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Positioning Buried Utilities using an integrated GNSS approach

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ABSTRACT

In the UK there are some 4 million kilometres of buried pipes and cables. Some of the water and sewerage pipes were laid down up to 200 years ago, and many during Victorian times. Any surveying carried out would have been relative to surface features that have now gone. Further to this, there has been very little coordination between utility companies to map their assets. This all leads to a situation whereby digging for a buried utility can be quite literally hit or miss. Dry holes are first dug to find the relevant utility, then the trench excavated has to be dug carefully in case there are other utilities buried adjacent. This all leads to a lengthened excavation process that leads in turn to congestion and disturbance, as well as increased excavation costs. One answer is to remotely locate the utility and coordinate it into a global coordinate system.

The University of Nottingham is involved with two projects; The EPSRC funded Mapping the Underworld and the dti funded VISTA projects. These are both four year projects and research methods that will allow continuous and reliable positioning in built up areas in order to position and re-locate buried pipes and cables. The positioning techniques include GNSS, GNSS simulation, INS, locatalites and smart stations. The following paper outlines the work carried out to date on the integration of these techniques as well as the results of field trials carried out to date.

KEYWORDS: GNSS, mapping, Locatalites, positioning, integration.

1. INTRODUCTION

In the UK, there are currently approximately 4 million kilometres of buried pipes and cables providing utility services. These are a combination of telecommunications, water, gas, sewerage, electricity and drainage. It is estimated that there are 1.5 million holes dug each year in the UK on highways and footpaths by utility companies so that they can install new services and maintain existing ones. This is in addition to road building and repair work carried out by the Highways Authority.

Over the past 25 years, the UK has seen an increase in traffic of 72%, with an increase in cars on the road of 14 million from 10 million in 1972. In addition, the amount of freight carried on the roads has increased by 69% since 1980. Latest Government figures forecast that road traffic will increase by about 40% over the next 20 years.

Congestion is an everyday part of our lives, and has many causes. Busy roads are very sensitive to small disturbances, such as accidents, weather conditions, traffic volume and road works.

One answer to enable these pipes and cables to be located is to map them on absolute terms e.g. using GNSS. This is simple enough for new pipes and cables being laid, but difficult to do so for those already underground. The combination of location devices such as GPS with detection devices such as Ground Penetrating Radar, Acoustics, and quasi-static fields is a way forward. In addition to this, the use of knowledge integration and pipeline-ground interaction can all add up to a combined system allowing the location of such utilities to become reality. However, this will be a mammoth task considering the amount of utilities in existence.

The following paper outlines two projects funded in the UK aimed at tackling the above issues, and focuses on the positioning aspect, and the ideas to be used in making GPS and future GNSS work in built up areas where the majority of utility location is an issue. In addition, the use of a Leica SmartStation using the Continuous Updating Technique developed at the University of Nottingham is discussed.

2. THE UTILITIES

Many utilities in the UK were laid in Victoria times when demands due to economic boom were large, with pipes in older cities being greater than 150 years old. Poor mapping techniques, and recording the pipes' location relative to a physical feature that no longer exists means that the exact location many of today's networks are unknown. In particular, their position relative to other pipes and cables.

In addition to this, many records do exist, but in a number of formats such as paper based, microfiche, and digital. Furthermore, the records that do exist are sometimes in-compatible between various companies, hence being able to position one company's pipes relative to another's cables is difficult.

Today, there is another boom in cable laying. The Government is actively promoting the use of broadband within the general population. Again, the fibre optic cables required for this are vast. Today there is well over 3 million km of fibre optic cables laid under the streets of the UK.

In 2001, the UK Government announced the target to have the most competitive and extensive broadband market in the G7 group of countries by the end of 2005. The DTI has commissioned research to benchmark the progress of the UK against the other G7 countries (Canada, France, Germany, Italy, Japan, UK and the USA), and also Sweden, Ireland and Australia (DTI, 2006).

