RiGHt: River Level Monitoring using GPS Heighting

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BIOGRAPHIES

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Roger Moore is Senior Scientific Officer, and Head of the Environmental System Section, of the Institute of Hydrology. He holds a BSc degree in Civil Engineering from the University of Edinburgh and an MSc in Hydrology from Imperial College London.

INTRODUCTION

The RiGHt project, ‘River Level Monitoring using GPS Heighting’, has been carried out over the last two years. This was a collaborative project involving the University of Nottingham, Science Systems (Space) Ltd and The Institute of Hydrology, and was supported through a grant awarded by the British National Space Centre (BNSC), under the UK Government’s Space Foresight Programme. The objectives of the project are to address the problems of continuously monitoring river heights at any location in the World, using a remote floating platform.

The RiGHt project has developed a space-based real-time river level monitoring system using the real time kinematic GPS, satellite communications and a Geographical Information System (GIS). A GPS receiver was mounted on a river buoy together with other sensors for attitude determination of the buoy. Communication satellites, or terrestrial communications may be used for the real-time data-link between the buoy and a GPS reference station. A novel 4-D GIS was used to visualize real-time water level information and analyze and manage other hydrological information.

Full trials of the complete system, including the prototype buoy, the communications systems, and the GIS software interfaces, were carried out in early February 2000. A site was selected on the River Trent, in Nottingham, which is very close to the Colwick river gauging station. The gauging station building provided ideal accommodation for the GPS reference station and the communications equipment, and the necessary power and security. For practical convenience the GIS packages and interfaces were also operated close by, but could have been at a distant location. All aspects of the river monitoring system were operated in real-time, although terrestrial communications were used for these trials, rather than the satellite link. The trials demonstrated the capability of the RiGHt system to determine river levels, in real-time, and to a centimetric level of accuracy. The full results from these trials are presented in this paper.

PROTOTYPE SYSTEM DESIGN

The prototype GPS buoy river level monitoring system consists of following four main components:

- A river buoy with a GPS receiver, pressure and tilt sensors, and an autonomous power supply
- A two way data-link (terrestrial) to a nearby GPS reference station
- A GPS reference station with satellite or terrestrial communications capability
- A central station with the hydrological database and the integrated GIS.

The river buoy is a key part of the system. The prototype river buoy consists of a simple wave-rider marine buoy (modified by the Proudman Oceanographic Laboratory), which has been adapted to accommodate a geodetic GPS receiver, and other sensors. A dual frequency receiver is used, which has the capability of two-way communications and on-board GPS real time kinematic (RTK) processing. The receiver is mounted inside the buoy and a marine GPS...
antenna is mounted externally. In addition a small low power UHF data link is used to communicate with the reference receiver, which is based on the river-bank. The buoy operates autonomously and so battery power is provided, which is sufficient for the prototype. Clearly, a longer-term deployment would require a more careful review of the power requirements, and perhaps the addition of solar power. In order to correct the determined height for the attitude of the buoy, and for the changes in freeboard, a tilt sensor and a pressure transducer are also mounted in the buoy. The data from these auxiliary sensors is integrated into the GPS data message transmitted to the reference station.

The GPS reference station is located on the river-bank, and this provides the reference GPS data for the differential carrier phase computation. A compatible dual frequency geodetic receiver is used, and the antenna position is determined using conventional static GPS carrier phase positioning. Ideally, the separation between the reference station and the buoy should be kept as small as possible, but separations of a few tens of kilometers should not significantly degrade the results. It is feasible that in a practical application several buoys could be associated with a single reference station. At present both GPS receivers are operating at a 1-second data rate. For pragmatic reasons it was decided that, in the prototype system, the data from the reference station would be transmitted to the buoy, and the GPS processing take place within the buoy. It is envisaged that the processing would usually take place at the reference station.

The resulting position and height of the buoy, after correction for tilt and freeboard, are transmitted to the central facility using a commercial data link. The prototype system has integrated both a terrestrial packet transmission facility and a satellite communication link. The exact route has no effect on the overall system architecture, and is totally transparent to the user. The data rate is comparatively low, as only time tagged coordinates and height are transmitted, typically once every 15 minutes.

