High Resolution Airborne LiDAR for the Recording of Archaeological Monuments

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Abstract

Within the archaeological community the application of traditional ground based survey techniques for the 3-dimensional recording of monuments has been successful, but with several limitations. Within the past seven years the application of LiDAR technology for the capture of landscape topography data has been used to great effect. However, the accuracy and resolution of height data created using fixed wing sensor platforms does not effectively record the subtle monument features that can be recorded using ground based survey methods. This paper describes the use of the FLI-MAP 400 helicopter LiDAR system in the production of high resolution DTMs and DSMs. Three contrasting archaeological monuments and landscapes were recorded using this technology. This paper describes the data capture, processing and subsequent visualization of the resulting topographic surface models. Finally the economic benefits of employing this technology is discussed in comparison with conventional ground based survey methods.

Keywords

LiDAR, 3-dimenional survey, aerial survey, helicopter, DTM

1. Introduction

Since its inception in 1992, The Discovery Programme has employed various technologies and methodologies for the 3-dimensional recording of archaeological monuments. Initially these technologies provided suitable solutions, however, the lack of context for many of the surveys and the high level of time investment required limited their production. With the advent of survey, specifically LiDAR, the rapid collection of high resolution topographic data of relict features is now available to the archaeological surveyor. This paper discusses the application of the FLI-MAP400 high resolution LiDAR data in the 3-dimensional recording of archaeological sites and landscapes.

2. The evolution of 3-dimensional archaeological survey

With the advent of the total station the ability to record the cultural components of the landscape in three dimensions has been exploited by many archaeological surveyors over the past three decades. Initially utilizing traditional ground survey technologies of total stations and later RTK GPS, the capacity to record the subtle morphological remains of human activity on the landscape has been a powerful advance to aid archaeological investigators to unravel the evolution and functions of archaeological sites using non destructive methods (Bowden 1999). Examples such as the Topographic survey of the Hill of Tara completed in 1996 (*Fig. 1*) highlighted the effectiveness of the techniques in identifying new monument features (Newman 1998). However, due to the intensive level of field collection required to create a successful topographic model (Corns and Shaw 2004) the extent of the surveys often fail to record the 3-dimensional component of the wider landscape which can provide the monument with its valuable context.

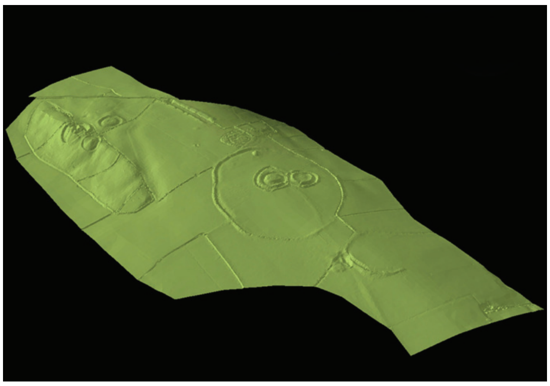

Fig. 1. 3-dimensional TIN model of the Hill of Tara surveyed over three seasons using total stations.

To resolve many of the limitations created by the use of ground based survey methods efforts were made to adopt the techniques of aerial photogrammetry, which for decades have been employed to great effect by the national land mapping bodies. The resulting 3-dimensional digital surface models (DSM) and associated orthophotographs have been well received by the archaeological community in the detailed recording of archaeological complexes and the landscape environs in which they are situated. Following several applications of the technology to archaeological surveys several limitations were identified. The ability to create detailed 3-dimensional models equivalent to those produced by traditional ground based survey methods was difficult. As many relict landscape features in Ireland are on grass and pasture lands the ability for the automated pixel matching routines to differentiate between the similar greens was problematical. To automatically generate a DSM, large pixel correlation matrices were employed, effectively lowering the resolution of the final 3-dimensional models. Although field based survey data collection was reduced, the level of desk based effort required to create and edit the DSMs through the digital photogrammetric process was large. This process was also not applicable to archaeological surveys where forestry was dominant due to the inability of the technique to record land surfaces beneath the vegetation canopy.