The UK currently has the most extensive broadband infrastructure in the G7 group of countries, with over 97% of households and businesses now able to receive broadband. BT announced in summer 2004 that it expects availability of broadband to rise to over 99% by the end of summer 2005. There are over 6 million subscribers in the UK and there are around 60,000 new connections each week (DTI, 2006).

Many utilities are reaching the end of their design lives. National Grid Transco, for example, has a programme to replace all their iron mains within 30 metres of properties over the next 30 years (HSE, 2006). Thames Water will replace more than 1,600 km of iron mains in London over the next 5 years.

The utilities companies are being pushed by the customers' demands. It is now difficult to place more utilities into the tight space under the streets of some of the older cities without the risk of damaging those already in place.

The increasing use of plastic pipes, however, is making detecting the utilities through geophysical techniques even more difficult.

It is common practice to dig a series of trial holes in order to locate the utility required, then to come back some days later to excavate the actual trench. This causes extra disruption as well as excavation costs.

2. MAPPING THE UNDERWORLD

The UK's Engineering and Physical Sciences Research Council (EPSRC) announced in 2004 that it was establishing a programme as an initial attempt to start tackling the above issues. It organised a "sandpit" exercise, whereby invited academics, industrialists and EPSRC all got together in the Autumn of 2004 to think of ideas that could be put forward as research projects. The EPSRC put £1 million into the programme, and as a result four projects were funded, there being;

- Buried asset location, identification and condition assessment – a multi-sensor approach.

- Mapping and Positioning.
- Knowledge and Data Integration.
- Enhanced Methods of Detection of Buried Assets.

Further to this, a network programme was also separately funded;

- Mapping the Underworld Network.

The above projects bring together academics from Universities in Bath, Birmingham, Leeds, Nottingham, Oxford, Sheffield and Southampton. In addition to which, industrial companies, notably UK Water Industry Research (UKWIR) are also heavily involved with the projects.

The overall work will last for 4 years, and started in the Summer of 2005. In addition to the research work, the projects will organise workshops on regular basis in order to disseminate the findings and ideas. The project has a web page www.mappingtheunderworld.ac.uk, and further details about the work may be found here.

The overall aim of the project is to investigate the feasibility of several novel approaches, alongside greatly enhanced existing approaches, to be combined in a single multi-modal approach to the location, identification and condition assessment of buried assets. These include developing Ground Penetrating Radar, Acoustic, Quasi-static field techniques, interaction of the soil in previously excavated areas as well as the interaction of the soil with the utility and integrating their combined information with the location of the data. The devices will be surface based, whereby a suite of sensors will sweep across an area, as well as being pipe based, so that the sensors are taken through a water pipe and the surrounding utilities detected.

2.1 Mapping and Positioning

The overall objective of this sub-project based at the University of Nottingham is the research and development of a prototype positioning system to conduct precise 3D positioning at a centimetre level, using pseudolite and Locatalite transmitters, currently available commercial GNSS technology and GNSS simulators developed and available at the IESSG. A suite of algorithms and a software package for the data processing and simulation of GPS, Galileo and pseudolite measurements will be researched and developed. System validation will be conducted at Nottingham, as well as field trials with the remainder of the project teams.

The accuracy, availability and reliability of satellite based positioning are very dependent on the number of tracked satellites and their spatial geometry (Santerre, 1991). One of the limiting factors in using GPS is the requirement of having direct line of sight with the satellites themselves and the GPS receiver. Most of the mapping of the “underworld” will be based in built up areas where line of sight to a sufficient number of satellites is not always possible. In addition, the presence of trees, as well as buildings, can cause masking issues, as well as introducing multipath errors.

This part of the project will research various means of improving the position availability, integrity and precision through a GPS based system, augments with other systems such as Galileo, GLONASS, INS, Locatalites and pseudolites. The reliable and accurate positioning of the overall system is an underpinning issue.

