geared toward a production environment. A package which showed good potential was GPS PROC written Waypoint Navigation (now Northern Surveys). After a brief meeting with the authors (Daren Cosandier and Hugh Martel) various changes were proposed to the setout/logging and post processing software to integrate to the new system. Software to generate waypoints for the setout program to read, as well as to convert to local coordinates and orthometric heights was written by DSS. Although the phase processing provides some quality control checks, extras were required at the eonversion stage, including checks on the RMS of the phase, RMS of the CA code and checks on ambiguity drift.

INITIAL TESTS

The target date for delivery of all components was the 1st July, to allow one week of testing before survey production, due to start on 7th July. Unfortunately all components were late except the software and palmtop computers, finally arriving on **14th** July. The project the new equipment had been assigned to was commenced using Ashtech P code receivers, in a real time differential mode.

To add to the complications of late equipment, the project area was some 800km from the closest city in the Strzelecki Desert area of Australia, thus all equipment likely to he required had to be carried%- board.

On the day of arrival at the project area, the equipment was set up and operated using choke rings on base and remote. Differential corrections were being received, but intermittently (every 40 or 50 seconds). The system was showing excellent set out ability with errors being sub metre, providing the age of the differential correction was less than ten seconds. On attempting to navigate to a waypoint, it was discovered that the waypoint bearing was 360" minus the real bearing. With a quick mental calculation required to determine the correct heading more points were checked some ten kilometres from the base station to check radio coverage and system performance.

Due to under design, the power supply to the Sharp PC 3100 data logging unit, overheated and melted its casing, causing the computer to revert to its internal batteries, which had insufficient charge, the system clashing.

A larger heatsink and plastic case for the power supply were built that night and an attempt made to solve the intermittent nature of the differential corrections

'The radio was designed to shut down after a continuous transmission of 60 seconds. This meant the differential corrections had to be sent in packets ie send a packet of data, then shut down transmission on the radio momentarily. Initially, the NovAtel was set to release its data to the modem every second. which worked well with four satellites. However with extra satellite corrections being transmitted the length of the message grew, until it was longer than one second (at 1200 baud), thus only one in forty or fifty transmissions were clearly received at the remote. Since it is possible to have ten different differential corrections, the practical maximum data transmission rate (at 1200 baud) is every three seconds. The message is preceded by a 200ms lead, and followed by a 100ms tail.

Although there had not been a problem with processor time, the NovAtel DCSB differential record type was chosen instead of RTCM104, to free up processor time on the NovAtel board.

The system was now functional and comprehensive testing undertaken by driving to points previously set out and post processed to centimetre level using the Ashtech P12.

After some twenty or thirty points were checked, results indicated random errors of less than 0.6m with most being less than 0.4m. The phase data was then downloaded from the PCMClA card in the Sharp palmtops to a Renard 486 laptop computer for post processing.

A rapid static solution was performed on the first ten minutes of data, and then the filters set to kinematic for the remaining data (while the vehicle moved to each point).

The first point closed within a centimetre of the Ashtech P code solutions, but the ambiguities began to drift soon after, indicating an undetected cycle slip. At the next check point, the post processed position was 2Ocm in error. Fortunately, a ten minutes Rapid Static had been performed on this station, so ambiguities could be re-established

This rapid static reestablished ambiguities to integer values (again agreeing with the Ashtech solution), but the software again lost the integers soon after the vehicle began moving.

This ambiguity wander continued throughout the data, indicating a software problem. To reaffirm this, some Ashtech data was processed through the software, with perfect results.

More trials were performed on both Ashtech and NovAtel data, with the same outcome. Several phone calls were made to Waypoint Consulting and NovAtel. until it was discovered that Waypoint were not using the Locktime measure of the NovAtel cards. This measure gives the number of seconds of continuous phase lock on each satellite, and thus is a cycle slip detector.

