

A Digital Drawing Tool for Recording Excavations: the Nikon iSpace System

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Abstract:

To date, no digital methods of acquiring graphical excavation records have proved sufficiently simple, fast, accurate and/or affordable to have successfully replaced traditional drawing tools. One of the authors recognised that the iSpace tracking system from Nikon Metrology NV, normally used in aerospace and automotive industries, might be used for the very different purpose of making excavation drawings faster and more accurately than drawing by hand with the bonus that each drawing would be inherently geo-referenced. Discussions between the authors lead them to conduct field trials at excavations at Mont Beuvray (ancient Bibracte), France. This paper describes the Nikon iSpace system, the field trials, and compares the drawing times of our iSpace results against traditional hand-made drawings.

Key Words: *iSpace, Drawing, 3D, Tracking*

Introduction

While computing has had a large impact on the way we work with the records originating from excavations (site databases, intrasite GIS analyses, web pages and excavation blogs, etc.), it has made relatively little impact on the way we actually make these records at the excavation, despite attention to this field by authors over the last decade or more. Since at least the turn of the millennium, many authors have sought to make the creation of the graphical records of excavations faster by using digital acquisition methods such as photogrammetry (Barcelo et al. 2002), orthorectification of photographs (Reali & Zoppi 2001), tracing from photomosaics (Avern 2001a), using total station points for drawings (Schaich 2002), 3D Modelling (Avern 2001b) and laser scanning (Doneus & Neubauer 2004). Yet none of these methods have become mainstream techniques because, we suggest, none have proved to be a complete solution in terms of speed, simplicity,

accuracy and affordability, leaving many, if not most, excavations resorting to the traditional tools of permatrace, pencil, drawing frame, string line and tape measure.

One of the authors has previously proposed a theoretical recording system which attempted to address these issues (Avern 2001a). This system would have used a hand-held laser scanner, whose position and orientation is determined through time by an accurate large-volume tracking system, to record the topography and colour information of every context. At that time an appropriate tracking technology was not available to realise the concept, however, today there is a system which meets these needs. It is the iSpace large-volume tracking system from Nikon Metrology NV (a branch of the Nikon Corporation).

The iSpace system is commonly used in aerospace and automotive industries to accurately measure single points in space.

One of the authors (GA) recognised that the iSpace tracking system, might be used on an archaeological site to take point coordinates (for spot heights, find locations, etc.) as a simpler, faster and more accurate alternative to a standard total station theodolite. More significantly, with the iSpace system operating in a continuous tracking mode, it could also be used as a highly accurate, high-speed drawing tool. This might be achieved by using one of the system's sensors as a "digital pencil" and tracing it along a line, a boundary or around a perimeter of a context or feature. The 3D point data gathered in this fashion could be turned into a line drawing which would be virtually identical to those typically made on excavations.

Further, it seemed that the system would have very significant advantages over traditional (and other) methods in terms of the very rapid

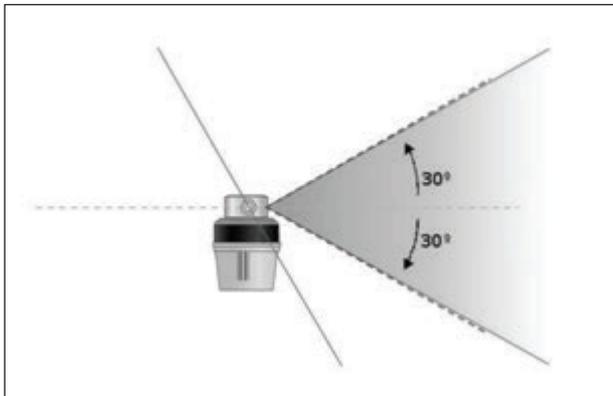


Figure 1. The paired infrared laser fans are projected at $\pm 30^\circ$ from horizontal.

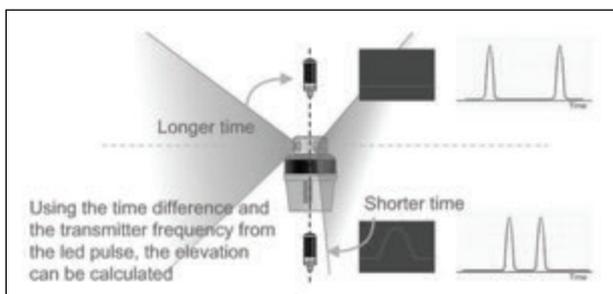


Figure 2. The paired infrared laser fans are tilted 30° from vertical, one clockwise, the other anticlockwise.

speed at which drawing might be done, the very simple and intuitive recording tools used to gather the data, the greater accuracy of the system (and hence of the resulting drawings) and, since each drawing would be composed of thousands of geo-referenced 3D coordinates, that each drawing produced would be inherently geo-referenced.