The overall aim of the project is to investigate the feasibility of several novel approaches, alongside greatly enhanced existing approaches, to be combined in a single multi-modal approach to the location, identification and condition assessment of buried assets.

2. VISTA

A second project called "Visualising Integrated Information on Buried Assets to Reduce Streetworks" (VISTA) has recently been funded by the UK's Department for Trade ad Industry (DTI). This project brings together the University of Nottingham and University of Leeds, as well as UKWIR and 18 other organisations, including various utility companies, professional organisations, excavation companies and survey companies.

The research planed for this project focuses on enhancing and integrate existing legacy asset information, together with dynamically acquired accurately geo-referenced data in the street and develop novel techniques to display the resulting knowledge to digging teas and network planers.

One such visualisation idea is to use Augmented Reality. This was developed at the University of Nottingham as a means of visualising underground data such as utility location (Roberts *et al.*, 2002). However, the visualisation is only as good as the source data, so if the source data is inaccurate, then the utility will be visualised in the wrong place. Such a high-tech AR system could give the excavator a false sense of accuracy, and he may well excavate without caution. Therefore, the accuracy, and an indication of the accuracy to the user, of such data is vital. Figure 1 illustrates a screen shot from an AR device used in the Yorkshire Water region (Evans *et al*., 2003).

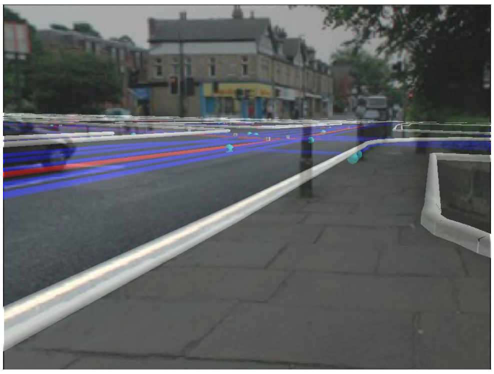

Figure 1. A screen grab of the AR system used in Headingly.

2. THE NOTTINGHAM TEST NETWORK

A test network has been established around the University of Nottingham in order to try out the various positioning techniques and combinations mentioned above. The test network was meticulously coordinate using a combination of precise levelling, total station and GPS observables (Taha, 2007). The network comprises of points with known coordinates in a variety of scenarios, from an open sky scenario to a very built up scenario.

Figure 2 illustrates the test network as well as the various difficult scenarios encountered.

Figure 2. The Nottingham Network.

2.GNSS Simulation

The project has developed software that will allow simulation of GNSS in different scenarios, Figure 3. This allows the user to input a Digital Elevation model, such as shown in Figure 4, and GNSS ephemeris data. This is possible using GPS and GLONASS data, and is planned to also incorporate Galileo and Beidu/Compass constellation information.

