The Potential for Archaeological Mapping Using GPS and Satellite Imagery

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BIOGRAPHY

Dr Peter Dare joined the University of New Brunswick as an Associate Professor in August 2000. His main areas of expertise are Geodesy, GPS and Operational Research. Previously he had been in the School of Surveying at the University of East London, England. Before that he worked in the UK for Hunting Surveys Ltd and D J Herriott Ltd.

Peter is a member of the American Geophysical Union and the UK Operational Research Society. He is a Fellow of the Royal Astronomical Society, a Fellow of The Royal Institution of Chartered Surveyors and a member of FIG working group 'Reference Frames in Practice'.

ABSTRACT

Merv, in Turkmenistan, is one of the oldest and most completely preserved cities along the Silk Routes in central Asia. The remains span 4000 years of human history. It was a key city in the trade routes between Europe and India and was declared a World Heritage Site in 1999. Many buildings, dating back more than 2500 years still exist on the site, and archaeologists have been carrying out fieldwork on the site since 1992 under the auspices of the International Merv Project (IMP). The IMP was initiated mainly due to a rising water table combined with a rising population: together these pressures threatened the buildings. This paper details the approach taken to provide a GPS geodetic control framework for current and future archaeological fieldwork.

The GPS campaign took place in September 2000. The control network was linked to the International Terrestrial Reference Frame (ITRF) by use of data from the International GPS Service. By linking the network to the ITRF, the coordinate system can be re-established in the future should the monumentation be destroyed. Processing has been carried out using Leica's SKI-Pro software. Results show that an accuracy of approximately 20 cm is achievable processing vectors of 2000 km in length. This data will be reprocessed later using the University of New Brunswick's scientific GPS software package DIPOP.

The primary purpose of the control provision was to determine coordinates of visible Ground Control Points (GCPs) for satellite imagery to be obtained in April 2001. The satellite imagery will then be used to create a base map. The base map will enable isolated archaeological mapping information to be combined into one common spatial framework. This paper therefore also discusses selection and coordination of the GCPs.

INTRODUCTION

In 1992, the International Merv Project (IMP) was created to carry out a detailed archaeological study of Merv. Merv (now called Mary) in Turkmenistan is one of the oldest and most completely preserved of the oasis cities along the Silk Routes of central Asia: Merv's history goes back over 4000 years. It was known as a centre of learning as well as commerce and the Islamic scholar Omar Khayyam wrote several works on mathematics while resident there. The IMP, established by the Institute of Archaeology at University College London, England, has been visiting the archaeological site since 1992 and details of the archaeological remains are given in Herrmann [1999]. The latest report on the archaeological fieldwork is in Herrmann et al. [2000]. The IMP was established as there were, and still are, major threats to the archaeological remains. Made principally from mud brick, these threats come from:

- An increased population near to the site.
- A rising water table eroding the base of the monuments.

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- Continued weathering slowly eroding the monuments.

All these threats are visible in Figure 1.

Figure 1. Threats to the archaeological remains.

The Merv site is particularly important as, unusually, the different ages of settlement are reflected by different horizontal locations on the ground, whereas it is more usual for the depth of the remains to reflect the age of the settlement. This horizontal variation in age is shown in Figure 2.

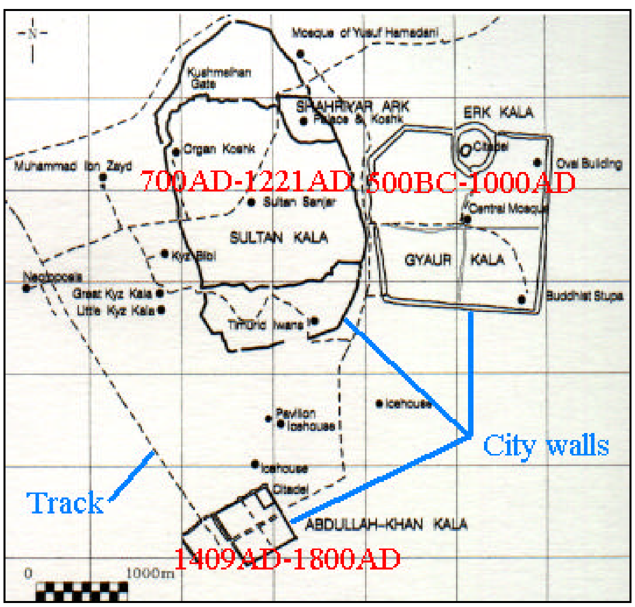

Figure 2. Layout of the Merv site (after Herrmann and Petersen [1997]).

