# Construction Plant Control Using RTK GPS

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**Key words:** GPS, RTK, Plant Control, Construction, SiteVision.

## ABSTRACT

The use of GPS for construction plant control and guidance is a hot topic in the world of geomatics. Research has been underway for many years into this area, mainly based on using such RTK GPS systems on bulldozers. GPS allows real time centimetre positioning that allows the bulldozer's driver to operate the machinery in a semi-autonomous manner.

Research has been underway at the University of Nottingham for a number of years, investigating the use of GPS for such an application. The research focuses on using RTK GPS for both bulldozer and excavator control.

The following paper details the work conducted at Nottingham, using a Trimble SiteVision system. The work conducted focuses on both controlled trials as well as field trials. An extensive series of real life trials have been conducted, whereby a bulldozer, using the system, was used to re-shape a 100m x 50m piece of ground. The work involved, as well as the results are detailed in the paper.

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## 1. INTRODUCTION

The use of GPS in the field of surveying has become wide spread over the last decade. Its uses range from GIS mapping and topographic surveying to large network surveys. With the advent of real-time kinematic (RTK) GPS positioning, the boundaries of possible uses of GPS in surveying and civil engineering has been further extended to include setting-out and real-time mapping. Over the last five years or so, GPS manufacturers have been designing systems which provide guidance for construction plants without the use of stakes or boards but rather taking the design right into the driver's cab. One such system developed by Trimble Navigation Limited is the SiteVision GPS System. This system is designed to provide real-time guidance for bulldozers and graders.

At the Institute of Engineering Surveying and Space Geodesy (IESSG), University of Nottingham, some trials were recently conducted with the aim of performing a complete real-life project using the SiteVision system from start to finish. This allowed a complete view of all preparation and installation work that was required to be obtained. The main aim was to compare how accurately the resulting surface guided by SiteVision met with the intended design surface. This test follows previous research work conducted at the Institute by Dr. Gethin Roberts [Roberts, 1997].

## 2. SITEVISION GPS FOR DOZERS AND GRADERS

Trimble's SiteVision GPS System is designed to provide stake-less horizontal and grade control for bulldozers and graders. The GPS receiver (Trimble MS860) on the bulldozer uses information sent from the base station via a UHF data link to determine the position of the blade in real-time (using OTF integer ambiguity resolution) to within 2 - 3 cm [SiteVision GPS Operator's Manual 2000]. This position is then compared in real-time with the design data that is loaded onto the SiteVision display unit. This is then passed onto the vertical (left and right) light-bars, which indicate to the operator whether the blade is "above", "on", or "below" the design level and also to the horizontal light-bar to provide horizontal guidance.

A complete SiteVision GPS System was donated to The University of Nottingham by Trimble Navigation Europe Limited. The main components of the system are: the Trimble MS750 base receiver, the Trimble MS860 receiver with dual antenna input, the rugged micro-centred antennas and the SV170 display unit (which is a rugged computer) and light-bars. Other parts of the system include the antenna masts, and other brackets and cabling. Radio/modems are also required to transmit and receive data from the GPS base station. Half watt SATEL radio modems were used in this test.

## 3. PRELIMINARY SURVEYS

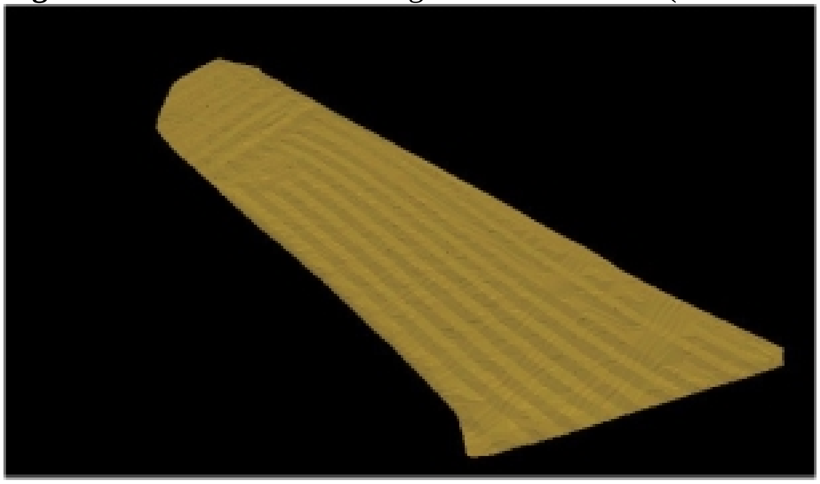
The site for the trials was a field in the village of Hose in Leicestershire. The village hall had acquired a plot of land adjoining its current sports ground in order to extend its sporting facilities. The field was previously part of a farm and still contained the "ridge and furrow" landscape characteristic of farming techniques used in the middle ages. This farming technique developed furrows, some 50 or 60 cm in depth in order to catch and store rain water.