The usual method of cycle slip detection checks the difference between the predicted phase (last phase measure plus phase rate * delta time) and the measured phase, can not be used for small cycle slips on the NovAtel card, as the accumulated doppler is not reset to zero when small slips occur. Cycle slip detection on a NovAtel receiver must look at Locktime first, then delta phase.

This modification to the Waypoint software required a new record structure for the logging, as well as detection in the processing software, and thus took some days to complete and be tested, before being sent via modem to Australia. The results were then excellent, with the NovAtel system achieving the same accuracy in both setout and post process as the Ashtech P code. but achieving two to three times the production.

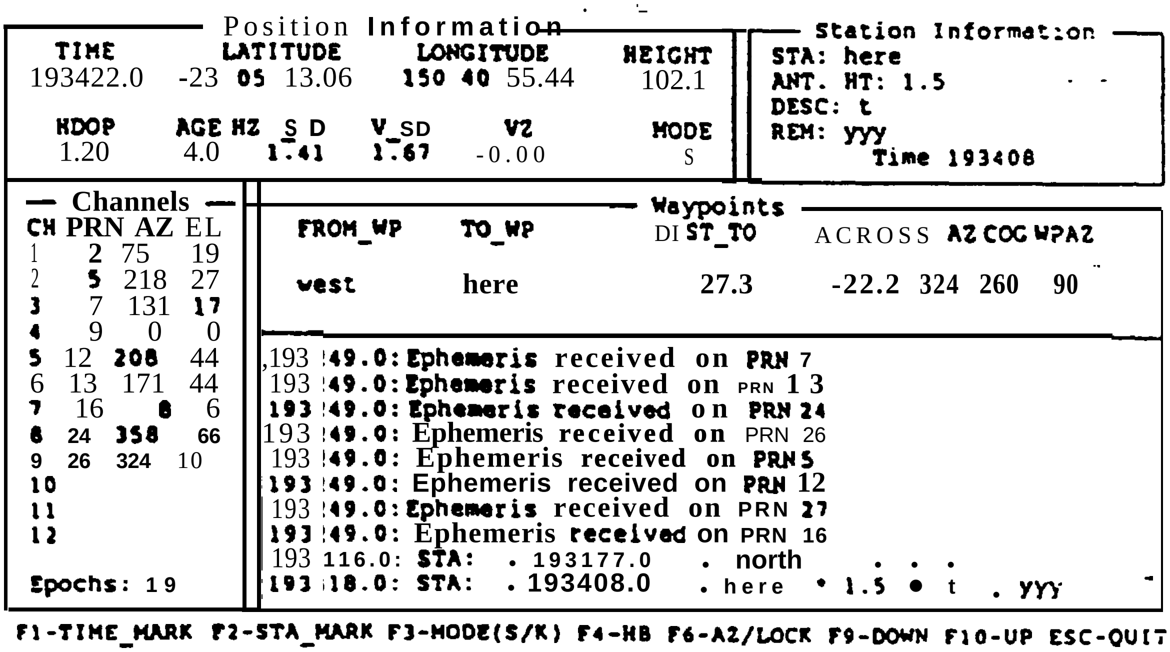


Figure 1. Sharp Logging and Navigation Screen

The principal **advantages** of the new system were:
- its ease of use, due to the single screen format for navigation, satellitew information. position etc., rather than using three or four screens with the Ashtech
- the automatic loading of way-points from a file, which were easily scrolled through, rather than hand entered in the field.

The MODIFICATION PROCESS

The system had been setup in the field due to the late delivery of components, so the interconnecting wiring was far from trouble free. The power socket on the Evaluation module installed by NovAtel was a 2.lmm 'push-in' DC plug which could easily be bumped and disconnected. Due to space requirements on the evaluation kit face, a miniature BNC plug and socket was installed. Although this type of connector is not designed for power, it serves this purpose very well, and provides a very positive connection. This modification has been carried out on nineteen receivers, with no failures to date.

