The Automation of Piling Rig Positioning using Satellite GPS

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ABSTRACT

The paper is in two parts:

Part one describes the Stent Automatic Pile Positioning and Recording system (SAPPAR) which was launched in November 1994. The system utilises a Trimble satellite global positioning system (GPS) to assist rig drivers to accurately position the rig over a pile position without the need for setting out. Advantages of the system include: Cost savings by removing the need for site survey staff. Faster set-up times over pile positions.Increased accuracy - the system can reliably position the rig to within $\pm$ 25 mm. Removal of problems resulting from damage to setting out pins. Constant monitoring of pile position. Links to CAD for data input and as-built drawings.

Part two describes a further development of the system in collaboration with Lancaster University and Casagrande, the Italian rig manufacturer. The aim of the research is to fully automate the final positioning process. This represents one of the first uses of GPS for real-time automation. The system hardware components include: Ultra-compact PC104 processor cards for a compact and robust embedded system. Minimum sensing on the rig to minimise cost and maximise robustness. Limit sensors to facilitate on-board safety.

The control algorithms were developed on a fifth-scale model in the laboratory and two distinct approaches are described. The importance of careful consideration of safety issues is stressed.

1. THE SAPPAR SYSTEM

The construction of both bored and driven large-diameter piled foundations are now commonly constructed using fully hydraulic piling rigs, as opposed to the more traditional crane-mounted technology. Fully hydraulic rigs provide the opportunity for the addition of enhanced automatic control, and this paper describes the first two steps in improving rig performance and efficiency.

In November 1994 Stent Foundations Limited launched their Stent Automatic Pile Positioning and Recording System (SAPPAR). The system involves the following components:

- A Trimble 4000 Series differential, real-time kinematic, on-the-fly, satellite GPS receiver mounted in the cab. These terms and the GPS system are described in more detail in the next section.
- A satellite receiver antenna mounted on the top of the rig mast. The extra height gives optimum receiver performance even when working in relatively congested urban sites.
- A two-axis verticality sensor mounted on the rig mast.
- A flux-gate compass to provide information on rig orientation.
- A hardened PC computer in the cab running a specially customised version of Trimble's "Hydro" software which was originally developed for the offshore industry.
- A simple keypad and LCD display for the user interface.

The overall system data-flow context diagram is shown in figure 1

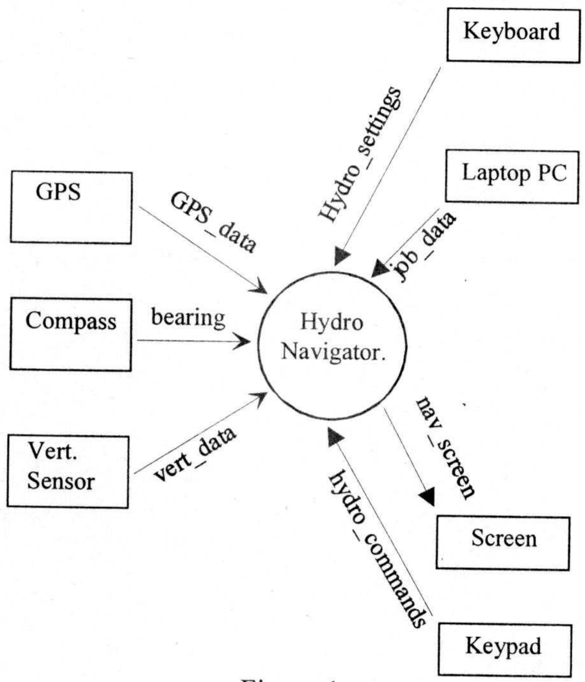

Figure 1
System context diagram

The operation is as follows:

1. The site boundary details and pile identification numbers and coordinates are imported into Hydro. The coordinates may be with reference to a local site grid.
2. The rig driver selects a particular pile number and it is highlighted on the screen together with a representation of position and orientation of the rig.
3. The driver steers the rig towards the designated pile and his position on the screen is constantly updated. As he approaches the pile the scale of the screen changes, zooming-in on the pile and presenting the driver with a bulls-eye type target.
4. The driver manipulates the rig to within 500 mm of the pile using the vehicle tracks, and then carries out the final positioning using the hydraulic actuators to control mast verticality, slew position and parallel motion. In this way the mast can be positioned to within $\pm$ 25 mm
5. The computer display informs the driver when he is within tolerance.

The system has been well-tried under site conditions and has been proved to offer the following advantages:

- Cost savings by removing the need for site survey staff.
- Faster set-up times over pile positions.

- Removal of problems resulting from damage to setting out pins.
- Constant monitoring of pile position (unlike conventional setting-out where the reference pin is lost once piling commences)
- Potential for direct importing of pile data from CAD drawings.
- Significant scope for the data-logging and subsequent recording and processing of site performance information.
- The system can be progressively retro-fitted to existing hydraulic piling rigs.

