Use of a Hand-held Laser Scanner in Palaeontology: A 3D Model of a Plesiosaur Fossil

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Abstract

The application of 3D laser scanning to Palaeontology could prove invaluable for creating, cataloguing and sharing virtual copies of fossil material over vast distances, while preserving the original specimen. The generation of accurate 3D models of sections of the scattered bones from an elasmosaurid plesiosaur fossil generated using a Polhemus FastSCAN^{TM} *hand-held laser scanner and associated technologies, Farfield Technology SilverLining*^{TM} *and Delta*^{TM}*, is presented.*

Keywords: *Laser Scanning, Palaeontology*

1 Introduction

Palaeontology, derived from the Greek palaios (ancient), is the study of life in the past, based on plants, vertebrates and invertebrates, and encompasses biology, behaviour, evolution, ecology, autecology (the ecology of a single species) and synecology (community interaction). The discipline reconstructs earth's history based on the information left behind, which has many inherent biases. Only the most indestructible evidence is usually preserved, so muscle and tissue, skin and hair, eggshell and stomach contents are rare. What remains (usually the fossilised skeleton) of an animal can be used to infer the behaviours, biomechanics, and life strategies of the individual, and an assemblage of multiple individuals, or multiple species, may reveal how an ancient community was structured.

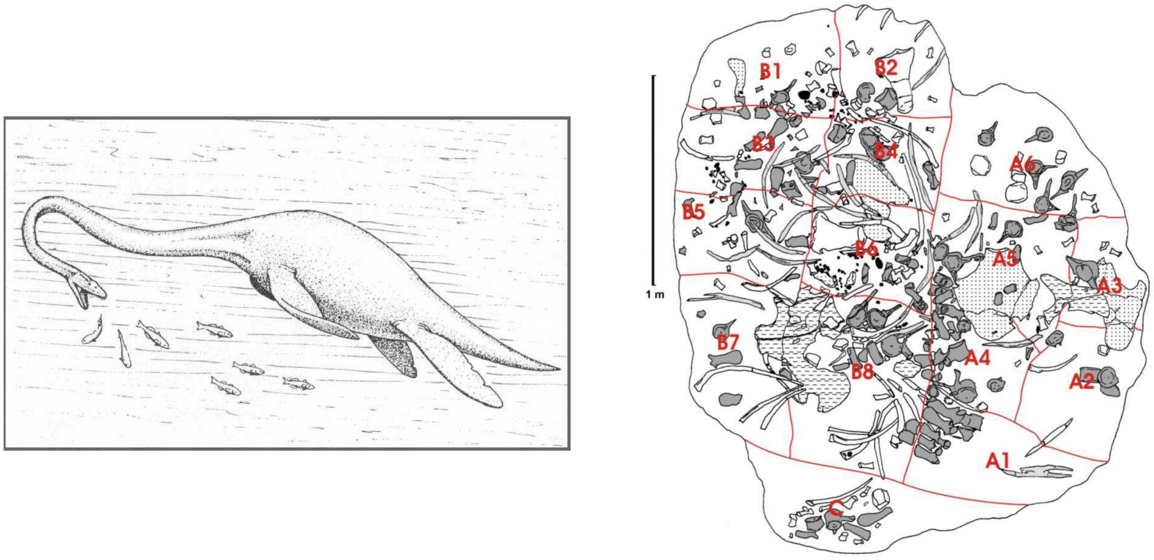
The application of laser scanning to Palaeontology produces 3D fossil replicas that palaeontologists can process, catalogue, study and share without the risk of damaging or destroying the original specimen. It also makes it possible to communicate their findings in an exciting and effective way, with applications to teaching and interactive museum displays. Recently, 3D laser scanners have been used in this area for the digitisation of large fossil skeletal elements [1], the study of dinosaur locomotion [2] and for 3D modelling of macrofossil material from a mosasaur [3].

Hand-held laser scanners are a popular tool for 3D digitisation. As the name applies, hand-held laser scanners consist of a non-contact range-finder based on projection and simultaneous detection of laser light, coupled with a means of tracking the position and orientation of the range-finder as it is scanned over the required region of the object's surface [4]. The Polhemus FastSCAN$^{\text{TM}}$ [5] is an extremely flexible scanner suitable for rapidly digitising irregularly shaped objects, such as a model or actual human body, and capable of modest resolutions and accuracy concomitant with the level of detail in these kind of surfaces [6]. It has found application in many medical applications from immobilisation casts in radiotherapy to assessment of facial swelling in dentistry [7]. In addition, it has been used in the 3D scanning of toys, in games, film, advertising and 3D web design [8]. However, its only application to the field of Palaeontology, as far as we are aware, has been for the 3D modelling of fossils in order to build a geological digital museum [9] as opposed to digitisation and reconstruction of large fossils.