An approach to Nikon Metrology NV (Leuven, Belgium) to explain the potential application met with enthusiasm and led to the authors teaming up to trial the iSpace system at the excavations at Mont Beuvray (ancient Bibracte), France.

Nikon iSpace

The standard iSpace system is based on 4 tripod-mounted transmitters, 2 hand-held probes (fitted with sensors) and a portable workstation (to calculate point coordinates).

The transmitters emit two types of infrared timing signals; a strobed timing pulse and a rotating pair of infrared "fans". The frequencies of the timing pulse and of the rotation of the 2 fans are identical on any one transmitter but each transmitter has a unique (identifying) frequency in the vicinity of 40Hz.

The fans are projected at $\pm 30^\circ$ from horizontal (Fig. 1). Importantly, each is tilted 30° from vertical, one clockwise, the other anticlockwise (Fig. 2).

Given the fixed rotational velocity of the turret from which the fans are emitted, the sensor in the higher position in figure 2 will detect only a larger time difference between the fans (indicated on the graph in the lower right of the figure) than would a sensor in a lower position. Indeed, the time difference between the detection of the two rotating fans is a function of the vertical angle (elevation) between the transmitter and that sensor, allowing the system to calculate the angle of elevation.

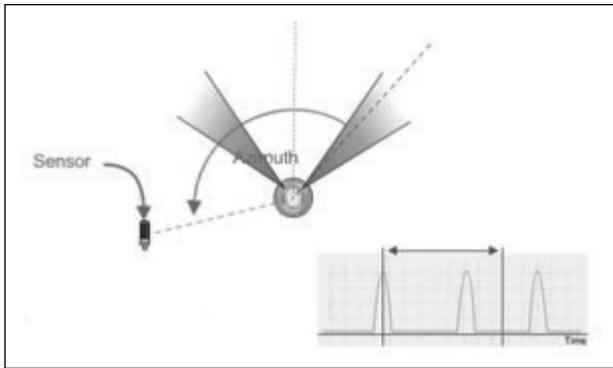


Figure 3. Grey dotted line – position of the mean of the fan timing signals when the strobe timing pulse occurs. Dotted line – the mean of the fan timing signals coincides with the line between transmitter and the detector. The time between these gives the horizontal angle (azimuth)..

The horizontal angle (azimuth) is the time difference between the mean of the 2 fan signals and the strobed timing pulse (Fig. 3). Together, these two angles proscribe a ray, from the transmitter, along which the sensor must lie. To determine the actual point in space where the sensor lies requires 2 or more rays (that is, visibility between the sensor and 2 or more transmitters). The sensor will lie at the intersection of two or more of the four calculated rays. While, technically, only two rays are needed to obtain a result, a third ray is necessary for any estimation of the accuracy of the result and the fourth allows for any occasional or temporary loss of line-of-sight between a sensor and any one of the transmitters.

The sensors are small, “lipstick-sized” cylinders connected to radio frequency transmitters. They convey timing data, collected from those transmitters to which they have line of sight, to the workstation which converts the timing signals into angles and determines the point in space at which the rays intersect, i.e. the 3D coordinates of the sensor. Coordinates are calculated 40 times per second (this can be reduced in the proprietary workstation software).

The iSpace system comes with two hand-held probes, both fitted with 4 sensors. Each sensor sends signals allowing the workstation to calculate the 3D coordinates of each sensor simultaneously. Given that the 4 sensors are in a fixed and calibrated configuration, the system can determine both the position of the measuring tip of the probe and the orientation of the probe (6 DoF). In practice, this means that the probes do not need to be held vertically and, in doing so, eliminate the major source of error when using the traditional total station and staff-mounted prism. The probes are also fitted with buttons to trigger recording episodes. Recording can be done in two modes; single point mode (for surveying, spot heights, find locality, etc.) or in continuous mode (for tracing around outlines of contexts or features). The two probes differ in their size; the 2m “iJavelin”, which is a convenient instrument for point surveys and for working in holes or pits (Fig. 4), and the 40cm “iProbe”, useful for making accurate drawings of contexts, features, sections, etc. (Fig. 5).