The movement of the population was due to a number of factors given by Herrmann [2001] and documented in Herrmann and Petersen [1997]. The ancient city of Gyaur Kala with its citadel Erk Kala (together occupied from about 500BC-1000AD) was quite deep, about 18 m in some locations, and coping with water must have been difficult. The centre began to have industry: thus it became crowded and smelly. So, about 700AD, people began to settle in the suburbs, around the next canal to the west, where it was more pleasant. And that was the beginning of Sultan Kala. The Abbasid, Abu Muslim then deliberately moved the government offices to the new site. Approximately 100 years later Sultan Malikshah decided to fortify Sultan Kala with walls.

Sultan Kala was vast. However, after a number of attacks by Mongol armies it was virtually deserted from 1221AD. Later, Shah Rukh decided to build a fine new fortified city: Abdullah-Khan Kala. This was occupied from about 1409AD-1800AD.

The importance of Merv is reflected by it having achieved the status of a UNESCO World Heritage Site in 1999.

MERV ARCHAEOLOGICAL CHALLENGE

The IMP has carried out an assortment of investigations during their site visits. These investigations - including fieldwalking, geophysical surveying, detailed excavation and surveying of standing monuments – have been carried out on local grids. These grids have been related to topographic and structural features to varying degrees of accuracy. The challenge was to provide a mechanism by which all these investigations could be brought together under one spatial framework valid for the whole site. In addition, any required fieldwork had to be completed by the middle of October 2000. This is because the 2000 period of fieldwork would conclude in October 2000, and there was no guarantee of funds to allow a visit in 2001.

ARCHAEOLOGICAL COLLABORATION

Collaboration with archaeologists is not new, and a variety of techniques have been adopted to solve particular archaeological problems, both on land and in water. McAnany [2000] describes how terrestrial techniques plus GPS helped map Maya sites (established approximately 1000BC) in the heavily wooded Sibun Valley of Belize.

The underwater mapping of remains in Egypt was carried out in the mid 1990's and is reported in Medard [1997] and Staudacher [1997]. Three techniques have been used to map the remains: traditional total station with reflector, an innovative system using an underwater base with mobile pointers and RTK GPS. This mapping was to attempt to establish whether or not remains on the sea floor were that of the 135 m high Lighthouse of Alexandria erected during the period 283BC-246BC but slowly destroyed by earthquakes until its final destruction in 1326. A more traditional combination of total station plus reflector was used to survey shallow underwater remains with an age of up to 5000 years in Greece [Sprent, 1994].

GPS-only solutions to archaeological mappings have also been carried out. Dare [1994] describes how GPS was used in an estuary near Maldon, England, to map fish traps established by the Saxons between 657AD and 920AD. GPS was necessary due to the limited access times to the site, and the historical sensitivity of the site; this meant that no permanent fixtures could be left on the site between visits to carry out the fieldwork. The mapping was required to aid the development of a management plan of the estuary. Rauxloh [2000] explains how and why GPS was used to assist in the foreshore survey of the River Darent in England. Archaeological remains outcropping in the riverbanks were to be mapped to provide information regarding the proposed development of a nearby industry.

MERV SOLUTION METHODOLOGY

A number of options were considered to solve the Merv archaeological challenge:

- Traversing and detail survey.
- Aerial photography.
- Satellite imagery.

The traversing and detail survey option was rejected (despite being successfully used on other archaeological projects as described previously) for a number of reasons, these include:

(i) All fieldwork had to be completed by the middle of October 2000. There would simply not be enough time to cover such a large area.