We are using the FastSCAN laser scanner to digitise a 2m by 2m elasmosaurid plesiosaur fossil specimen. The motivation for this work was to separate bones that would have come to rest on the seafloor from those that would have penetrated the sediment. This paper discusses the preliminary stages in the digitisation, 3D representation and surface reconstruction of this fossil specimen.

2 Materials and Methods

The object to be scanned was the scattered and fossilised remains of an elasmosaurid plesiosaur (characterised by a long neck and a small head, see Figure 1(a)), a Cretaceous marine reptile. It was unearthed from the banks of the mid-Waipara River in north Canterbury, New Zealand, where it was found encased in stone. The remains were subsequently split into 15 sections, as indicated in Figure 1(b).



(a)

(b)

Figure 1: (a) Artists impression of a plesiosaur, reproduced from http://www.oceansofkansas.com/nz-aus/nzples1.jpg and (b) Map of the elasmosaurid plesiosaur fossil specimen.

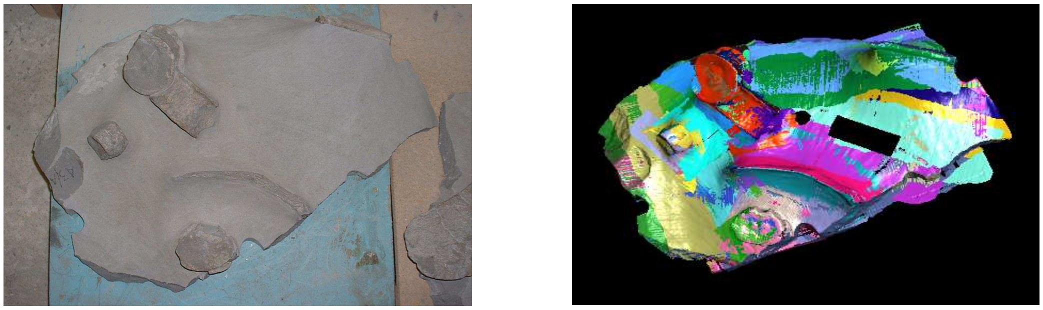
The FastSCAN laser scanner system used for the digitisation is comprised of the handheld unit known as a wand, the electronics processing unit (PU), the electromagnetic (e-m) reference and a laptop computer (see Figure 2(a)). The range finding optics are contained in the wand, which consists of a centrally mounted laser line generator and a miniature camera. The e-m tracker, also mounted in wand, allows the computer to determine the position and orientation of the wand at all times, and hence locates each profile relative to the transmitter. Both the video processing and tracker electronics are contained in the PU. The e-m reference generates a magnetic field that varies in 3D and is used to determine the position and orientation of each e-m tracker. Any metal in the vicinity that deforms the magnetic field will distort the computed position and orientation of the receiver, and hence distort the scanned image [10].

(a) (b)

Figure 2: Experimental Setup. (a) The FastSCAN system. (b) Specimen and electromagnetic reference.

Each block, of the 15 blocks making up the object, was placed on a wooden box to be scanned, raising it from the floor and any potential metal distortion (see Figure 2(b)). The transmitter is then placed in a central position on the block, fixing it with respect to the object. The operator points the wand at the object, and the camera on the wand records the intersection of the laser line and the object, i.e., a profile. The three-dimensional location of the profile with respect to the wand is computed using triangulation. The complete surface is scanned by smoothly sweeping the wand over different parts of the surface, collecting many profiles grouped into several sweeps. Multiple overlapping sweeps are usually required to scan an object. Scanning time for each block varied according to its size and detail, with the scanning taking on average 30 minutes for a block of dimensions 700x500x200mm.

The resulting cloud of points is then connected to form a polygonal mesh by a process of Delaunay triangulation [4]. Figure 3 illustrates block A2 and the corresponding raw scan surface, with the sweeps used to digitise it highlighted as different colours. A total of 60 sweeps were required to capture the detail, resulting in 989,196 points and 1,781,790 polygons or facets, with a total file size of 8.8MB. The raw scan data for the blocks scanned to date range in size from 3.3MB to 17.8MB.



