Recording the uncollectable with low cost low tech: successful photogrammetry in the field using a mobile phone to create digital 3D models.

Nigel R. Larkin[1] & Steven Dey[2]

[1]Cambridge University Museum of Zoology, Downing St, Cambridge, CB2 3EJ , UK.

[2]ThinkSee3D Ltd, 10 Swan Street, Eynsham, OX29 4HU, UK.

Abstract

There are many different ways to record the three-dimensional morphology of a specimen in detail. Most techniques rely on expensive, cumbersome and delicate equipment requiring a power supply. However, if a very large and heavy fossil or geological feature in the field cannot easily be removed to a museum or is in danger of imminent loss it would be very useful to be able record the three-dimensional morphology of the find accurately and in detail there and then with readily available low-cost equipment and with simple techniques.

Fortunately, experimentation has shown that photogrammetry using a standard 5-megapixel mobile phone digital camera can produce very good quality digital 3D models of specimens in the field (such as short dinosaur trackways) that are useful for research. Unlike some scanning methods this also provides a photographic overlay to the morphological model creating, effectively, a 3D photographic record of the specimen and surrounding context.

Even specimens larger than 1 m^2 can be recorded to a level of sub-millimetre resolution with such a device in reasonable lighting conditions and if the relevant photographic techniques and image processing techniques are well understood. The software required to convert the photographs into 3D models is readily available and low cost. Current mobile phone cameras can even produce results that are better than digital SLR cameras in some low light conditions and they are improving every year. As most people have a mobile phone with them when on fieldwork, with a little training anyone can undertake scientifically useful 3D scanning.

The example given here is a slab of mid-Jurassic Saltwick Formation rock (approximately 1.2m x 1.0m x 0.2m weighing in in the region of 500kg) containing two parallel dinosaur tracks in the form of slightly raised footprint casts (Figs 1 & 2). Found in Long Bight near Whitby on the Yorkshire coast in February 2017 it was impossible to move but faced being destroyed by 'Storm Doris' whose arrival was imminent. 65 photos were taken with an old cheap mobile phone (a GT-I8190N camera on a 2014 Samsung Galaxy) including the sides of the slab and underneath as far as possible, specifically so that a photogrammetric 3D digital model could be made of the specimen. The following day the trackways were found to have survived the storm and 81 photos were taken on a Canon Powershot SX50 HS 4.3 digital camera so that virtual 3D models made from both sets of data could be compared.

Fig 1 (Left) The slab containing the double dinosaur trackway with NRL for scale.

Fig 2 (Below) One of the raised 'footprints'.

Methods

Photogrammetry generates digital 3D models from multiple photographs taken from different positions around an object. A major advantage compared with other methods, such as laser scanning, is that the 'scanning' part of the process is very cost effective as all that is required is a digital camera to capture the data. Therefore it is an ideal method for use in the field when looking at large specimens and geological features. It is even possible to take accurate measurements of features in the resulting digital 3D model, particularly useful if the specimen itself was difficult to access, as long as a scale bar or an object of known size (a geological hammer for example) is placed on the specimen in a few photographs to act as a reference. This will allow the digital 3D model to be made with a relevant scale.

The accuracy of virtual 3D models of fossils produced with photogrammetry can be equal to or even better than other scanning methods but this is dependent on four main influences whether using a mobile phone or more sophisticated camera: (1) the quality of the photography; (2) the quality of the light in the environment; (3) the surface quality of the specimen; and (4) the processing of the images into a 3D model.

1. **The quality of the photography.** Oblique angled photographs across a specimen can be partly out of focus due to a limited depth of field if care is not exercised, so overly oblique shots should be avoided. Distance from the subject is important. Too close and lens distortions can cause issues. Too far away and the resolution of the images - and therefore the resolution of the eventual model - will be reduced. Multiple photos from numerous angles around the subject need to be taken, ideally with an 80% overlap between photos. Fig. 3 shows the various positions (the blue rectangles) of the mobile phone used to model the slab containing dinosaur tracks found on the coast at Whitby.