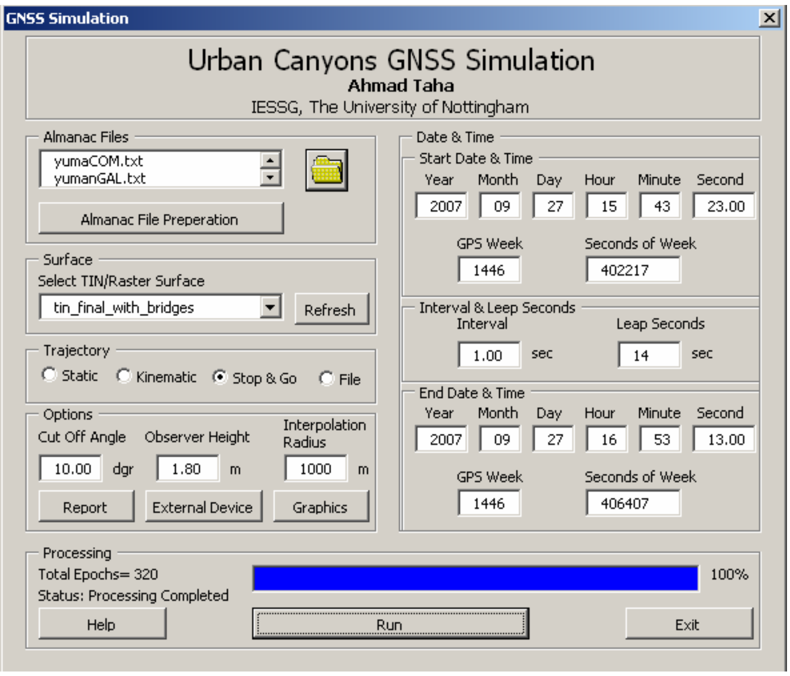

Figure 3. The GNSS Simlation Software.

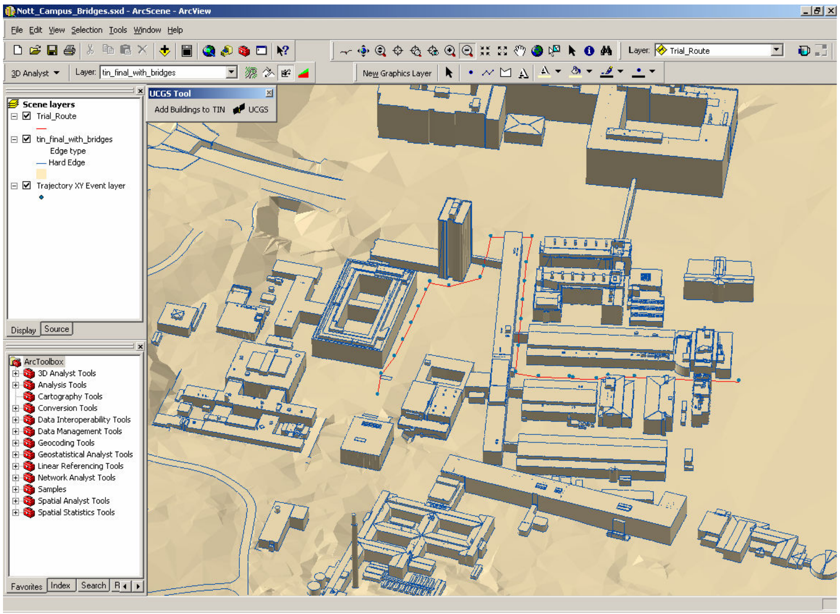

Figure 4. A DEM of the University used in the GNSS simulator.

The output from the software includes information such as DOP values, number of satellites and sky plots, Figure 5, which take into account the DEM information and hence the obstructions caused in the built up environment.