Normally, iSpace is used in aerospace and automotive industries, where exacting standards applied to the setup of the system can result in measurements with an accuracy of 0.2mm.



Figure 4. Using the 2-metre long “javelin” probe to survey wall foundations of PCI (see Fig.7) (iSpace transmitter in foreground).



Figure 5. using the “iProbe” to draw section 205_728_007 (Photo: Antoine Mailler – Bibracte EPCC) (see Fig.9).

For archaeology, where such precision is not required, transmitters can be set up at a greater distance from each other (approximately 50m) while still achieving millimetre accuracy. The standard system proved ample for the area we had to cover on our excavation at Mont Beuvray. Had we needed to cover a larger area we could

have simply added further transmitters.

Our setup time, with 2 people, was 30 minutes (including system calibration and geo-referencing). However, we used a prototype iSpace system which required mains power, so our setup time includes laying power cables across site and starting the generator. The latest iSpace system is now fully battery-powered and, we suggest, could be set up in as little as ten minutes with the help of more people.

Field Trials at Mont Beuvray

Mont Beuvray, in the Parc Naturel Régional du Morvan in western Burgundy, France, is believed to be the site of the Iron Age oppidum of Bibracte. Caesar writes that Bibracte was the main settlement of the Gallic tribe, the Aedui, who were his main allies during his Conquest of Gaul (58-52BCE). Indeed, Caesar is believed to have written *De Bello Gallica*, his account of the conquest, when he overwintered

RECORDING TIME (in minutes)	iSpace	Drawing by hand	Photomosaic
205_728_001 Plan - tuile remblais	8	180 (x2*)	
205_728_002 Plan – tuile, pierres	175	Not attempted	180 (x3) + 120*
205_728_003 Topography under _001	70	300	
205_728_004 Section canalisation	12	Not attempted	
205_728_005 Section canalisation	13	Not attempted	
205_728_006 Plan - canalisation	12	Not attempted	
205_728_007 Section – Pâturage de Couvent	95	210	
205_728_008 Composite site plan			

* This 180 minute task was performed by 2 students.

**This photomosaic was subsequently traced to make a plan drawing. The tracing took 14 hours.

Table 1. Drawing Times.

at Bibracte. The city underwent considerable rebuilding in Roman style in the La Tène D/Augustinian period. Today Mont Beuvray is the site of one of the most extensive and long-lived series of excavations in Europe coordinated by the organisation Bibracte EPCC. Teams from a dozen or more European countries have excavated here every year since 1984.

Our proposal to Bibracte EPCC was to bring a Nikon iSpace tracking system to work beside one of the excavation teams. Our aim was to record the time taken for the excavation team to make its drawings and compare this with the time it took us to draw the same terrain using iSpace, as well as comparing the quality of the pairs of drawings. Important to the following descriptions, it should be noted that our aim was always to produce a printed drawing that the archaeologist could hold side by side their hand-made drawing for comparison. The reasoning behind this was that we wanted to present iSpace as a tool which fitted with existing practices and which required no special changes in the way archaeologists did their work or recorded their excavations. In retrospect, it would have been better to choose the point at which the drawing enters the site database as our comparison point since the database, not the paper product, is the endpoint of recording in excavations. This point will be discussed in detail elsewhere.

We joined Bibracte's Archaeology School, led by Chiara Martini, at their excavation on a late Roman domus PC-1 in the area of Parc aux Chevaux, where they worked on 2 trenches containing collapsed roof tiles of the peristyle and on another area revealing part of the canalisation on the east side of the building.

We also visited the excavations of the Hungarian team from University Eötvös Loránd, Budapest, on the Roman basilica/mediaeval convent site in the area of the Pâture du Couvent.

ArcTron GmbH generously allowed us to use

their ArcheoCAD software in this trial. By tagging our data with ArcheoCAD codes as we collected, our point data was given attributes and turned into 3D vector CAD drawings. These drawings were later exported from ArcheoCAD as 2D excavation drawings.

Results

Our drawings

We used the iSpace to gather data for 8 drawings; 7 from PC1 (Archaeology School) and one at Pâture du Couvent (Hungarian team) (Table 1).

Beside our 7 drawings from PC1, the Archaeology School made only 2 comparable drawings at one of the peristyle trenches (our drawings _001 and _003).

The Archaeology School considered that the area at the other peristyle trench (our drawing _002 and Fig. 6) was too large to draw efficiently and was, instead, photographed for construction of a photomosaic, the times for which we use in our comparison below.