The task definition was to remove the topsoil on the field, level the sub-soil removing the ridge and furrows and then replace the top-soil (which is required for grass seeding). There was also the limitation that it was not possible to take away or bring in any extra soil. All these considerations had to be taken into account when creating the design. Figure 1 shows the site before any grading work was performed. It is possible to see the undulations of the field against the hedge in the background.

**Figure 1:** Field at Hose Before Grading Commenced

A preliminary survey of the site was conducted using GPS. A GPS receiver and an antenna, carried in a backpack were used for this survey. The height of the antenna was measured and then data was collected at 1Hz while walking along and across the ridges. The data was then post-processed and the resulting positions were used in creating a 3-D surface model. The 3D model in figure 2 shows very distinctly the ridge and furrow landscape.

**Figure 2:** 3 D Model of the Original Ground Level (Produced Using n4ce software)



## 4. CREATING A SITE CALIBRATION

SiteVision is designed to work with plane co-ordinate systems only. There is the option to select from certain standard plane co-ordinate systems installed, otherwise a site calibration is required to perform a transformation between WGS84 (used by GPS) and the local site co-ordinate system.

The site calibration was conducted by establishing seven control points on site (at least 3 are required) using static GPS observations. This provided the WGS84 co-ordinates of these stations. The site co-ordinate system chosen was the OSGB National Grid and so the local co-ordinates were obtained using Grid Inquest (www.qualityeng.co.uk) which provides the transformation between WGS84 and OS national grid using the OSTN91 geoid model. If another site system was being used, all that would be required is for a traverse to be carried out to establish the site co-ordinates of the station. Using the 7 control points with co-ordinates in both WGS84 and Site systems, a transformation was performed using the Trimble Geomatics Office (TGO) software. The site calibration information is an essential part of the configuration file which is downloaded into the SiteVision system via a compact flashcard.

## 5. CREATING A DESIGN

The design was created using Trimble Survey Office (an earlier version of TGO). However it can be created using any Computer Aided Design (CAD) software which is able to export the design in 3-d faces DXF format. The DXF data was converted into a TTM (Trimble Tin Model) format using Trimble SiteVision Office. The SiteVision Office software allows design data to be imported from various sources such as a Terramodel project or a Paydirt grid file, and it converts the data into the TTM format. SiteVision Office also allows the user to view the design, view profiles along the design, and transfer the design onto the flash card. It can also lock the data card to prevent accidental file deletion.

During the course of the excavations this design had to be changed as the amount of clay subsoil that needed to be moved was quite large and also due to the fact that the excavation was falling behind schedule. In addition the design had to tie-in with the adjoining football field which in itself was not a perfect slope. This showed one of the advantages of such as system as only a limited delay occurred due to the change. The reason for this was that, while the top half of the field was being excavated, the change in the design for the bottom half of the field was implemented using Trimble Survey Office (TSO).

## 6. INSTALLATION

The SiteVison system was installed on a D5M Caterpillar bulldozer on hire from SINBAD Plant Hire Limited. Figure 3 shows the bulldozer after installation. The bulldozer was also fitted with the BladePro3D Robotic Total Station System (its receptor can be seen on the central mast in figure 3). However due to technical difficulties tests with that system could not be performed.

**Figure 3:** Bulldozer with SiteVision GPS installed


Measurements of the antenna height and bulldozer blade were taken and recorded in the SV170 display unit.

## 7. SITEVISION GUIDANCE

The SV170 rugged computer display unit and the light-bars are the primary means of guiding the operator to the required level. Where an automatic option is available, the system would be connected to the machine's hydraulics and the vertical guidance of the blade would be done automatically. However, the system tested here was a manual system and did not have that option available.

