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Single Camera Photogrammetry for Reverse Engineering and Fabrication of Ancient and Modern Artifacts

John Kaufman[a]*, Allan EW Rennie[a], Morag Clement[b],

[a]Engineering Dept., Lancaster University, Lancaster. LA1 4YR,UK
[b]Kendal Museum, Kendal. Cumbria. LA9 6BT,UK

*Corresponding author. Tel:- + 44 01524 594298; fax: +44 01524 381707. *E-mail address*; johnkfm@gmail.com

Abstract

Photogrammetry has been used for recording objects for well over one hundred and fifty years. Modern photogrammetry, or digital image capture, can be used with the aid of a single medium range digital single lens reflex (DSLR) camera, to transform two-dimensional images into three-dimensional CAD spatial representations, and together with the use of additive manufacturing or 3D Printing technology, geometric representations of original cultural, historic and geological artifacts can be fabricated in a process known as Reverse Engineering. Being able to replicate such objects is of great benefit in education; if the original object cannot be handled because it is too old or delicate, then replicas can give the handler a chance to experience the size, texture and weight of rare objects. Photogrammetry equipment is discussed, the objective being simplicity of execution for eventual realisation of physical products such as the artifacts discussed. As the processing power of computers has increased and become more widely available, and with the use of computer software programs it is now possible to digitally combine multi-view photographs, taken from 360° around the object, into 3D CAD representational virtual images. The resulting data is then reprocessed, with a secondary computer program, to produce the STL file that the additive manufacturing machines can read, so as to produce replicated models of the originals. Three case studies are documented: the reproduction of a small modern clay sculpture; a 3000-year-old Egyptian artifact; and an Ammonite fossil, all successfully recreated, using additive manufacturing technology.

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Keywords: photogrammetry; reverse engineering; DSLR camera; non-invasive reproduction; 123D Catch; PhotoScan; Studio Pro5; cultural heritage; education; additive manufacture.

1. Introduction

Three-dimensional (3D) imaging has been in existence since the invention of Lenticular's Stereoscope in 1860. Thus, the idea of a two-dimensional (2D) image being converted to a 3D image is not new. Photogrammetry, as it is referred to, "is the practice of determining the geometric properties of objects from photographic images and is as old as modern photography" [1] and dates from the mid-nineteenth century. Since the late 1990's, Laser Scanning (LS) has moved to the predominant non-invasive method used to replicate both large and small objects, such as large historic buildings and small statues.

The first digital camera was invented in 1975 by Sasson, who was an engineer working for Eastman Kodak® [2]. These cameras have developed from the low resolution 0.01megapixel early camera to 60 or 80 megapixels at the top end of today's professional range. Photo-manipulating/enhancing computer programs have been able to stitch 2D digital photo images together for a number of years, creating panoramic views of city, sea or landscapes [3]. More recently, with the help of i5 and i7 CPUs and the large amount of RAM that modern computers can now accommodate, software is available which is capable of stitching 150 or more, high resolution digital images together to form a virtual 3D representational image [4].

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2. Research Objectives

In this paper, it is shown that with the use of photogrammetry, virtual 3D models can be created, without a high level of computer expertise and without the use of relatively expensive or complicated 3D laser scanning equipment. Many software programs claim to be able to convert 2D digital photographs into 3D virtual images. On investigation, it has been found that many are still in development and are not necessarily available for use except experimentally. Several commercial computer programs are available with a proven and reliable record to “stitch” multi-view digital images together to produce a 3D image.

Two programs were used in this research for the primary software processing of the digital images [4, 5]. In addition, the high resolution point cloud images produced were filtered and converted to STL files by a third program [6], ready for additive manufacturing (AM) machines to replicate and produce geometric representational models. The use of this technique could contribute to the reproduction, restoration or repair of damaged or broken antiquities by non-invasive methods at modest cost and by laypersons, who are computer literate but not necessarily expert in the use of specialised software.

By using a relatively modest DSLR camera, expensive LS is not required to capture the data necessary to produce 3D virtual images, and experienced technicians are no longer required to operate such equipment. A comparison between photogrammetry and laser scanning, their techniques and characteristics has been shown in Barsantia et al [7]. The primary research task investigates how well these software programs convert the digital 2D image into AM models, and compares results obtained with the original object. The research investigates the tactile surfaces of the replicated models and compares them to the original objects; it considers whether those replicated models, when scaled up and down, lose surface detail and whether the AM models created could be substituted for the original.

3. Data Capture Methods

One of the main objectives of the research was concentrating on the ease of reproducing artifacts without complex hardware or software. A mid-range Nikon D3100® DSLR camera was used, the digital data obtained being in JPG, or common image format. A standard fixed focus prime 50mm lens, which has a wide f1.4 or f1.8 aperture and minimum lens distortion and very good depth of field, was considered, but a Nikon 18/55mm DX® auto focus lens was chosen, being directly compatible with the camera and able to automatically refocus around the subject from the many positions and angles encountered. Minimum lens distortion was achieved by keeping to the higher focal length end of 35/55mm on the lens. The disadvantage of this lens as opposed to a fixed lens is that the depth of field is not as good and slower shutter speeds are required as the aperture is not as wide. A resolution of 3456 x 2304 pixels per frame was used throughout, which equates to approximately 8 megapixels.

- **Method 1 – open room set-up**

The methods of lighting and camera positioning for the artifacts were different in each case study, the common factor being that shadowless, flat lighting was required to illuminate all the artifacts, as any shadow distorted the image captured and processed by the software. The same was true for any highlights or reflections that the lighting might have caused. In Fig.1 the windows are covered so as to diffuse the natural daylight and help create a shadowless room. The main indoor lighting consisted of two bip® fluorescent floodlight control units on telescopic stands, each with three separate switched 50W 5000K bulbs and white defusing front covers and, if needed, two small lamps with 45W 5500K bulbs. Indirect daylight was utilised if available. Any small difference in colour temperature, known as White Balance, was automatically adjusted by the D3100 camera “as digital cameras have a far greater capacity to compensate for the varying colours of light” [8].

The first study, a small modern clay head sculpture, has been included to show a comparative method in both AM printing and data capture. This semi-glazed painted head, measuring 105mm x 95mm x 85mm, was placed in the centre of a room on a pedestal whilst the camera was moved in a full circle around the object and a digital image captured every 20°. The model clay head is seen, arrowed, in the centre of the room (Fig.1).

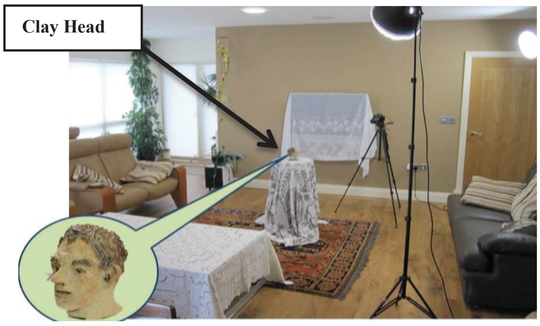

Fig. 1 Indoor Open Room Setup

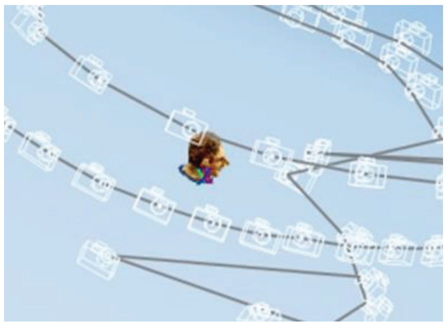

Fig. 2 Multi Camera positioning around Clay Head