(ii) Interest from local police and civilians would have considerably slowed the work.

The aerial photography option was rejected as:

(i) There would be no time to organize flight coverage before the October deadline.

(ii) It was highly unlikely that any premarking for later photography for would still exist at the time the photography was taken.

It was therefore decided to obtain 1m panchromatic orthorectified IKONOS imagery for the site. This had the advantage that a complete base map for the site could be obtained. This would automatically include all archaeological remains with a size of at least 1 m. Thus, without the necessity of physically visiting relevant points with a reflector related to a total station, all archaeological remains of at least 1 m size would be mapped. As the image would not be available before the mid-October deadline, it was decided to delay the image collection until April 2001. This was to give the best chance of minimum cloud cover and minimum vegetation cover.

To provide control for the image, 5 Ground Control Points (GCPs) needed to be visible in the image (4 near the corners and 1 near the centre). Accuracy requirements were 0.5 m with respect to the International Terrestrial Reference Frame (ITRF) with a relative precision of 0.2 m horizontally and 0.6 m vertically (1ó).

The opportunity was also to be taken to establish some permanent control in the area by submerged earth anchors. In this way any future archaeological visits could be tied to the same reference system. In addition, decoy slightly-raised earth anchors were to be deployed to increase the chance of the submerged earth anchors not being removed.

To provide for the ITRF link, data was to be collected at a minimum of one point for as long as practically possible. To assist with accuracy assessment, ideally more than one point would be connected to the ITRF.

By linking the network to the ITRF, this would mean that if all control in the area was unusable (e.g., destroyed, removed) in future archaeological fieldwork, it should be possible to re-establish the coordinate system to an accuracy level better than a dm.

IKONOS IMAGERY

The IKONOS satellite, launched on September 24 1999, has generated enormous interest from the Geomatics community. This is mainly due to the 4 m (CE90%) accuracy achievable [Space Imaging, 1999], speed of acquisition of imagery, and the potentially vast range of applications (e.g., mapping, forestry, planning). Independent tests reported in Li et al. [2000] confirm this accuracy. Toutin and Cheng [2000] show that it is possible using independent software to improve the quoted accuracy of 50 m (CE90%) imagery to the same 4 m CE90% accuracy.

This paper assesses the potential for using IKONOS imagery for archaeological investigations, using Merv as a case study.

GPS FIELDWORK

All fieldwork made use of Leica GPS System 500 geodetic GPS receivers. The work carried out can be split into three main categories:

- Observations to link the local control to the ITRF via the International GPS Service (IGS).
- Coordination of local control points.
- Coordination of GCPs for future IKONOS imagery.

All GPS observations were carried out during the period September 25-29 2000. Detailed records were kept for the control points created. This was accomplished by a combination of photographs and hand drawings; for an example of a photograph, see Figure 3. The control networks established can be seen in Figure 4.

Figure 3. Photograph of IKONOS GCP.

Coordination of local control points:

This required the provision of four permanent earth anchors outside the immediate area of interest plus one close to the accommodation (point 'Base'). To increase the chances of permanency, decoy earth anchors were also established near to the earth anchors of actual interest.

Observations to link local control to ITRF via IGS:

Observations were made at the Base point on each day for between 2 and 10 hours – this will be the primary point connected to the ITRF. In addition, points NW and SE had observations carried out over a six-hour period on one day to improve the link to the ITRF.

Coordination of GCPs for future IKONOS imagery:

This required the coordination of GCPs that it was anticipated would be clearly visible in the IKONOS imagery to be obtained in April 2001.

The same GPS data collection methodology was used for the local control network and the GCPs. The mask angle was 15 , a 10 second epoch rate was used and 10-15 minutes of observations were made at each point.