There are four distinct modules to the system, the **GPS** Card, Radio, Modem and Computer Controller (Sharp PC **3100**), each requiring power. The Sharp computer requires an input of 6.2~ DC, while all others require 12 volts. The modem can be **powered** from the radio, as these are generally used as a pair. A power distribution box was built to bring the main power in, check it is greater than 10.5 volts (indicated by a LED), then distribute it via a fuse with LED indicators to the individual devices. A transformer to 6.2 volts to power the computer was built in. thus eliminating the need for any external electronics. A power outlet for a fan was also installed to help cool the base station in extreme heat.

A contract had been negotiated with Rees Geophysical in Oman which would require the system to be used in a vehicle where possible, - backpacked over sand dunes, then returned to the vehicle. This situation could occur many times **per day, so** it was essential that the mounting of the instruments and antennae allowed easy access,

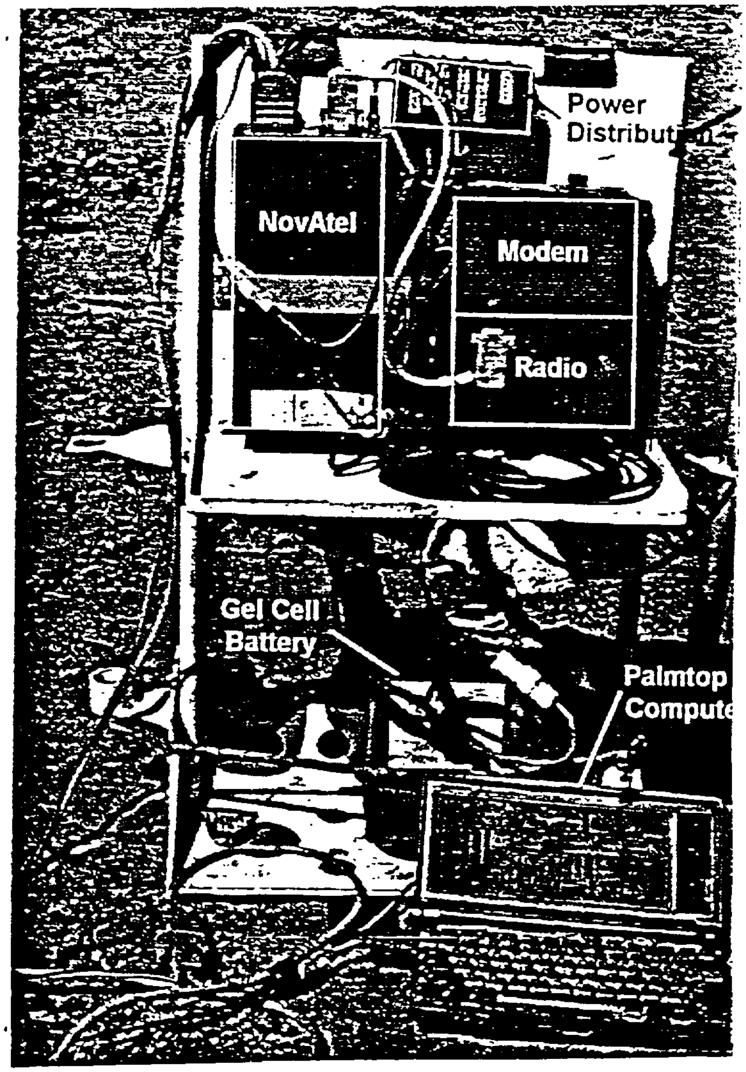


Figure 2. The System Showing Individual Modules

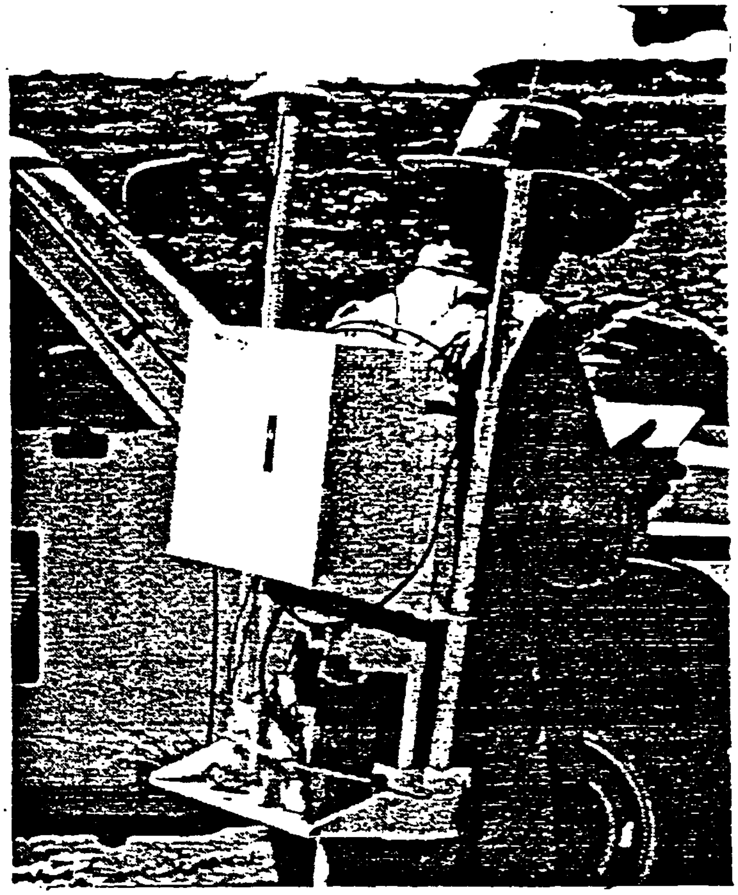


Figure 3. Backpack in Use

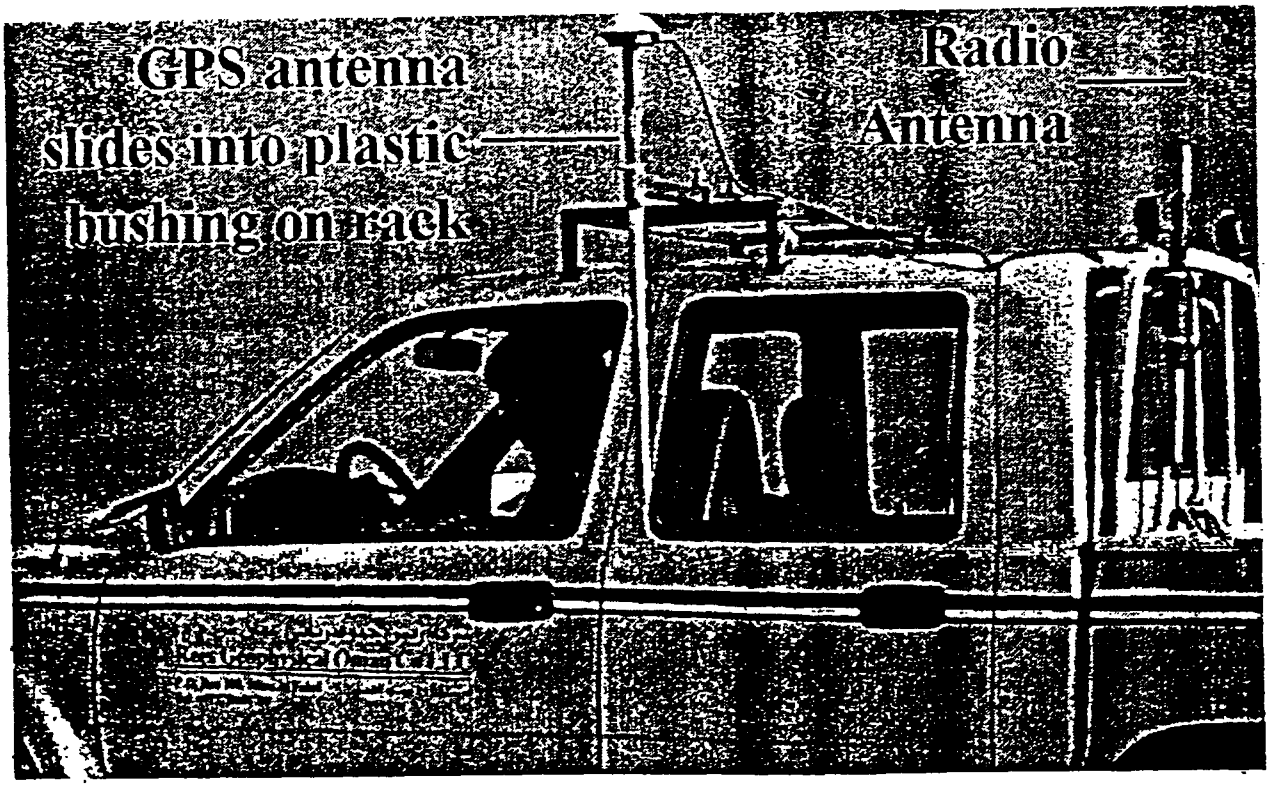


Figure 4. **Vehicle** Mounts for antennea

without a loss of phase lock when transferring the equipment in and out of the vehicle.