Note that while we gathered the data, we did not produce a drawing 205_728_003. This drawing was of a single context and was supposed to show the highly irregular topography of the context which lay below the tile rubble recorded in 205_728_001. We gathered much surface data with the intention of constructing a TIN surface model and then producing a 2D gradient map to illustrate this topography. However, initial attempts at modelling suggested that our data was not sufficiently dense to provide sufficient topography for a good result.

Our drawings _004, _005 and _006 represent 2 section drawings and a plan from another part of the excavation at the canalisation at the edge of the domus PC1. In the last 2 days of the Archaeology School, the students moved

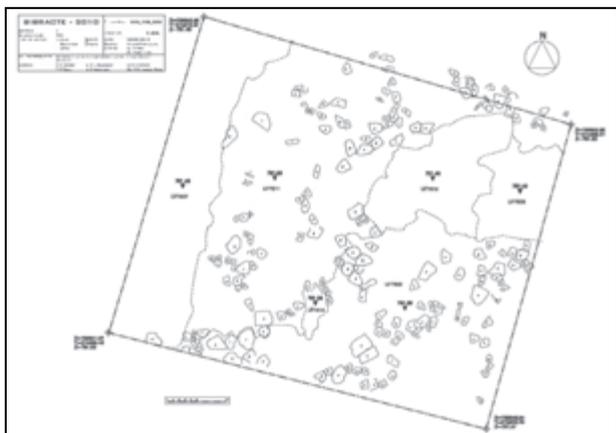


Figure 6. Drawing 205_728_002 - Plan of part of the peristyle of PC-1 showing tile rubble deposits. Data captured by iSpace in under 3 hours (using ArchaeoCAD drawing software from ArcTron GmbH).



Figure 7. Drawing 205_728_008 - Site plan of PC-1. Green – base of walls; brown – tops of walls. Drawings 205_728_001, 002, 004, 005 and 006 have been imported into this plan.

to this area to assist another excavator. They were employed in other activities and did not attempt to draw these sections and plans. As we had the iSpace system there, we were able to quickly gather the necessary data for the drawings.

We also visited the excavations of the Hungarian team at Pâturage du Couvent to draw a very difficult section. The section was stepped and contained 3 protruding walls, one entering at an angle (Fig. 8).

Finally, in our spare time we gathered sufficient point data to make a plan of the whole PC1 site (Fig. 7).

Comparing drawing times

We should be very careful to note that it is impossible to make direct comparisons of those recording times given in the table above because the processes of digital and hand-made drawings, and their results, are very different, as we consider below.

For the sake of this discussion let us break down the making of drawings into 3 steps;

- setup - where all the drawing materials and aids are gathered together and set up on site,
- data gathering - where the actual drawing is made,
- finishing - where annotations are made, the drawing is incorporated into the recording system and, ultimately, is digitised.

Setup times

Each hand-made drawing has its own setup time. Similarly, each photomosaic will have its own setup time (which would include the setting out and geo-referencing of the targets and the photography). The iSpace system, however, is set up only once a day, whether it is subsequently used to make one or many drawings. For this reason we did not include the setup time in the iSpace figures above.

Finishing times

Finishing times depend, ultimately, on what you consider to be the finished record. As explained above, our initial aim was to put paper



Figure 8. Drawing traced from photomosaic (courtesy of Bibracte EPCC).

drawings in the hands of the archaeologists that they could compare side by side with their own and so we only collected times for the students to finish the hand-made drawing. Normally, the hand-made permatrace drawings would be digitised, involving splitting the drawing into many levels of attributed data. However, we did not measure any digitisation times for the hand-made drawings, so this step is not included in the table above. Of course, our results from iSpace were essentially a finished result ready to be dropped into the digital site model.

While we did print paper versions of our drawings we have not include these “finishing times” in the above table since they are essentially an unnecessary step in normal practise. Additionally, they would not say anything about the performance of the iSpace

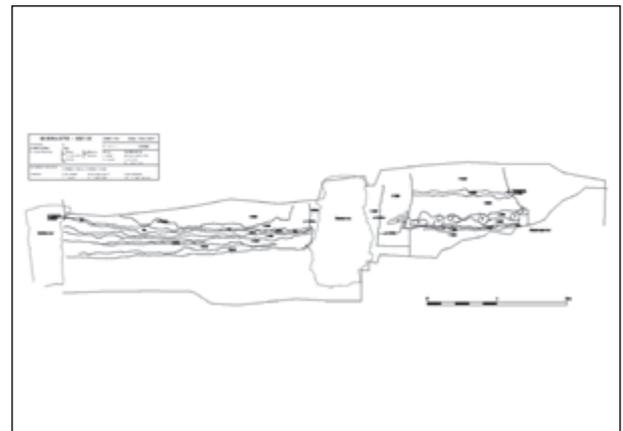


Figure 9. Drawing 205_728_007 - Section drawing from Pâturage du Couvent.

system but only be a reflection of the functioning of the ArchaeoCAD software.