2. **Light quality**. Bright diffuse light is best for taking photographs for photogrammetry purposes, such as being outside on a cloudy day in the spring or summer. Changeable light conditions, dark shadows and/or bright sunlight on surfaces are not ideal. Highlights from bright sunlight tend to move position between different photographs and shadows obscure the surface colours and texture of the specimen. Both of these would lead to 'noise' and inaccuracies in the final 3D model.

3. **Surface quality**. Photogrammetry works best with highly textured subjects. It does not work on very shiny objects, or transparent or very monochrome objects. For example, a very plain white surface would not scan as the algorithms in photogrammetry need to see features 'moving' from image to image to determine depth. If those features do not exist or reflective highlights move between shots, the process of building the virtual model will fail. The highly-textured surface of fossils, such as footprints and their surrounding rock, is particularly suited to photogrammetry as the algorithms involved rely on differences in surface colouration and texture to recreate the 3D geometry.

4. **Processing the images**. Processing the data efficiently requires a reasonably good computer, such as an (SD) Intel i7 with 32Mb RAM and a good GPU card (for example, NVIDIA). Even then, processing photographs into 3D models is an extremely computing-intensive process, often requiring many hundreds of millions of calculations. So, if there are a lot of photos it is sometimes necessary to reduce the resolution. Photogrammetry software helps by allowing the data to be broken into blocks to process it in smaller sets and thereby not overwhelming the computer's resources all in one go. The software used to make a model of the Whitby specimen was Agisoft Photoscan standard edition.

Weaknesses in any of the above four factors can lead to 'noise' in the final virtual model or lower resolution of detail, or, in extreme cases, failure to create the 3D model. It is usual for some of these factors to be imperfect, so compromises have to be reached. However, the photogrammetry process itself is quite robust and can sometimes cope with quite poor inputs. In reasonable conditions, much larger specimens than the footprint slab can be captured this way, even large geological features and landscapes.