A vinyl backpack on an alumiaium frame was selected. however it soon became obvious that the equipment would overheat due to the lack of air movement inside the vinyl pack. Several other designs were investigated, with the final design being a custom made aluminum frame, with a flat aluminium sheet for instrument mounting. A battery compartment at the base allows nvo (one as a spare) IOAH gel cell batteries to be carried. The instrument section is covered by an alumiaium box which slides on from the top, and protects the equipment from sun, rain and dust. If required, a cooling faa forces filtered air over the NovAtel and radio heatsink and pressurises the inside of the box, thus reducing dust.

The antennae (radio and GPS) are mounted on aluminium poles which slide into housings on the sides of the backpack. The final dimensions of the backpacks are 38cm x 60cm x 18cm, with a total weight of 8kg. For shipping the units, two packs fold together to protect all electronics and form a shipping box.

Mounts located on vehicles have a plastic bush which the poles slide into. This ensures the pole can easily be transferred from back pack to vehicle and visa versa, and reduces vibration on the pole. The GPS antenna pole is machine to 0.6m, and has a thread in the bottom to allow two or more pole5 to be screwed together. This feature eliminates errors in antenna height measurement, as the height can only be 0.6m, 1.2m, 1.8m etc.

To allow the system to be mounted on a bulldozer, an enclosure containing all components was required. The steel box has sockets on the front panel for power, radio and GPS antenna cables and RS-232 (9pin) socket for the Sharp palmtop communications The box houses all parts of the system in modular form, and measures 2Ocm x 13cm x 28cm and weighs 5kg. The modular format has been retained to allow simple fault detection and replacement. A new version of navigation software was written by DSS to allow computer illiterate bulldozer operators to navigate themselves around a seismic grid to sub metre accuracies The OEM card used for this purpose are 2111R cards, which have no phase capability, but still produce sub metre real time results.

Due to an availability problem, a replacement has been designed and built for the NovAtel OEM evaluation kits. This new design enclosure has all the features of the NovAtel product, but with a better power connector and power warning function. The first warning is an LED when power falls below 10.75 volts, then a buzzer when power falls below 10.5 volts. These thresholds are adjustable, and have been set at these limits to accommodate Gel Cell batteries.

SYSTEM PERFORMANCE AND RELIABILITY

In terms of DGPS setout. the system has performed above all expectations. As it is somewhat inconvenient to carry a choke ring on the remote aateaaa (except in a vehicle situation), tests were undertaken to determine the DGPS set-out error with only a choke ring on the base station. These tests have been performed in a desert environment, so multipath is not a large factor.