**Figure 4:** The SV170 and the Guidance Light-Bars

Figure 4 shows the SV170 displaying the profile screen and the light-bars which indicate that the blade is above the design grade by up to four times the threshold value (which for this test was set to 0.050 m). The SV170 can display in profile view how far off the dozer cutting edge is from the design level. It also shows the cut and fill values for the left and right side of the blade. A plan view of the site showing the boundaries and contours was also loaded into the SV170 and the display can be toggled between plan, profile and text views.

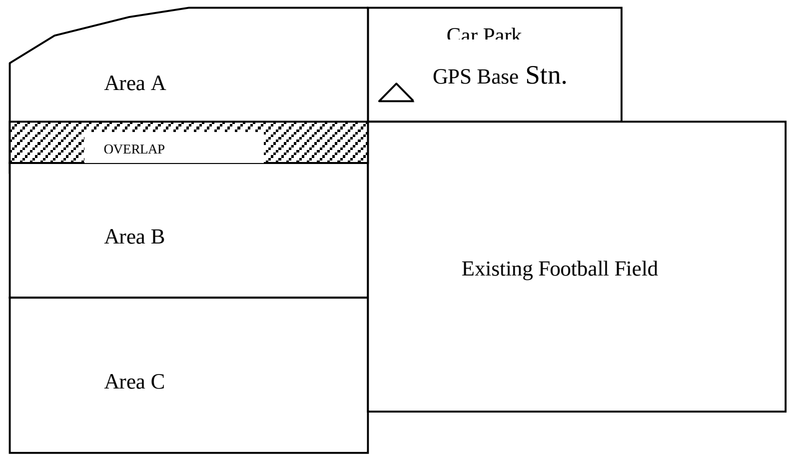
Once the SiteVision was set-up, the bulldozer operator needed minimal input and could focus on the job of moving soil.

## 8. RESULTS

One of the aims of the trial was to assess how precisely, the final surfaces produced by the GPS guided bulldozer compared with the design surface. This was done by taking spot height measurements on the levelled subsoil and topsoil surfaces using a Leica TCA 2003 servo assisted total station with a 360° ATR (Automatic Target Recognition) prism. The accuracy of the measurements taken in standard mode with the $360^0$ ATR prism is quoted as: ±5mm in distance and ±5 mm for the angle (horizontal and vertical) [TPS-System 1000 User Manual].

It should be noted that the accuracy of the system is limited by the type of soil aggregate that is being worked on. The finer the aggregate the better the performance. Therefore the results of the trials are shown for both the subsoil (sticky clay) and the topsoil (loose soil). Also the work was done in three sections with the weather increasingly wet as work progressed. GPS positioning is not affected by the weather, however the soil is, with the clay becoming very sticky and forming large clumps in wet conditions. The results for those 3 segments and the weather effects will be analysed as well.

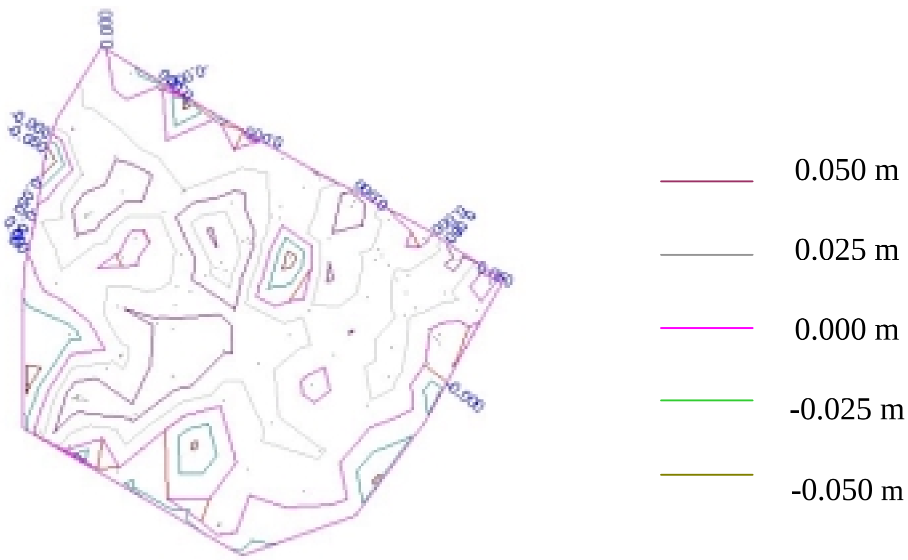
**Figure 5:** A Schematic Map of the Site and some if its Adjoining Areas




**Area A –** The field sloped downwards, this area was at the top of the slope and adjoining the car-park. The weather was dry while working on this section. Its planimetric area is 2,200 $m^2$.