3. The birth of LiDAR

With the advent of LiDAR technologies (Light Detection And Ranging), the ability to aerially record the topography of vast swathes of landscape remotely was now available to the archaeological surveyor. Many research projects (Doneus and Briese 2006a; Bewley *et al.* 2005) have powerfully illustrated the potential for this technology to record the archaeological landscape in three dimensions, including those areas of terrain beneath tree cover (Doneus and Briese 2006b). Another factor that has made the application of this technique advantageous is the relatively short time period between the commissioning of a survey and the creation of the final functioning Digital Terrain Models (DTM). Usually the horizontal and vertical accuracies of the final data models are 0.6m and 0.15m respectively (Boyd and Hill 2007). These values are suitable for topographic modelling of archaeological landscapes. However, the ability of this technology to successfully extract all the subtle features of an individual monument is questionable. As height point resolution is based upon the frequency of the LiDAR sensor and the air speed of the sensor platform, fixed wing LiDAR have the disadvantage that the speed of the plane can only be reduced to such a point before stalling occurs.

4. FLI-Map 400 LiDAR system

In 2006 The Discovery Programme was made aware of a new aerial LiDAR system to rival that of fixed wing. Operated by BKS, Coleraine and Fugro, Netherlands the FLI-MAP 400 LiDAR system utilises a twin engine helicopter as the operating aerial platform beneath which three laser scanners and various imaging devices are suspended (*Fig. 2*).

Fig. 2. FLI-MAP 400 Helicopter LiDAR system (Fugro).

This technology was devised for the 3-dimensional recording of infrastructural assets such as train lines and electrical distribution cables. To be able to capture these features effectively, the accuracy must be approaching the levels achieved by GPS and be of a sufficiently high resolution to define the objects.

Range	< 300m
Altitude	40–400m
Laser Frequency	3 X 150 kHz lasers (7° forward, nadir, 7° aft)
Scanning Angle	60°
Accuracy (relative)	Horizontal 5cm Vertical 3cm
Multiple Returns	4
Positioning	2 RTK GPS
Imaging	11 Mega pixel still DV

Table 1. Summary of FLI-Map 400 technical details.

5. Application to archaeological survey

The opportunity to apply the FLI-MAP 400 LiDAR technology to an archaeological landscape was presented to the Discovery Programme through the funding of two surveys by the Heritage Council: Newtown Jerpoint abandoned medieval settlement in Co. Kilkenny and Dún Ailinne prehistoric hillfort in Co. Kildare. Both sites consisted of multiple earthwork features and in the case of Dún Ailinne much of the important features are beneath vegetation cover. Two different resolutions were implemented for each survey (Newtown Jerpoint 50 pts/m², Dún Ailinne 15–30 pts/m²) to establish the required resolution in order to successfully record subtle topographic features.

On first inspection the resulting point cloud data sets indicated that the level of detail recorded was superior to traditional ground based survey methods, with the significant level of penetration beneath the vegetation (*Fig. 3*).

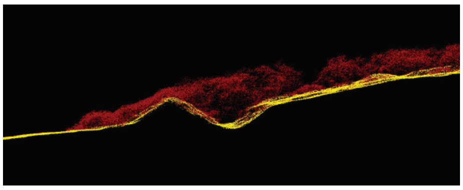

Fig. 3. Cross section through LiDAR generated point cloud of the tree covered bank features at Dún Ailinne.

Several stages of data processing were carried out by BKS before final surface models were created. These included:

1. Transformation of data to WGS84 & ING
2. Production of tiled ASCII DSM
3. Removal of vegetation, buildings and above surface features using a combination of intensity and video inspection
4. Production of tiled ASCII DTM

Both DSM and DTM ASCII datasets for each site were tiled to enable successful surface models to be created as the total point numbers were unmanageable (Newtown Jerpoint 30 million pts, Dún Ailinne 40 million pts). Surface models were created using ArcGIS 9.2 including 3D Analyst and Spatial Analyst extensions. Firstly TIN models were created from each tile ASCII xyz data set. These were subsequently rasterised to improve display performance and merged into a single seamless DTM and DSM. Hillshade analysis of the generated surface was carried out to aid the identification and description of archaeological features. The production of the hillshade models emphasised the level of detail that was being recorded using this technology. Low relief features such as wheel track marks were evident upon the surface modes. In addition to the DTM and DSM data orthoimages covering the complete survey area were supplied.