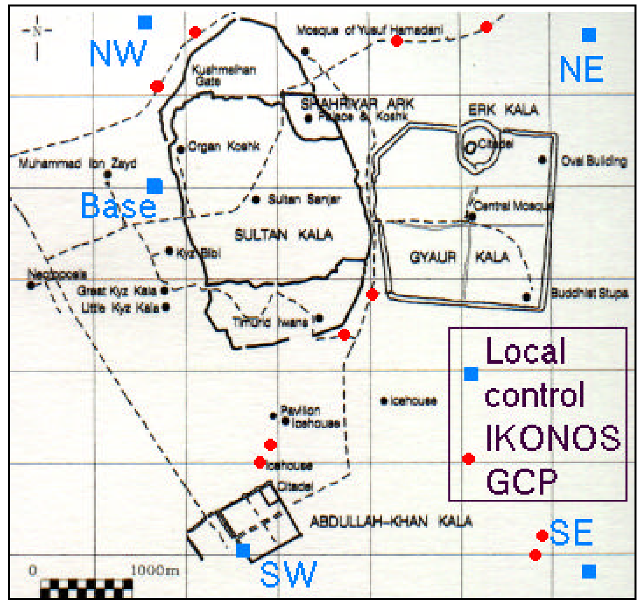

Figure 4. Control established on the Merv site (after Herrmann and Petersen [1997]).

The ideal GCPs are 'cultural features'. These include road intersections, and sidewalk intersections. These features should have well defined edges with high contrast. Because of a lack of these ideal GCPs (see Figure 5), most GCPs were the intersection of bridge edges (marked with concrete blocks) with canals (see Figure 3). Although only five GCPs were needed, each point was doubled up to increase the likelihood of having 5 usable GCPs visible in the image. In addition, to assist with the location of the GCPs on the image, a kinematic track map was made.

COMPUTATION AND ANALYSIS

Four IGS points close to Merv were selected to provide the link to the ITRF: they are shown in Figure 6. Other points considered were Wuhan (China) and Bangalore (India). Wuhan was not used as it was decided the point was too far away from Merv (approximately 2000 km

East of Lhasa). Bangalore (ID: IISC) was not used as preliminary investigations suggested the results would be inconsistent at the metre level when compared to solutions from the other four IGS points. In addition, there are two points in the 1997 list of ITRF coordinates with the ID of IISC.

Figure 5. Lack of 'cultural features' on the site.

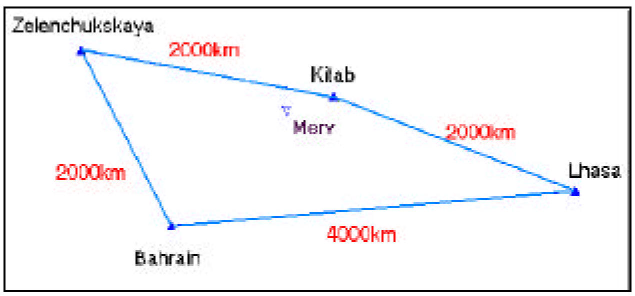

Figure 6. IGS points used to connect the Merv network to the ITRF.

When connecting the local control point Base to the ITRF, Leica's SKI-Pro will have to process vectors of upto approximately 2000 km in length. To assess its ability, two aspects were considered:

(i) Loop misclosures.
(ii) Coordinate misclosures.

The misclosure of the loop Bahrain – Zelenchukskaya – Kitab – Lhasa – Bahrain was determined for each day GPS observations were made at Merv. The misclosures using only IGS data are shown in Figure 7. It can be seen that for all days, the misclosure was less than 20 cm for a loop approximately 10000 km long.

The coordinate agreement was analysed by constraining Zelenchukskaya and Lhasa to the ITRF97 coordinate values (updated to the period of the observations) and determining the coordinates of Kitab and Bahrain, again for the five days observations were made at Merv. These misclosures in the horizontal and height components are seen in Figures 8 and 9. It can be seen that the horizontal misclosures are all less than 25 cm, and the height misclosures are all less than 20 cm.

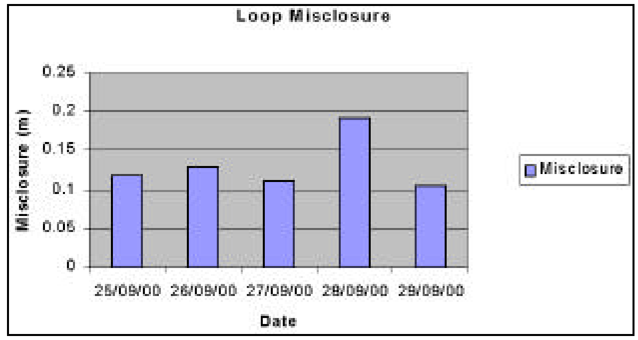

Figure 7. IGS loop misclosure.