2. SATELLITE GLOBAL POSITIONING

In recent years there has been a breakthrough in the performance of GPS systems and in the view of the authors this development now represents one of the greatest opportunities for construction automation and robotics. Not only can centimetre level accuracy be achieved, it can be achieved on moving objects with update rates of several times a second. For the benefit of delegates this section briefly describes the operation of such GPS systems.

Most commercial GPS systems use the U.S. Defense Department system of 24 SATNAV satellites (although there is an alternative Russian system of GLONASS satellites). These orbit at about 20 000 km, and at any one time, somewhere between five and eleven satellites are in view from anywhere on earth. The basis of positioning is the very accurate measurement of distance from the terrestrial receiver antenna to several satellites. This distance is determined by the time taken for a signal to travel from the satellite to the receiver. Knowing the distance from one satellite enables the position to be fixed to the surface of a sphere centred on the satellite. Knowing the distance to two satellites enables the position to be located on the surface of a circle which is formed by the intersection of two spheres. Knowing the distance to three satellites enables the position to be reduced to two points on the circumference of the above circle. Knowing the distance to four satellites, in theory, enables the coordinates of a specific point in space to be determined, however the measurement of the distance is subjected to numerous errors and so modern systems usually like to see about six satellites and use sophisticated averaging techniques to arrive at a best estimate of the position.

A complication arises from the fact that the satellites give out signals in two codes on different frequencies. The C/A-code (Coarse Availability code) is the signal used by yachtsmen and cheap hand-held receivers used by climbers. The P-code (Precise code) is subject to what is known as "selective availability". Deliberate errors are introduced which can only be decoded by authorised military users. Thus the accuracy of the signal is eroded for ordinary users. A single receiver will currently provide about a one metre accuracy with the military P-code and about a hundred metre accuracy with the A/C-code, although this can be improved upon if the receiver is given plenty of time to settle.

The big breakthrough in accuracy comes with the use of two interconnected receivers. One receiver (the base station) is set-up over a known survey point and is thus capable of calculating the difference between its known position and that indicated by the satellites. This difference is then transmitted via radio modem to the other receiver (the rover) which makes the same corrections to its position. High quality systems also make use of phase difference ambiguities between the two code signals. This is how centimeter-level accuracy is achieved. The distance between the base station and the rover is currently limited to about ten kilometers, which ensures that the two receivers are looking at the same set of satellites and are subject to the same atmospheric errors. One base station can serve several rovers which means that a strategically placed base station could provide for a whole city.

The term "real-time kinematic" refers to the ability to update rapidly the position of moving receivers and is obviously a requirement for control applications. When a receiver is first switched on it takes some time to initialise itself (currently about two minutes). If a receiver loses contact with the satellites for any reason then it must re-initialise. The term "on-the-fly" refers to the ability of a receiver to re-initialise without the need to return to a previously known point which was a feature of earlier receivers.

3. AUTOMATIC POSITIONING

3.1 System hardware

Following the success of the GPS it was decided to further develop the system by automating the final positioning and the Construction Robotics Group in the Engineering Department at Lancaster University were approached. Even when the driver has manouvered the rig to within half a metre of its target position it can still take about ten minutes to get the mast both perfectly vertical and within the required positional tolerance. The aim was to at least halve this time. For safety reasons it was decided that the rig tracks should remain under the control of the driver, but that the final adjustments to the verticality, slew and parallel motion rams should be under computer control. It was decided to install the system on a new driven cast-in-situ hydraulic rig and the manufacturers -Casagrande of Italy - have been fully cooperative in fitting the appropriate valves and wiring at the manufacturing stage. The research is partly financed by the U.K. Engineering and Physical Sciences research Council (EPSRC) under the Innovative Manufacturing Initiative (IMI).