Thus, interpretation of the table above will depend on what is considered as being the end result. If it is a digital file, then our quoted times are good and the others are far too low. If it is to have a paper drawing in your hand, the other figures are good and we have under-quoted ours by, we would suggest, 10 minutes.

With optimised drawing software and familiarity with that software, we believe that it ought to be possible to turn the data output of iSpace into a drawing of professional standard in around 10 minutes (since the data is already attributed, it simply needs the addition of titles, North and scale). Revisiting some of the above times with this figure in mind, some interesting figures are obtained:

- Our plan drawing 205_728_001 would have been made in one tenth of the time. And this could have been achieved by one person instead of the two required to produce the hand drawing, i.e. 95% more efficiently.
- Our section drawing 205_728_007 would have been made in half the time.
- All of our results are digital files, so no

further time would be spent converting them into vector diagrams.

- Our plan drawing 205_728_002 would have been achieved 92% more efficiently.

Despite all the caveats and conditions mentioned above it is still perfectly clear that the gathering of data on site is very much faster using the iSpace system than by traditional drawing methods.

Drawing quality

In terms of the quality of the drawings that were produced, it is clear that our plan drawings were far superior (Figs 6 and 7). Three factors play a part in this:

- the far greater accuracy of the shapes of objects and features in our drawings, since iSpace gathered many hundreds of points from the entire perimeter of every feature, as opposed to the commonly-used hand-drawing technique of measuring and plotting a small number of points and simply joining them “by eye”,
- the overall accuracy of our drawings, since iSpace measures each of these hundreds of points far more accurately than the way in which the few points are measured for the manual drawing (*viz.* by using a drawing frame and measuring tapes to trilaterate back to reference points),
- the very professional appearance given to our results by the ArchaeoCAD drawing software.

In terms of quality, only the digital drawing made from the photomosaic (Fig. 8) by Bibractre EPCC staff was comparable to our plan drawings. However, we suggest that this drawing will have irregularly distributed errors due to perspective distortion (Avern 2004) and

will thus not be as accurate as our equivalent drawing (Fig. 2).

Our only problems arose with the section drawing 205_728_007 from the Hungarian team’s excavation in the Pâture du Couvent (Fig. 9). This was offered to us as a particularly difficult section to draw and as a test of the iSpace’s ability. The difficulties lay in that the section was stepped, had 2 walls protruding from it by as much as a metre, and had a third wall running into the section at an oblique angle. Our mistake was to try to record every part of the section at its extremities rather than in one plane (as much as was possible). Thus in figure 8 the boundary lines between strata, which clearly lay against the wall in reality, apparently terminate before reaching the wall. This is because the end of the wall which we drew lay 1m away from the strata and the plane of our section does not lie perfectly normal to the plane of the wall. Similar issues arise between other features and the line denoting the limit of excavation.

One must remember that the data which makes up this drawing is, in fact, perfectly accurate. When viewed in 3D, our data made perfect sense. Rather, the problem is one of reducing 3D information to 2D. If the section had been a simple vertical face, we would have no problem.

Conclusions

Our trials at Mont Beuvray, France, confirmed our idea that the Nikon iSpace system might be used as an efficient 3D drawing tool for archaeological excavations. We successfully used iSpace to make very accurate archaeological drawings, very quickly. While direct comparison of times is difficult we are confident in saying that drawing with iSpace gave incredible time savings by allowing us to make our digital drawings at least 2 times, and up to 10 times, faster than traditional drawing. From these results we confidently assert that digital acquisition for excavation drawings has

finally become a real, effective and economical possibility.

On the basis of our results, Nikon Metrology Europe NV launched an iSpace system specifically for Archaeology at CAA2011 Beijing. The cost of the new system is €85,000. While this is substantially more expensive than a total station, it has numerous advantages, including ease of use, ease of producing drawings, no practical line-of-sight problems, recording is performed by one person, it is more accurate and, we predict, much faster. In the future we aim to run a similar comparison to that reported here, between iSpace and Total Stations for making excavation drawings.

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