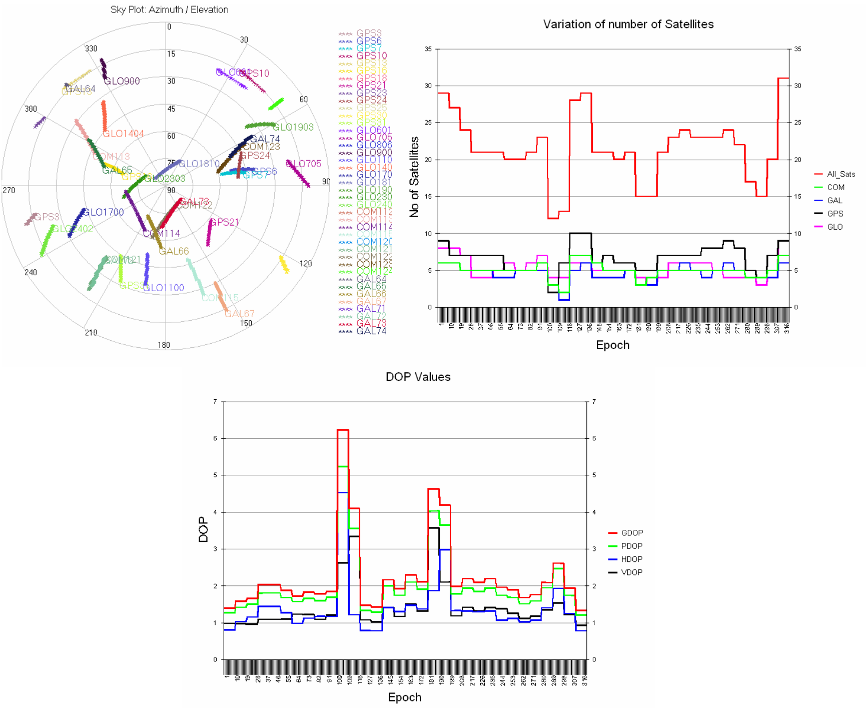

Figure 5. The Output from the GNSS Simulator.

2. COMBINED TOTAL STATION AND RTK GPS APPROACH

The Leica SmartStation is used as part of this project. One of the main areas of research has been that of fully integrating the GPS and total station data through a Continuous Updating Technique (CUPT). Currently, the SmartStation uses the RTK GPS to coordinate the initial traverse points, and orientation. However, the CUPT uses the RTK data and the total station data at every epoch. Further details about this can be found in Taha (2007).

According to (Biasion *et al*., 2005), in 1993 Leica Geosystems registered a USA Patent for a "Surveying system including an electro-optic total station and a portable receiving apparatus comprising a satellite position measuring system". This has now been implemented in an instrument called Leica SmartStation. SmartStation comprises of a TPS1200 total station with an ATX1230 SmartAntenna. The SmartAntenna is a 12 channel dual frequency GPS RTK receiver that fits on and communicates with the total station (Leica, 2006)

Typically, the GPS provides the user with a real time high accuracy position wherever RTK fixes are possible using either local reference station corrections or reference network corrections (i.e. SmartNet, Virtual Reference Station, etc). Then the user operates the Total Station to measure angles and distances to the objects that have to be surveyed in restricted areas. By using two of the GPS points together with the total station observations, the SmartStation can automatically transform non-GPS coordinates (termed temporary coordinates) into the required grid coordinate system, in this case OSGB36.

The SmartStation uses Leica's SmartCheck algorithms to compute the position coordinates from at least 5 well distributed satellites at 10° above the horizon (10° cut off angle) (Leica, 2006). The RTK position coordinates are then updated continuously as long as the SmartStation continues to receive GPS data (L1 and L2 phase and code observables) and the corrections from reference stations. This technique is used to ensure the highest possible RTK reliability for SmartStation RTK fixes at a range of about 50km using network reference stations. The horizontal precision is 10mm+ 1ppm and the vertical precision is 20mm + 1ppm (Leica, 2006).

The integration between GPS and Total Station as well as working in the urban canyons presents several issues to be considered which, as a result, can affect the accuracy of the SmartStation coordinates. These issues include obstructions, multipath, reference station precision and the use of different coordinate systems. Several types of obstruction, such as buildings or tall walls, can block the signals from one or more satellites from reaching the GPS antenna. Although the signals can pass through trees with light foliage, the strength of the signals will be reduced. Usually users choose open areas where there are few obstructions, such as at road intersections, open spaces and even on the tops of buildings, in order to set up the SmartStation in order to acquire sufficient satellites.

Multipath signals can occur if the SmartStation is set up close to a building or near a tall wall. Nevertheless, the influence of these signals can be smoothed by using both the SmartAntenna and the GPS processing algorithms (Leica, 2006). However, if the object has a very smooth reflective surface, multipath may be particularly severe and as a result it may take longer than usual to compute an RTK position fix.

The GPS rover within the RTK technique receives corrections from either a local base station or a reference station network to compute the user's real time position. The accuracy of this position is dependant on the base station or the reference network accuracy. For example, Leica SmartNet is enabled by the network of Ordnance Survey (OS Net) base stations which as a result dependant on the OS Net accuracy. According to OS Net quality tests conducted by (Ackroyd and Cruddace, 2006), a consistent precision and accuracy are achieved across the OS Net with overall east, north and height RMSE of 11 mm, 16 mm and 31 mm respectively.