Numerous tests in the Middle East and Australia indicate no systemic bias, with mean of all components (latitude, longitude and height) zero The mean of the radii position error (2D) was 0.26m (σ=0.25m), and of zero (σ=0.55m) in vertical. However it should be noted that large spikes appear occasionally in the data (see Graph 1). These spikes are very short in time, so the chance of positioning a point incorrectly is very small. To guard against this occurrence, all data collected is post processed using the phase to give a result to less than 5cm.

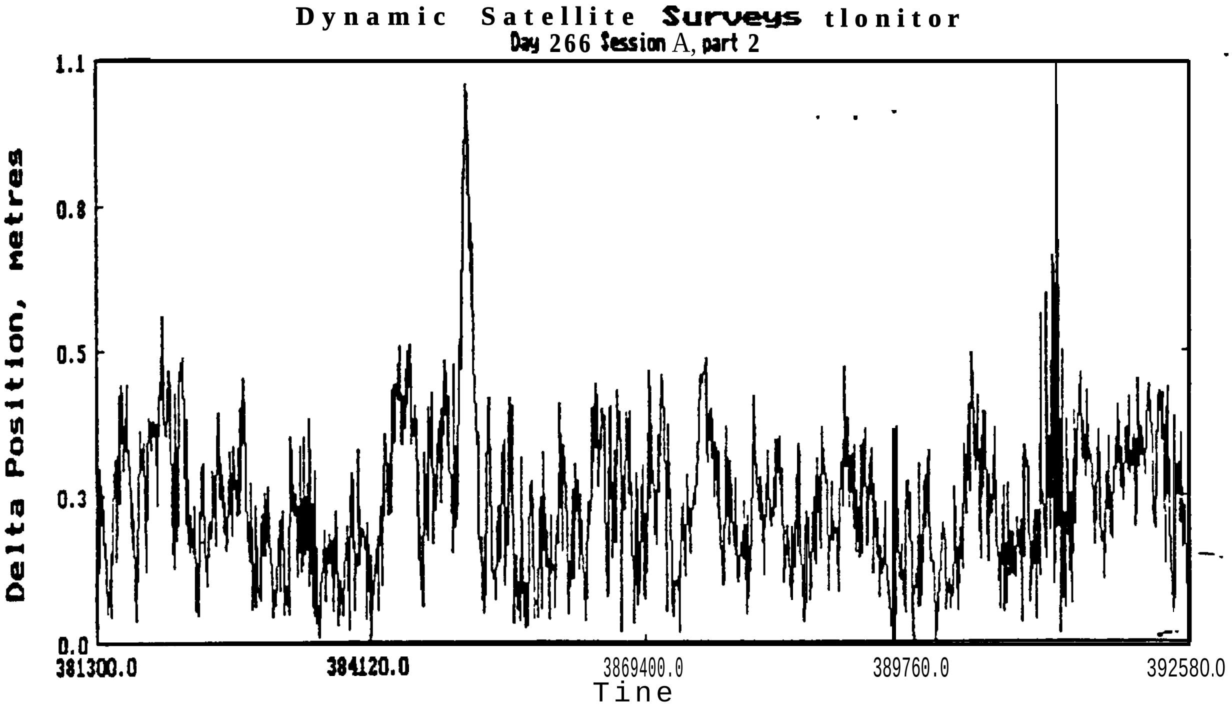
Some explanation has been given by NovAtel for these spikes, however they are not quite as predicted. New firmware version recently received may fix the problem, however exhaustive tests have not been performed to verify this.

In high multipath, low signal situation such as heavy tree cover, the system still performs well, but 2D errors climb over a metre.