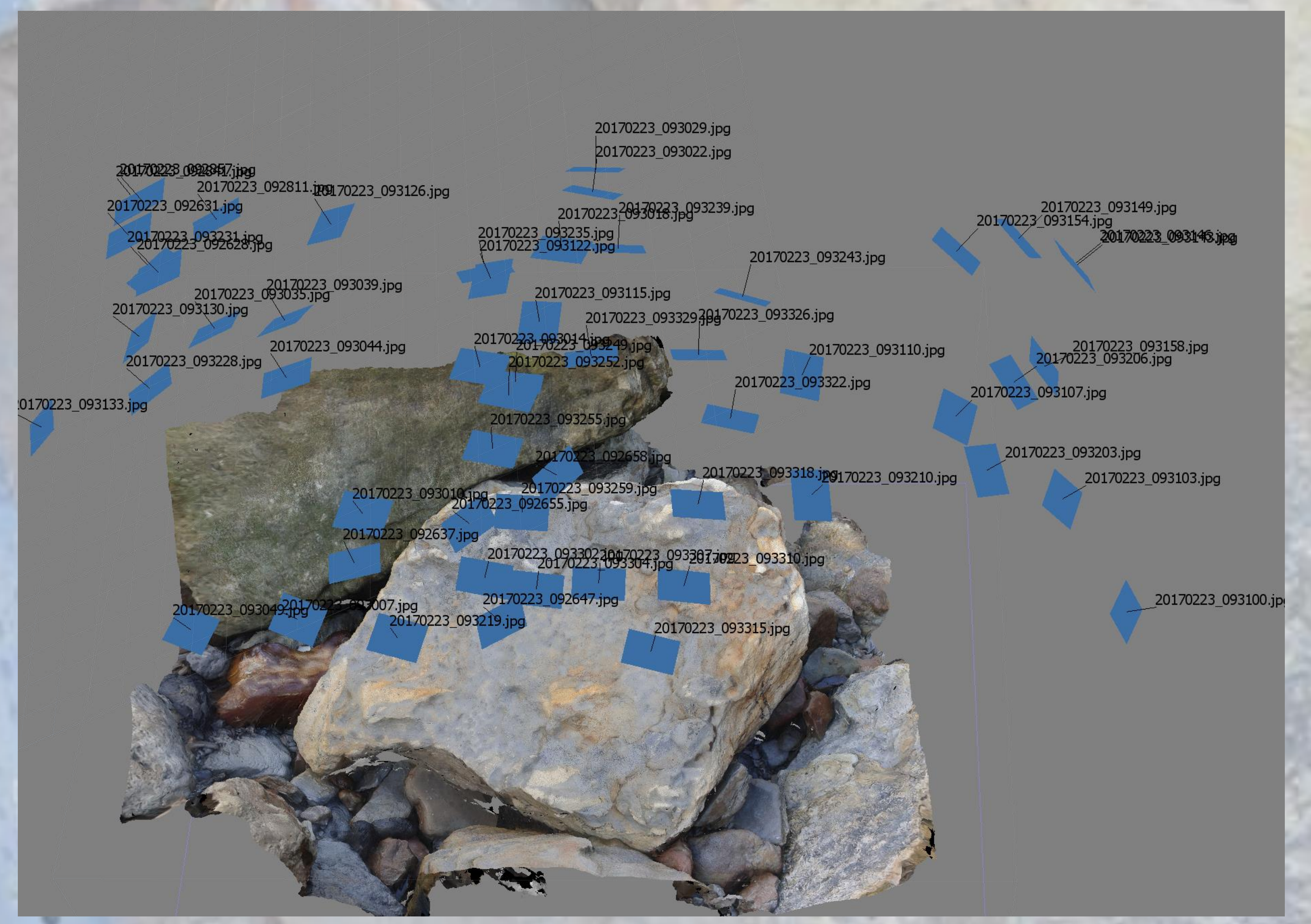


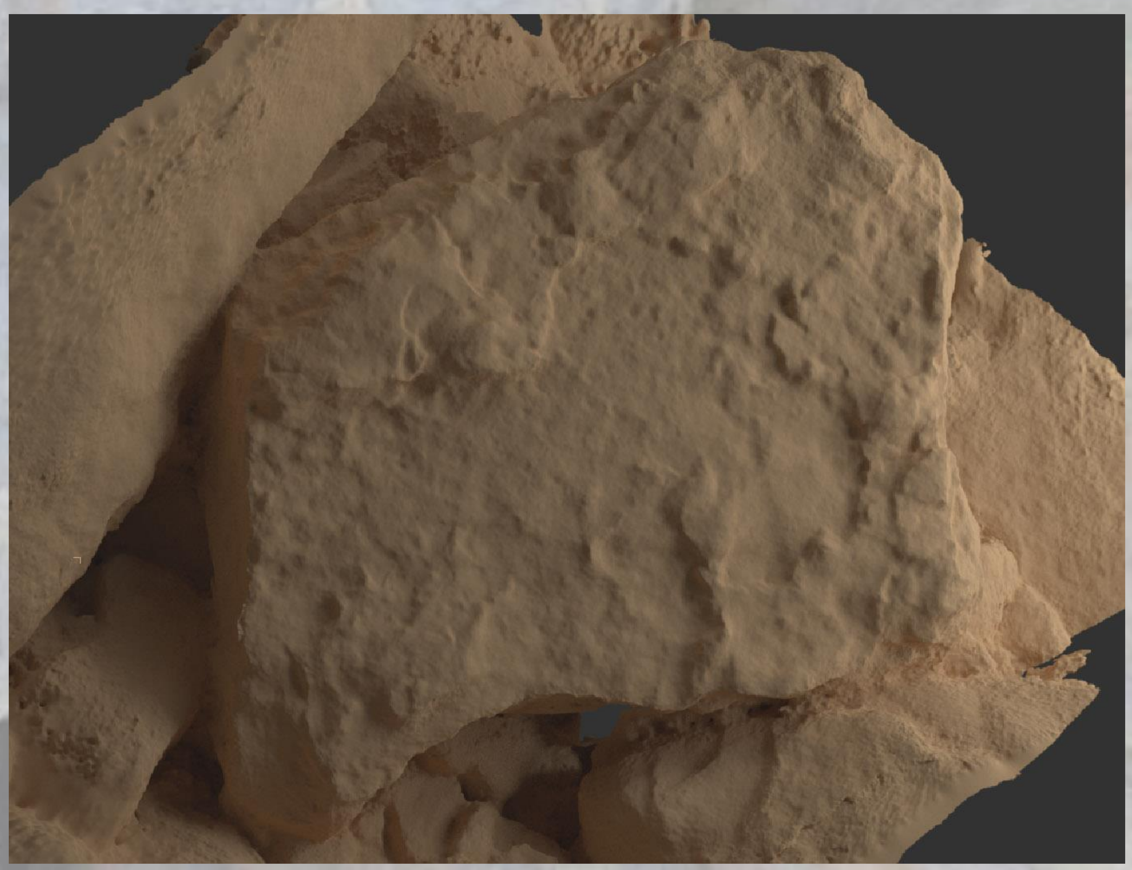
Fig 3 (Left) The blue rectangles indicate the various positions of the mobile phone around the slab when taking photos to model the specimen. The 3D digital model made from these mobile phone images is also shown. The colour overlay can be removed to reveal a blank 3D model showing the morphology only (i.e. Fig 4, below).