Universally, GPS coordinates are in the WGS84 coordinate system. These coordinates are given as X, Y, Z Cartesian coordinates, or latitude, longitude and ellipsoidal height. However, a total station always works in grid coordinates (Easting, Northing and Orthometric Height). Therefore, in order to be able to use the GPS position for total station measurements, the SmartStation must convert the WGS84 coordinates to the required grid coordinates system such as OSGB36.This conversion can introduce some errors. Even so, the OSGB36 coordinates system will be utilized in CUPT tests. The CUPT

2. CUPT TESTS – RESULTS AND ANALYSIS

To asses the accuracy of the SmartStation set up points (both the occupied and measured points), the differences between the 'truth' coordinates and the SmartStation point coordinates were calculated (Table 1). This table shows that the RMSE in plan coordinates were found equal to about 0.06m and 0.01m for the measured and occupied control points respectively. These figures indicate the high accuracy for the occupied controls over the measured points. Further, the plan coordinates maximum error was found equal to about 0.09m and 0.07m, in East and North coordinates respectively, in 'COATS1' point. This error could be due to employing a technique of traversing to propagate the coordinates from the starting point ('STOP' point) to this point. Also, it could have a positive or negative sign which could be appear, in some cases, to decrease as can be seen on the following points (TOWER, ST2 and ST1).

'Truth' coordinates - SmartStation coordinates						
Point ID/ Type	**dE** (m)/ Mrd	**dE** (m)/ Occ	**dN** (m)/ Mrd	**dN** (m)/ Occ	**dHt** (m)/ Mrd	**dHt** (m)/ Occ
ST10	--	-0.0060	--	-0.0200	--	-0.0271
STOP	--	-0.0030	--	0.0107	--	0.0153
COATS3	0.0043	--	-0.0453	--	0.0175	--
COATS2	-0.0760	0.0050	-0.0638	0.0072	0.0226	-0.0044
COATS1	-0.0912	--	-0.0685	--	0.0198	--
TOWER	-0.0633	--	-0.0620	--	0.0150	--
ST2	-0.0410	0.0071	-0.0610	-0.0117	0.0223	-0.0134
ST1	-0.0160	0.0078	-0.0500	-0.0092	-0.0028	0.0003
RMSE	**0.0578**	**0.0060**	**0.0590**	**0.0126**	**0.0180**	**0.0153**
Mrd=Measured, Occ=Occupied, -- No solution						

Table 1. Differences between 'truth' coordinates and SmartStation point coordinates

The overall height accuracy is slightly better than the plan accuracy in both measured and occupied points (Table 1). Besides, the height RMSE for the measured ('0.018m') was found very close to the occupied one ('0.015m'). However, there is about a '0.03m' error in 'ST10', this point was used as reference object, which increase the RMSE for the occupied points.

From the above comparison between the measured and the occupied points, it can be seen that the point type, wither it is occupied or measured, can directly affect the accuracy of such points. The occupied points' accuracy can, for comparison with measured points' accuracy purposes, be dependant on the factors described in the SmartStation Overview section. However, the measured point accuracy is dependant on the occupied point accuracy plus other factors such as observation accuracy (distances and angles) and instrument precision. These additional factors can decrease the measured point's accuracy, and this is demonstrated when comparing the errors in the 'COATS2' measured point with that of 'COATS2' occupied point which gives a significant improvement in both the plan and the height.

The occupied points could have up to about '0.02m' plan error and '0.03m' height error (Table 1). These errors could be reduced by loosely combining RTK positions with total station observations (distances and angles). For this purpose, four CUPT tests were held to asses the accuracy improvement for the final solution. The first two tests were sets of two inter-visible occupied points ('ST10&STOP' -Test1 points, Figure 6- and 'ST1&ST2' -Test2 points-). Direct total station observations, both forward and backward observations, between these occupied points were used. This will be called the direct method.