In terms of phase data, the NovAtel cards produce clean phase data which is easily processed Thi Locktime counter appears to be over sensitive, as many cycle slips indicated by the Locktime are not cycle slips when processed

Gaining, maintaining and n-acquisition of lock on satellites is exceptional, the system locked on to five or six satellites quickly, while other receivers could not gain a position (ie four satellites).

While the system has many teething problems, often associated with external cabling and wiring, overall it has proved reliable. All components have failed in the system a! different times. but-each occurence has been easily diagnosed. and a single module (it radio, modem, NovAtel or computer) replaced.



Graph 1. Typical DGPS Position Error Showing Characteristic Spikes

The Sharp computers are not as robust as first thought, and have an inherent power problem, causing the unit to not accept external power, and ultimately crash when the internal batteries fail. A problem with the RS-232 port on the Sharp causes corruption to occur if the keyboard is beiig used when large volumes of data are being received through Com1 port. The solution to this problem is to type the data in slowly, and avoid the times when phase data is being sent (in our case every 10 or 15 seconds). As some calculations arc performed on the incoming data, the 8086 processor in the Sharp becomes overloaded, and slows down key entry. The solution to all these problems has been found by using a Prolinear 386 Palmbook.

CURRENT USES AND ENVIRONMENTS

As mentioned previously, this system is used for 2D and 3D seismic SETOUT and survey in Australia and oMAN (Middle East). These two areas have extremes of TEMPERATURE ranging from -5°C to >50°C.

Boreholes for mineral exploration previously drilled, and since covered in by cultivation have been located rapidly. This involved determining the rotation. scale and offset of the original (arbitrary datum) grid in the field, then commencing setout.

Several GIS applications have been undertaken, including the survey of 800km of roads and tracks in heavily forested areas.

The implemantation of bulldozer guidance exposed the system to a large amount of vibration, as the antenna is mounted in front of the ROPS cage, over the blade. The metal case containing the radio/modem/NovAtel units are all mounted inside the cabin, with the computer immediately in front of the operator, between the clutch controls.

The system has been used to find land boundary marks in rural, forested areas. Despite poor signal and a high multipath environment through the tree cover, the system operated above expectations.

FUTURE DEVELOPMENTS

The problem previously mentioned with the Sharp computer have been eliminated by the use of Prolinear 386 Palmbook computers. These computers are only slightly larger (19mm longer) than the Sharp, but have a 386SX processor. The 386 processor has eliminated all the key entry and communication problems, and also allowed larger more complicated waypoint generation programs to be run in the field. Robustness of these units is still under test, however they do not suffer from the power problems of the Sharp. It is hoped to implement multi tasking in the nearfuture.

To reduce the weight of the backpack unit further. a carbon fibre unit is planned.

In **many** cases, Real Time Kinematic or Real Time Processing is of little benefit, and may only serve to complicate the issue, and increase the weight of the units. When reliability is assured, RTP will be incorporated into some new units for specific applications.

The instrument cases developed for the bulldozers is to be built from aluminium to reduce weight, and with better access to components inside. This case will then be fitted with locating lugs to clip directly onto a backpack. This modification will reduce the space required in a vehicle, by only using the backpack when walking.

A common problem with most GPS systems in antenna cables becoming tangled. This is especially true with portable -backpack operations. A simple retraction and coiling device is being investigated to eliminate this problem.

CONCLUSIONS AND SUMMARY

Tbis discussion has focussed on the practical aspects on the development of a DGPS system from a users perspective.

In retrospect **the** project has proved to be both cost effective in the medium and longer terms. Problems [illegible]h instrument breakdowns are now easily overcome by field personnel, thus reducing downtime and freight charges. Comparing the breakdown history of these units to other ‘off the shelf units DSS owns, the downtime history is considerably better.

The system has satisfied all the initial criteria well, except perhaps the availability of NovAtel components at times.

The knowledge and experience gained, and the money and downtime saved has made this a worthwhile development project. and the system is assured a future in many new applications.

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