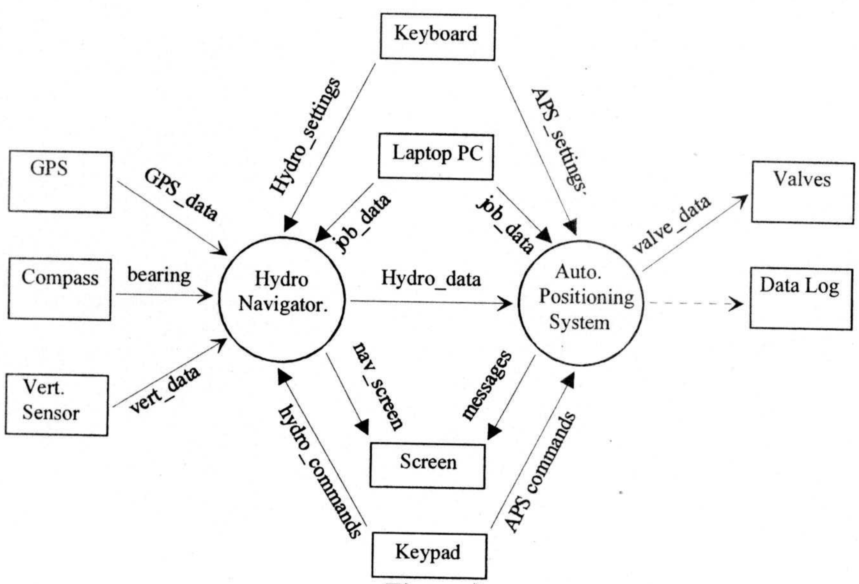

Figure 2

Auto-positioning context diagram

It was decided to retain the Trimble "Hydro" software in the automatic positioning system, but its extensive PC memory demands (both base and higher) mean that it cannot be run concurrently with the control software on the same PC. Consequently two PCs are required on the rig. The two PCs communicate via a serial RS232 link. The system context diagram is extended as shown in figure 2, where each circle represents a PC computer.

For reasons of safety and ease of use it is regarded as important that the user interface remains simple with only one screen and keyboard. It was therefore decided to dispense with the previously used hardened laptop PC and to switch to a more customised solution. The ultra-compact PC104 standard was adopted. These are PC computers in the form of circuit boards measuring less than 100 mm square. They can be combined with other interface cards such as extra RS232 serial port cards and digital to analog converter cards by means of a stackable bus system. A typical stack is shown in figure 3.

Two PC104 stacks were used. A single LCD flat panel display was mounted in the cab.

3.2 The development model

To aid development a fifth-scale model of the rig was constructed in the laboratory. Although of much simplified construction it included the four key degrees of freedom that had to be controlled.

The GPS positioning could not of course be used indoors, so a system of strings was connected to the top of the model mast which caused potentiometers to rotate when the mast moved. Software then converted the movement into an X-Y position, thus creating pseudo-GPS. The aim of the controller is to make the mast vertical and then position it accurately over a designated point on the floor. A laser pointer was fixed to the mast in such a way that it projected a point on the floor.

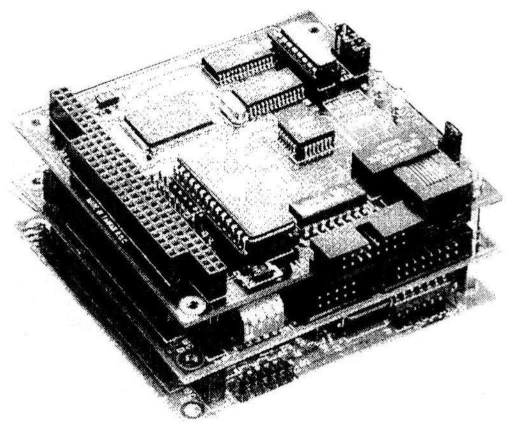

Figure 3
Typical PC104 stack

3.3 Control issues

The conventional approach to the problem is as follows:

1. Fix sensors on all the degrees of freedom
2. Read the GPS position
3. Knowing the geometry of the rig components calculate the required changes in angle at all joints
4. Drive the joints to the new angles
5. Check the GPS and repeat

However this conventional approach was not followed. As an alternative the control is based entirely on the existing GPS and verticality sensor. No additional sensors were added to the rig joints. In other words the GPS signal is used to provide the feedback for real-time control. This has the following advantages:

- It reduces the need for expensive, rugged sensors which often produce problems in harsh environments.
- It means that small changes in rig geometry can be tolerated without the need to revise software.

A disadvantage is that the speed of movement must be slow enough to cope with the relatively slow update rate of the GPS data. Two types of controller have been evaluated. The first is known as a PIP controller (proportional integral plus). A dynamic model of the rig is obtained by measuring the response of it to a series of pseudo-random inputs. The model is them used to design optimum values for the control feedback parameters. This approach has been successfully tested on the model and has achieved accurate positioning within thirty seconds.

The second approach is a simple proportional rule based controller with a ramp at the start to provide smooth movement. More work needs to be done to fully test this approach, and then a decision will be made as to which approach to adopt for the prototype system.

3.4 Safety issues

Safety has been given careful consideration throughout. The principal problem lies in the fact that the rig can become unstable, and topple, if the mast is moved outside a complex safe envelope. Some examples of hazards that have been considered are:

Operational hazards	Driver engages auto when an obstruction prevents free movement of the mast.
	Driver engages auto when the mast is too out of vertical.
Hardware hazards	Electro-hydraulic valve sticks open.
	Digital to Analog converter fails.
Software hazards	Auto engages when the mast is too far away from the target
	Controller drives the mast the wrong way
Operating system hazard	Controller hangs-up waiting for a damaged serial input to respond
Integration problem	GPS looses lock and freezes output values

3.5 Future work

Work will proceed on two main fronts. Firstly consideration will be given to extending automation to the piling process itself. Several areas have been identified where it is believed feedback control can improve the performance of bored pile construction.

Secondly effort is being put into exploiting the benefits of IT by taking advantage of the computer in the cab. Work is progressing to link input data to CAD and also to log selective site data so that the business process can be improved.

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