Using LISCAD a height difference contour model was created. This model shows the height differences between the design and the finished surface. The finished surface was created from the total station spot height measurements. The height difference contour model for areas A, B and C's subsoil are shown in figures 6, 7 and 8 respectively.

**Figure 6:** Height Difference Contour Model for Area A-Subsoil.




On balance, the excess of fill required for the area was 39 $m^3$.
**Area B** – Middle of the slope, adjoining the football field. There was a mixture of both dry and wet conditions while working on this section. Its planimetric area is 5,537 $m^2$.

**Figure 7:** Height Difference Contour Model for Area B Subsoil.

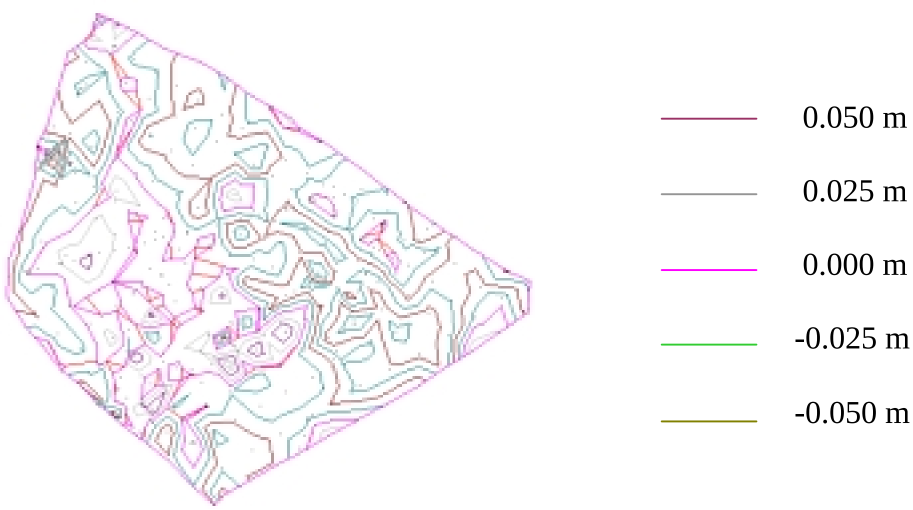

**Shortfalls:** Cut:
Planimetric Area = 541.8 $m^2$
Volume = 6.2 $m^3$

Fill:
Planimetric Area = 4994.9 $m^2$
Volume = 206.7 $m^3$

Balance: Deficiency of fill = 200.5 $m^3$. Therefore, for Area B, 200 $m^3$ subsoil will be required for the surface to come up to the design level.

**Area C –** Bottom of the slope, adjoining the football field and tennis courts. Very wet weather conditions prevailed while working on this section, 6,379 $m^2$.

**Figure 8:** Height Difference Contour Model for Area C Subsoil.




Shortfalls: Cut:
Planimetric Area = 4981.2 $m^2$
Volume = 208.5 $m^3$

Fill:
Planimetric Area = 1397.9 $m^2$
Volume = 25.3 $m^3$

Balance: Excess of cut = 183.2 $m^3$. Therefore for Area C, the removal of 183 $m^3$ of subsoil will be required for the surface to come up to the design level.

Using a 2m x 2m grid, each of the above surfaces were interrogated and a file of the 3D co-ordinates of each grid intersection was produced. The same was done with the design file. A program was written which compared the plan positions and computed the height difference for common points. The results for each section are shown in figure 9. For clarity, the graphs for Area A and Area C have been offset by +0.1m and –0.1m respectively. A $6^{th}$ order polynomial was fitted to the values in each graph to show the trends in the results.

There is a repeated cyclic pattern in each of the graphs which is likely to be the result of two effects. Firstly, as a result of interrogating the surfaces using small horizontal strips and secondly due to the surfaces being rough towards the edges where the topsoil was accumulated.

**Figure 9:** Height Difference Graphs for Area A (dry conditions), Area B (mixed conditions) and Area C (very wet conditions).