Three digital models were created of the specimen. The first model was made from photos taken with the old mobile phone; the second was made using photos captured with the compact digital SLR Cannon camera; and a third model was made by combining these two sets of data. In all cases, the diffuse and constant light on the specimen from naturally bright but cloudy conditions was ideal.

The images were loaded into Agisoft PhotoScan and rendered into 3D models following the workflow in the application: aligning photos, building dense point cloud, building mesh, and building texture. All processes were set to high quality and decimation in the mesh build was avoided by using a custom mesh size set to a high value. PhotoScan performs camera calibration automatically using Brown's distortion model, but the photos had some EXIF data, which assists the calibration and camera alignment process. The texture file was a jpeg set at 4,096 x 4,096, using Photoscan's generic texturing method. The finished 3D models were exported from Photoscan as an OBJ file, with associated material and photo-texture file, and uploaded to the online 3D viewing and sharing platform 'Sketchfab' for sharing and discussion (see links below to view the models).

The output of the process is effectively a 3D photograph of the scene. The texture file overlays multiple photos on to the 3D geometry, adding data on the surface colouration. In Fig. 4, below, the specimen captured by the mobile phone is shown as a 3D model without the colour overlay, just showing the morphology of the specimen with angled lighting. Looking at the model without the colour can sometimes reveal morphological features that are otherwise hard to distinguish.

Results and conclusions



The clarity of all the models was found to be of high quality, showing millimetre scale details of the trackways in the 3D geometry and in the attached texture file. The digital SLR camera produced slightly better results than the old mobile phone but surprisingly there was not much difference. A good SLR digital camera would usually produce a better result than a mobile phone camera because the quality of the optics and resolution of the sensor mean it can capture more information. However, the latest cameras in mobile smartphones are very advanced and can make excellent photogrammetry tools. In poor light conditions, they can even produce better results than mid-range SLR digital cameras. They also have the advantage of being much simpler to use and are usually at hand when needed.

In the case of the Whitby trackway, photos taken with the old mobile phone produced very nearly as good a result as the digital camera and the model was certainly more than adequate as a record of the specimen and for identification and measurement purposes. Mobile phone cameras are improving every year so results using this technique are going to get even better with time.

In conclusion, capturing multiple images of an otherwise uncollectable object in the field with a digital camera – even an old mobile phone camera - can enable a scientifically useful 3D digital model to be built to record the specimen and from which measurements can be taken, as long as the principles of photography and how they affect the quality of the eventual model are well understood. This data can even be used to 3D-print a displayable hard copy replica of the fossil, if required.

Viewing the digital 3D models of the specimen

You can access the 3D digital models using the QR codes below. However, they may be slow to open on mobile phones. You can find the models on Sketchfab anytime by searching with the phrases 'Whitby Dino tracks from mobile' and 'Whitby Dino tracks from compact SLR'.

Left: The QR code that will take you to the digital 3D model of the trackway built from the photographs taken with the old mobile phone. ***Right***: The QR code that will take you to the digital 3D model of the trackway built from the photographs taken with the digital SLR Canon camera.

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