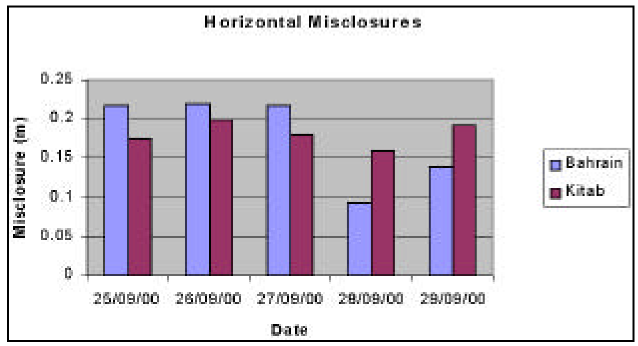

Figure 8. IGS horizontal misclosures.

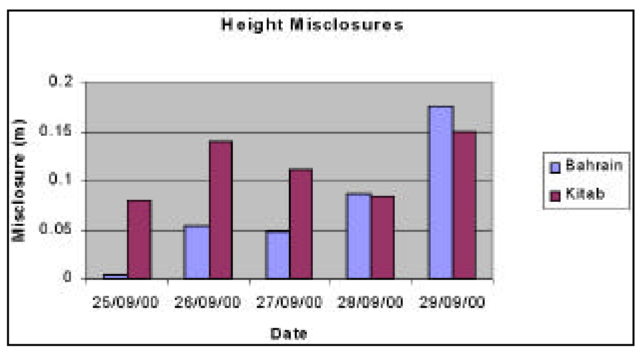

Figure 9. IGS height misclosures.

The vectors to the local control point Base from the four IGS points resulted in an ITRF coordinate for Base being determined with an accuracy better than the 50 cm requirement. The data collected at points NW and SE over a six-hour period on one day to improve the link to the ITRF has still to be processed.

To determine the coordinates of the local control and the GCPs, the local control point Base was constrained to its ITRF derived coordinate and the relevant vectors were computed using SKI-Pro. All the residuals resulting from a least-squares adjustment of these vectors were less than 2 cm.

FUTURE WORK

The link of the local network to the ITRF will be recomputed using the University of New Brunswick's scientific GPS software package DIPOP. It is expected that the loop misclosures and the coordinate misclosures will be less than their equivalent values computed using SKI-Pro. The local control and the GCPs will then be recomputed using SKI-Pro.

The ITRF coordinates of local control points NW and SE will be computed using DIPOP. This should enable additional assessment of the accuracy of the ITRF link to be made.

Once the basic IKONOS image is obtained, the GCPs will be identified, and the ITRF coordinates will be supplied to Space Imaging. Space Imaging will then provide an orthorectified image that will become the base map for the Merv site. Previous fieldwork can then be overlaid onto the basemap and structures digitized. This will enable archaeologists to study features of the site, e.g. the very different urban layouts of a Hellenistic planned city, a medieval organic city, and a post-medieval planned city.

CONCLUSIONS

A control framework has been established at Merv that should last for many years. The coordinates of the points have been related to the ITRF to better than 50 cm. IKONOS Ground Control Points have been coordinated also in the ITRF to provide control for imagery to be obtained in April 2001 – this imagery will form a base map. The base map will enable archaeologists to relate their previous isolated investigations to a common coordinate system. Comparisons of different urban layouts can then be made. It will be of fundamental importance for the Ministry of Culture of Turkmenistan to aid their management of the site. Thus there is a high potential for useful archaeological mapping using GPS and satellite imagery.

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RELATED INTERNET PAGES

A webpage of the work has been created at:

http://www.unb.ca/GGE/News/2000/Merv/Merv.html