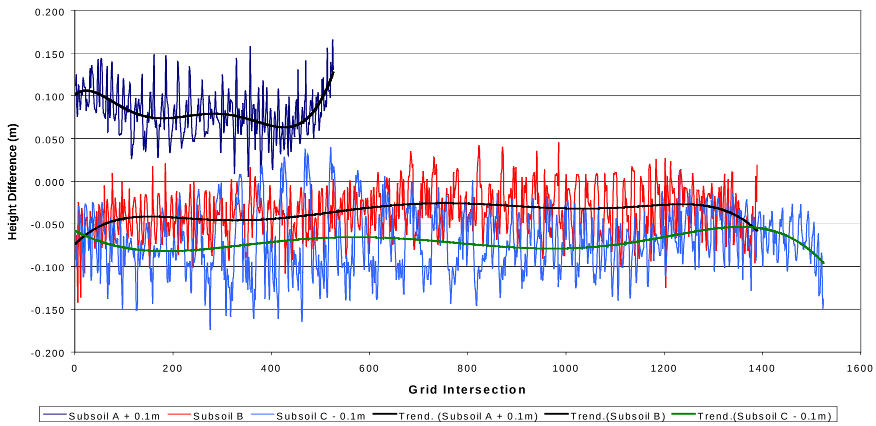



**Table 1:** summarises the results of the subsoil areas .

| | AREA A | AREA B | AREA C |
|---|---|---|---|
| **Average Difference** | -0.019 | -0.036 | 0.029 |
| **Standard Deviation** | ±0.027 | ±0.027 | ±0.036 |

On average the finished levels of areas A and B lie below the design surface while Area C on average is above the design. Area A which was graded in dry conditions was the closest to the required design surface. Area C which was graded under very wet conditions exhibited the largest variations. This was because the clay subsoil formed large clumps in increasingly wet conditions, hence it was difficult to achieve the smooth design surface.

The topsoil was replaced using an offset of +10cm above the initial design surface. The same analysis as above was repeated for the topsoil in each area, the results are shown in figures 10 and 11. There are no topsoil result for area A, as the project specifications required that Area A be left at the sub-soil level.

**Figure 10:** Height Difference Graph for Area B showing the Topsoil and Subsoil Results

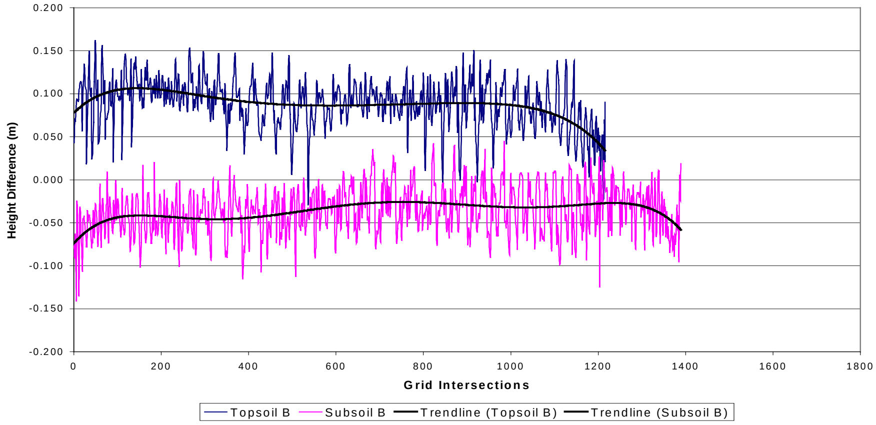



**Figure 11:** Height Difference Graph for Area C showing the Topsoil and Subsoil Results

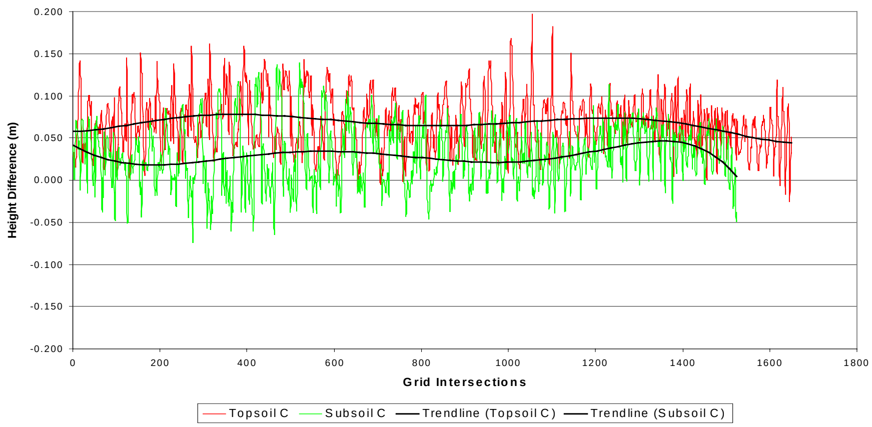



Table 2 summarises the results of the topsoil for each area. There are no topsoil result for area A, as the project specifications required that Area A be left at the sub-soil level.