From these two ventures it was proved that this technology was highly suitable for the 3-dimensional recording of archaeological monuments and their landscape context. Following further support from The Heritage Council the Hill of Tara archaeological complex in Co. Meath was chosen as the next site for applying this technology. The final DSM and DTM produced spectacular results (*Fig. 4*). Subtle archaeological features presented themselves with great clarity, including the large circular henge structure that was discovered using geophysics (Fenwick and Newman 2002), but little surface evidence was thought to exist. Considerable time is now required to fully interpret these models. Initial analysis has already identified the evidence for palaeostream features that align with a spring/well monument to the south of the main complex.

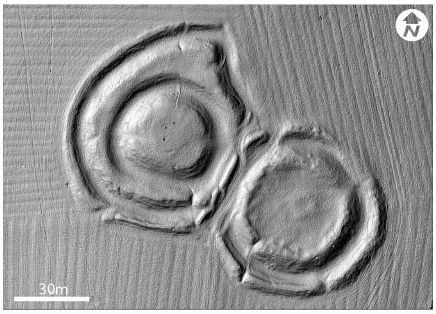

Fig. 4. LiDAR derived hillshade model of the Forrad and Tech Chormac conjoined earthworks on the Hill of Tara.

To effectively visualise the resulting DSM and DTMs hillshade processing based upon multiple light sources correlated to the frequency of relief features was implemented (Loisios *et al.* 2007). The resulting model has optimal lighting conditions to enable the identification of archaeological features. Experimentation of realistic visualisation was also carried out utilising Eon Vue 6 software, the resulting images, however, failed to have the same impact as a simple grey coloured hillshade model.

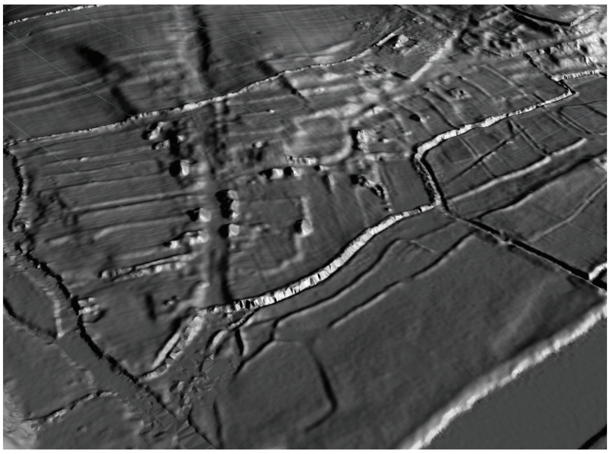

Fig. 5. Perspective view of 3-dimensional model of Newtown Jerpoint medieval settlement.

6. Economic comparisons

Initially the cost of each of these surveys was thought to be prohibitively expensive, but with reflection and comparison to the true costs of carrying out an equivalent survey using ground based survey technologies (GPS/Total station) the economic effectiveness of this technology to survey large monument complexes is clear. *Table 2* summarises the equivalent cost of carrying out the survey of the Hill of Tara using ground based methods for a 1m resolution model, an appropriate sample distance for ground based surveys and a 12.5cm resolution model, equivalent to the LiDAR data. These values are based upon the total costs of a landscape surveyor/s with a daily recording rate of 2000 points.

Survey Method	Total Cost
12.5cm LiDAR Survey	*€40,000*
1m Ground based Survey	*€337,000*
12.5cm Ground based Survey	*€26,500,000*

Table 2. Comparative survey cost of LiDAR vs conventional ground based survey methods.

7. Conclusion

Until recently the use of LiDAR for the topographic survey of archaeological features has been limited to small scale features within the archaeological landscape. With the application of the FLI-MAP 400 helicopter based LiDAR the subtle features of archaeological monuments can now be recorded with similar accuracies to ground based survey techniques but with a much greater level of resolution and definition. The resulting DTM and DSM surfaces enable the identification of new features and a more detailed record of those already recognized. Finally, in comparison the economic viability of implementing this technology as the primary data collection method for 3-dimensional archaeological surfaces is clear.

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