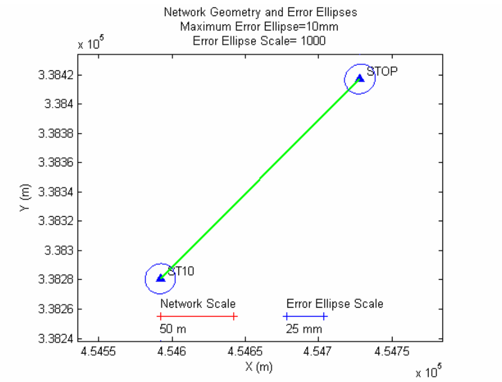

Figure 6. Test1 testing points - direct method

The third and the forth tests were for sets of two non-visible occupied points ('STOP&COATS2' -Test3 points- and 'COATS2&ST2'-Test4 points-). Indirect total station observations, both forward and backward observations, between these occupied points were used by mean of using one/or more total station setups. This method will be called indirect method.

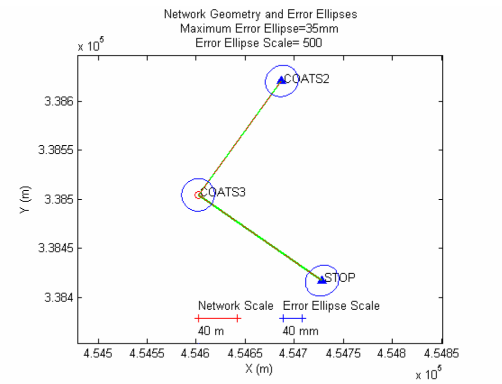

Figure 7. Test3 testing points - indirect method

The differences between the 'truth' coordinates and both of the occupied and CUPT coordinates were calculated (Table 2).

Station ID/ Test No	dE(m)/ Occ	dE(m)/ CUPT	dN(m)/ Occ	dN(m)/ CUPT	dHt(m)/ Occ	dHt(m)/ CUPT
ST10/Test1	-0.0057	-0.0030	-0.0200	-0.0160	-0.0270	-0.0071
STOP/Test1	-0.0033	-0.0060	0.0111	0.0077	0.0157	-0.0047
ST1/Test2	0.0078	0.0090	-0.0092	-0.0090	0.0003	0.0012
ST2/Test2	0.0071	0.0060	-0.0117	-0.0120	0.0059	0.0053
STOP/Test3	-0.0033	-0.0020	0.0111	0.0007	0.0157	0.0053
COATS2/Test3	0.0050	0.0040	0.0072	0.0172	-0.0044	0.0056
ST2/Test4	0.0071	0.0070	-0.0117	-0.0120	0.0059	0.0013
COATS2/Test4	0.0050	0.0050	0.0072	0.0072	-0.0044	0.0006

Table 2. Differences between 'truth' coordinates and both Occupied and CUPT point coordinates

Table 2 shows that CUPT is successful in making a significant improvement in the height component in both direct method (Test1) and indirect method (Test3) when low resolution occupied solutions are available. In case of high resolution achieved in the height component in the occupied solution (i.e. about '0.005m' error in both Test2 and Test4), CUPT results shown that it can maintain this accuracy or contribute a small improvement such as the improvement made in 'Test4'.

Since two occupied points are used in the previous four tests which mean that only slope distances are used in CUPT to loosely coupled the total station observations and RTK positions, CUPT results shown that there is no significant improvement in plan coordinates (Table 2).

One of the main reasons of developing CUPT is to integrate as many RTK positions available and keep updating the network positions as new observations pursue. Therefore, each point could have different coordinates after each successful adjustment. Variations of one point ('T26') from the 'truth' was calculated as the software continuously update its coordinates (Figure).