**Table 2:** Topsoil Results

| | **AREA A** | **AREA B** | **AREA C** |
|---|---|---|---|
| **Average Difference** | N/A | -0.012 | -0.032 |
| **Standard Deviation** | N/A | ±0.028 | ±0.031 |

The finished surface for the topsoil in Area B was on average about 1cm below the design. While Area C on average was 3cm below the design. From the graphs it can be seen that the requirement for a 10cm separation between the topsoil and subsoil was better achieved in Area B than in Area C. The bulldozer operator working on Area C's topsoil was a less experienced operator and this may also have influenced the results.

## 9. USEABILITY

The SiteVision system once installed and configured is simple and straight forward to use. The operator can change the display screen views from profile to plan or text view using a single soft-key. The preferred view on this job was the profile view. Two bulldozer operators worked on the project. The first was a new operator and the second was an experienced operator. The way the drivers used the system differed slightly. The first operator used the SV170 profile view to get an estimate of how far off the design the blade was, and then used the light bars for the finished grade. On the other hand the second more experience operator levelled the ground roughly by sight and then used the light-bars for the finished grade.

As stated earlier the system used to carry out this test was a manual system however automatic versions of the system are available. Both operators who were experienced at using an automatic laser levelling system, commented that an automatic system would be a lot better, especially for long jobs. The other reason for having an automatic system is that there is consistency in the results as it is not driver dependent. The quality of the finish depends on the reaction time of the driver in following the light-bars. This extra latency is reduced in an automatic system.

## 10. MEET THE ANCESTORS

During the excavations a local amateur archaeologist visited the site with a metal detector and was able to unearth a wide range of items ranging from the present day to the roman occupation of Britain. Some of the items include 16$^{th}$ and 17$^{th}$ century coins, buckles, arrowheads, musket balls and bronze roman coins which depict the Roman victory over the German tribes and date back to between AD 10 and AD 60. Figure 12 shows a photograph of some of the items found on the site.

**Figure12:** Some of the Coins and Items Found on Site

The field has been in constant use over the last 2000 years and maybe in 2000 years time future generations will look back with amazement at the ancient technology that was used in 2001 AD to create a sports field.

## 11. CONCLUSION

The SiteVision GPS System is able to provide real-time guidance for a bulldozer and produce a finished surface which on average is within 3 cm of the design. The accuracy of the System is however, affected indirectly by external factors such as soil type and weather conditions. The tests that were carried out in dry conditions and on the loose topsoil showed the best results where the finished surface was on average 1 cm away from the design. Larger variations occurred, however they were predominantly at the edges of the work areas. Driver experience may also have influenced the poor results in Area C's finished topsoil level. However, an automatic system would not only reduce driver fatigue but also but also allow for more consistent results that are not driver dependent.

The trial was conducted in an open field with unobstructed sky view of 6 - 8 satellites most of the time. However, on sites with limited sky view such as in deep open pit quarries or sites close to tall buildings or bridges, access to such a number of satellites may not be possible, thus limiting the systems accuracy and reliability. Integration with future satellite constellations such as Galileo, or with inertia navigation systems (INS) or pseudolites could overcome these problems.

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**Oluropo Ogundipe** gained a BSc (Hons) degree in Surveying and Land Information from the University of the West Indies in 1996. She then worked in the London area within the engineering surveying sector until starting her PhD in 1999 at the University of Nottingham. The focus of her research is in the use of Real-Time Kinematic (RTK) GPS on Construction Plant. She is a student member of the Institution of Civil Engineering Surveyors.

**Professor Alan Dodson** is Director of the Institute of Engineering Surveying and Space Geodesy (IESSG), and Dean of the Faculty of Engineering. He has a BSc in Civil

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