(a) (b)

Figure 3: (a) Photo and (b) Scan of block A2. Each colour in (b) represents a sweep.

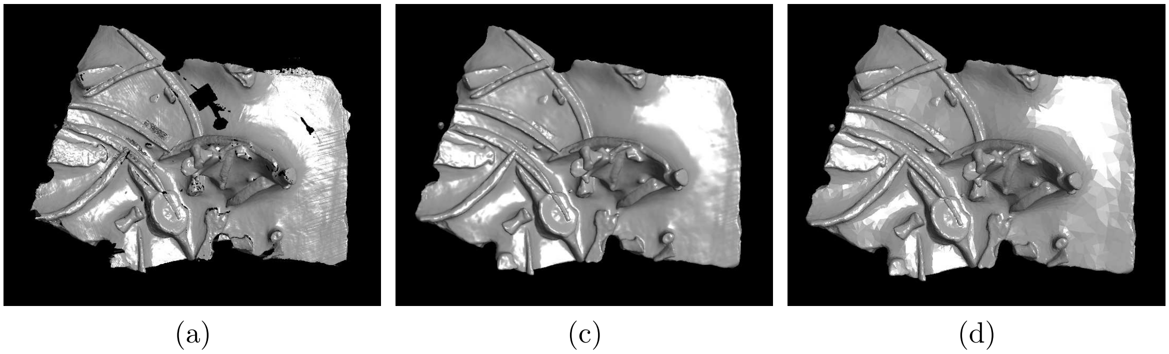
3 Data Processing

The data, which contains overlapping sweeps, is now registered, where registration refers to the process of bringing the sweeps into geometric alignment with each other. The sweeps will not always align perfectly, possible causes may include but are not limited to; small errors in tracker measurements, metal objects interfering with the magnetic locator and the transmitter being moved unintentionally during scanning [11].

The sweep registration is performed using a variation of Iterative Closest Point (ICP) [12] on each sweep with respect to all others, where ICP is an iterative alignment algorithm. Application to the raw scan data can significantly reduce the root mean square (rms) error of each sweep with respect to the other sweeps. For example, 10 iterations of ICP on block A2 reduced the maximum sweep rms from 2.54mm to 0.66mm. However, the large numbers of points and facets making up the raw data, means that this process is very memory intensive and time consuming on a typical desktop PC.

The registered raw data (see Figure 4(a)) is then loaded into FarField Technology SilverLining$^{\mathrm{TM}}$ and cropped, removing any unrelated points, e.g. those corresponding to the box the object was sitting on when it was scanned, and filtered, which involves the removal of clusters of outlying points, before surface normal vectors at each point are calculated. The surface is now modelled with a mathematical function known as a Radial Basis Function (RBF) [13]. This results in meshes with particular properties which are generally desirable, namely: the modeled surface is guaranteed to pass within a user specified tolerance of the input data, missing areas are smoothly interpolated over, extrapolated areas are generally well behaved, the generated mesh is hole-free and closed objects are water-tight, and finally noisy data can be smoothed [11].

A mesh is evaluated from the RBF model (see Figure 4(b)). A regular mesh generated from the RBF model, with these parameters, is very large, for example B5 which started out with 464,294 points and 917,243 facets in the raw data ended up with 548,219 points and 1,096,430 facets making up the RBF surface. It is possible to create a simplified mesh from the RBF model, hence we also performed a RBF feature based mesh simplification (see Figure 4(c)), which reduced the data to a more manageable level. For example, for B5 the RBF simplification reduced the number of points and facets to 191,177 and 382,346 respectively. This process is to be repeated for each block scanned.