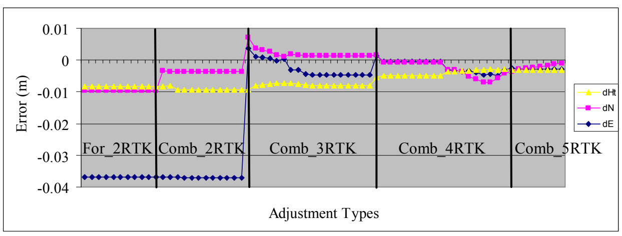

Figure 8. Variation of 'T26' testing point during CUPT

In Figure 8, For_2RTK means that only the forward total station observations with ‘2’ RTK points were used in the adjustment. Comb_2RTK, Comb_3RTK, Comb_4RTK and Comb_5RTK are representing that the forward and backward total station observations with ‘2’ RTK points, ‘3’ RTK points, ‘4’ RTK points and ‘5’ RTK points respectively were used in the adjustment. From Figure , significant differences can be noticed after ‘3’ RTK points are combined in the solution. Additional improvement also noticed as more RTK points added into CUPT. Further trials and results can be found in Taha (2007).

A method that could be useful to improve the overall accuracy is that of using both of the forward and the backward observations. In Test7, these observations were combined in CUPT with the ‘5’ RTK positions. The differences between the ‘truth’ coordinates and the results of the final adjustment performed by CUPT (CUPT/Comb5 solution) for the ‘28’ testing points were calculated and shown in Figure . CUPT results in Test were not compared to the SmartStation results since there is no option available in the SmartStation to provide with one solution for multiple observations.

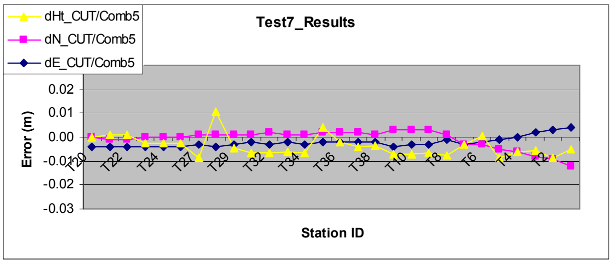

Figure 9. Test7 results

Figure 9 shows that the 3D coordinates achieved by CUPT are very close to the ‘0’ means that the solution is very close to the ‘truth’.

In Test8, the first RTK point, ST10 -used as RO-, and the forth RTK point, ST2, were removed and CUPT combines both of the forward and the backward observations with ‘3’ RTK positions. The differences between the ‘truth’ coordinates and the results of the final adjustment performed by CUPT (CUPT/Comb3 solution) for the ‘28’ testing points were calculated and shown in Figure 10. Note, there is no real time grid coordinates until at least two RTK control are detected.

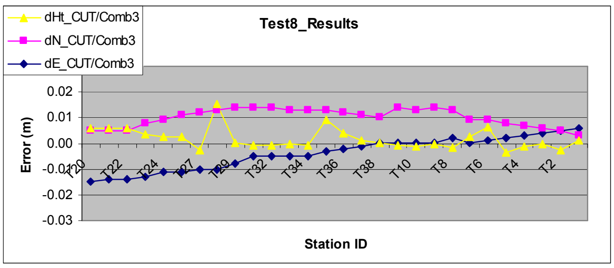

Figure 10. Test8 results

When comparing CUPT results obtained using ‘5’ RTK points (Test7 -Figure -) with those obtained (Test8 -Figure -), it is clear that ‘Test7’ provided better accuracy than ‘Test8’. This is due to use more RTK points in ‘Test7’.

3. CONCLUSIONS

The paper outlines the projects underway at the University of Nottingham, focussing on positioning buried pipes and cables. A multi directional approach is being used, incorporating various techniques such as Inertial Navigation systems, Locatalite and pseudolite technologies, simulating the future GNSS constellations, as well as fully integrating SmartStation data. This type of approach is the only way to enable efficient positioning in such a built up environment application.

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