The central facility, in this case the Institute of Hydrology, receives the data messages from the reference stations and the Hydata software automatically formats the time-tagged positions for input into a novel 4D Geographical Information System (GIS). This was initially developed, by the Institute of Hydrology, for the LOIS (Land Ocean Interaction Study) project and provides an ideal medium to integrate the river heights determined by the GPS buoy with other hydrological and environmental data. The novelty of the GIS arises because of the unique data structure at its core. This handles data with a where, what, when data structure, which is not geographically based, although geographical coordinates may be stored as an attribute (a what at a particular where). As a result the LOIS GIS is optimised to handle time varying data sets, such as changing river heights.

To incorporate river heights derived from multiple buoys and reference stations into a single GIS, there will be a need to calibrate vertical datum differences for the reference stations. The datum error can be reduced if a high precision geoid model is available, or a precise survey of the relative heights of the reference stations is conducted. This is an inherent problem to all height measuring systems. However, to simply measure changes of river height at a single location, the relative heights of different locations are not important.

**INITIAL TESTS AND PRELIMINARY RESULTS**

To initially test the potential use of RTK GPS and GLONASS positioning, several simulation trials were carried out by the University of Nottingham. A number of Ashtech ZXII dual-frequency GPS receiver were used along with two GG24 single frequency GPS/GLONASS receivers. Initially a simple test rig was developed and constructed by the IESSG and used for a series of simple trials on the University Campus.

A test rig was constructed from the tripod of a survey beacon, about 4 meters in height. From this a platform was suspended using elastic (bungee) cord. Two GPS (Ashtech ZXII) choke ring antennas and two GPS/GLONASS (GG24) marine antennas were mounted on the platform. By disturbing the platform from its rest position a rocking and swaying motion could be induced, which is similar in amplitude and period to the anticipated motion of the buoy in a real river. The configuration of the test rig is shown in Figure 2.
During the trials GPS data was recorded at 0.2s intervals and GPS/GLONASS at 0.5s. In all the trials the relative distances between these antennas are fixed, and this provides a useful check on the quality of the data and processing. The two reference station choke ring antennas were located on the roof of the IESSG building, which was only about 50m from the trial site. All choke ring antennas were of the same make and type.

A second trial was conducted using the survey boat of the Port of London Authority. The trials lasted for three days and took place a Gravesend on the River Thames. Multiple GPS receivers, all with Ashtech choke ring geodetic antennas, were mounted on the small survey vessel, which was surveying along the river or, for some time, moored alongside a tide gauge site. By using two of the receivers a fixed baseline, of known length, was again obtained, and this was used to check the quality of the GPS carrier phase data and processing. The baseline length was 3.588 m. In these trials an external comparison was also possible because of the close proximity of the tide gauge. Three consecutive days of observations were made from 10-12 November 1998. Each observation period was about 13 hours in duration. The RTK GPS derived baseline length was compared against its true value while the survey boat was cruising up and down the river, and the river height was compared with the tide gauge measurement whilst the boat was moored overnight.

The results shown in Figure 4 again demonstrate the potential accuracy of the RTK GPS approach in a harsh river environment. The agreement between the average GPS determined baseline length and the known value is of the order of a few millimeters, with only small gaps in the data. No significant cycle slips were found in these data sets, although there were periods of increased noise in the data.

The trajectories of the four antennas on the moving platform were calculated independently, using the differential carrier phase measurements between the receivers on the roof (static) and the receivers on the platform (kinematic). The distance between pairs of antennas, on the platform, were calculated at each observational epoch. The derived length between the two GPS antennas is shown in Figure 3. This length is fixed and so should be constant (at 0.442m). Once the GPS processing has resolved the carrier phase ambiguities the RMS of the differences in baseline length is about 8.2 mm. A period of about 1.5 minutes was typically required for initialization. For certain periods, GPS time 209720–209900 and 210290–210470, the accuracy of the length between the antennas is better than 3.5 mm. In addition to the natural vibration of the platform, three large movements were induced, at about three-minute intervals (around epochs 209900, 210080 and 210260). There was a swing of about 1-2 m in 0.5 seconds for each disturbance. These are clearly shown in the figure. The baseline length results from the test rig show potential millimeter precision. However, it is clear that there were undetected cycle slips in the results, especially during the second and third moves, from 210080 to 210260 seconds. In these trials the cycle slips were probably caused by the rapid change of the position, but similar effects could also result from multipath or obstructions in a real river environment.