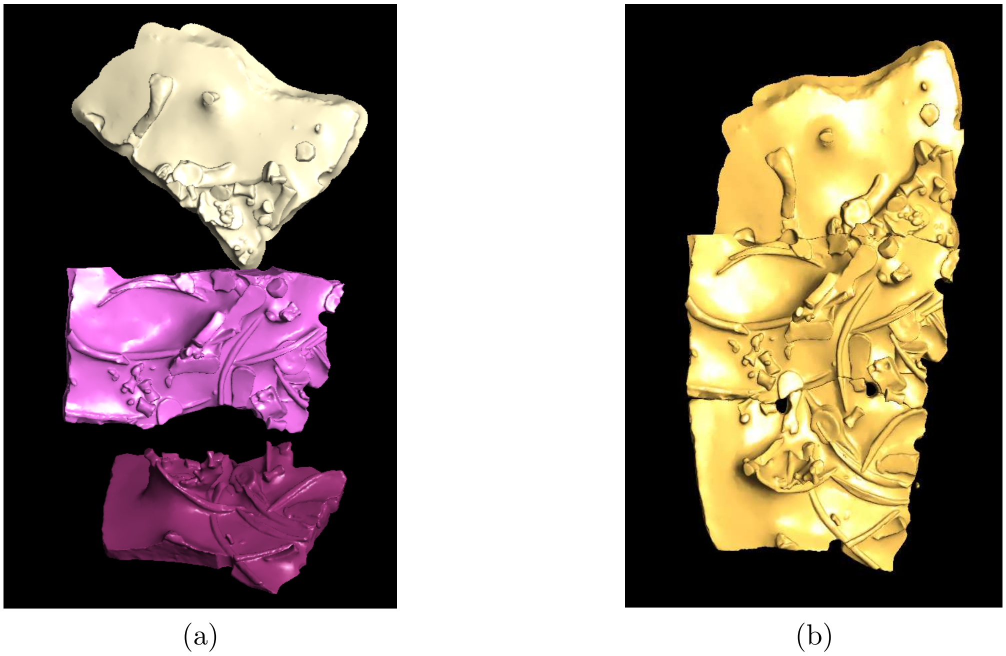
(a) (c) (d)

Figure 4: Block B5. (a) Raw Mesh, (b) RBF mesh and (c) Simplified RBF Mesh.

4 Reassembling the 3D blocks

Having generated accurate 3D models of several sections of the plesiosaur fossil, registration of the blocks with each other was now required to recreate the original object. The aim is to reassemble the entire object as seen in Figure 1(b). This was made more difficult as the blocks did not overlap. Manual alignment is possible, however the process is very time consuming and painstaking. Automatic alignment of the pieces was therefore required. This was achieved using FarField Technology Delta $^{\text{TM}}$, a scan comparison utility.

The pieces were loaded into Delta two at a time. A series of landmarks were then defined along the adjoining edges and a RBF variant of ICP employed to find the transformation that the second block had to undergo to minimise the landmark position errors. Obviously this method is only as accurate as the placement of the landmarks, and was easier for adjoining blocks containing detail that spanned the boundary. Very good results have been achieved to date using this approach, as illustrated in Figure 5.



(a) (b)

Figure 5: (a) Before and (b) After landmark based alignment of blocks B1, B3 and B5.

The reassembling of the original object is hindered by the size of the blocks, which still contain a large number of facets even after mesh simplification. The size is a direct function of the mesh resolution. It is likely that the resolution of each block will need to be reduced to enable the complete object to be reassembled in 3D using a standard desktop computer. This is currently being investigated.

5 Surface Reconstruction

After the original object has been assembled, the next task is to generate a single surface representing the entire object. Surface reconstruction from multiple range images involves three main steps; 1. Data acquisition from many range views, 2. Registration between different views and 3. Integration of the registered views [14]. Steps 1 and 2 were addressed in sections 2 and 4 respectively, and 3 is investigated here.

The merging of 3D meshes can be classified into unstructured and structured methods. Unstructured integration refers to the creation of a polygonal surface from an arbitrary collection of points in 3D space, whereas structured integration methods make use of information about how each point was obtained, such as using adjacency information between points within the one range [14]. The methods outlined here for the reconstruction of a single surface representing the plesiosaur fossil include both unstructured and structured approaches.

The first possibility is to revisit the points after the 3D object has been reassembled. Sweeps corresponding to edge information, redundant in the final surface, are removed and the complete surface is remodelled with a RBF. Since the RBF modelling is computationally intensive this may not be feasible for the entire object, but instead restricted to sections of it.

Another possibility involves the stitching of the adjacent triangle meshes to form a continuous surface [15]. Unfortunately, this 3D stitching process can be quite messy and does not always produce high quality meshes [16]. An alternative is to blend the range surfaces in a sampled volumetric space [17]. The application of these methods to this application is under investigation.

6 Conclusions

We have presented the preliminary stages in the digitisation and surface reconstruction of a large plesiosaur fossil. The processing methods investigated and presented here are restricted by the large size the object and are still ongoing.

7 Acknowledgements

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