The trajectories of the four antennas on the moving platform were calculated independently, using the differential carrier phase measurements between the receivers on the roof (static) and the receivers on the platform (kinematic). The
these trials was not processed in real time, but after the completion of the trials. However, real time processing was simulated in the laboratory. The data was processed using both Ashtech Office Suite (AOS) and the IESSG NOTF program, which is a component of the Nottingham GAS software package. No phase centre variation models were applied. Both software packages give comparable results, at the sub-centimetre level.

**FULL SYSTEM TRIALS**

Full trials of the complete system, including the prototype buoy, the communications systems, and the GIS software interfaces, were carried out in early February 2000. A site was selected on the River Trent, in Nottingham, which is very close to the Colwick river gauging station. The reference station GPS antenna was mounted on the roof of the gauging station building. This point had been previously surveyed, by static carrier phase GPS, with respect to a continuously operating GPS reference station at the IESSG building on the university campus (some 8km away). The difference in height between the GPS antenna and the river gauge bench mark was measured by conventional spirit leveling. During the trial the reference station GPS receiver, the PC, and the packet radio communications link were operated close to the building. A single data cable ran to the buoy, which was flexibly anchored to a structure in the river. For practical reasons the GIS, and receiving radio modem, were positioned inside the building, but could have been located at a completely remote location. The river gauge readings were recorded by the Environment Agency.

![Figure 4](image-url)  
**Figure 4**  
Differences between the GPS Baseline Length and its True Value

Figure 5, illustrates the comparison with the tide gauge record for about a 12-hour period. During this trial a tidal range of about 4.5 m was experienced. The level of agreement is consistently better than 1 cm, throughout the 12-hour period of the trial. These trials were conducted with the close co-operation of the Port of London Authority, under a separate project on the implementation of GPS and WGS 84 in marine navigation.

![Figure 5](image-url)  
**Figure 5**  
GPS Heights compared with Tide Gauge Height

The results were very encouraging. Not only did the GPS baseline results achieve a high accuracy when compared with the fixed baseline length, but also the GPS river heights compared extremely well with the external tide gauge measurements. The overall quality of the GPS data was very high and has caused few processing problems, despite a number of obstructions surrounding the river. The data from

![Figure 6](image-url)  
**Figure 6**  
RiGHt River Buoy in River Trent

The chart in Figure 7 shows the results from the trial, for two and a quarter hours. The river heights from the buoy, at one-second intervals, were averaged over each 15 minutes period, before transmission to the GIS. These were synchronised with the 15-minute levels from the Colwick river gauge. The oscillating tendency of the RiGHt levels, is not as periodic as it may first appear, but does require further investigation. It is possible that the RiGHt buoy was
sensing the correct river level, which may be being smoothed out by the river gauge. It has been suggested that the natural pulse of the river could be a cause, but this can not be confirmed without a more thorough study, and further controlled trials. There is also an apparent bias between the RiGHt levels and the EA levels, with the former being lower than the latter. However, the agreement of these raw results is remarkably good. The root mean square (RMS) difference is 9.8mm and the maximum difference 18.0mm.

Figure 7 RiGHt Trials Results

A systematic bias of -7.6mm has been determined and this has been removed from the raw differences. Small errors in determining the complex relationship between the various height systems could easily cause such as small systematic difference. Again, a more controlled trial would be needed to ascertain the veracity of this assumption.

Figure 8 shows the agreement between the EA and RiGHt river levels after the removal of the systematic bias. The RiGHt levels now have a more scattered appearance about the smooth EA trace. The RMS difference between the two series of river heights is now 6.2mm, with a maximum difference of 10.4mm.

CONCLUSIONS

The RiGHt River Level Monitoring System has been developed and successfully demonstrated through a series of trials, culminating in the final full trials in the River Trent. The agreement between the EA gauged river levels and the corresponding river level determined by the RiGHt buoy was of the order of 1cm. The root mean square (RMS) difference between the two series was 9.8mm and the maximum difference 18.0mm. A small systematic bias of -7.6mm was determined between these two series of river levels. After the removal of this bias the RMS difference was 6.2mm, with a maximum difference of 10.4mm. The initial goal of the RiGHt project was to achieve an accuracy of 1cm in the determination of river heights. The results from the full trial have shown that this ambitious target has been successfully reached. More extensive trials, over a longer period and in a more controlled environment are required to fully validate the expected and repeatable level of performance of the RiGHt system.

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