Science & Justice xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Science & Justice

journal homepage: www.elsevier.com/locate/scijus

Technical note

# A new method for the recovery and evidential comparison of footwear impressions using 3D structured light scanning

T.J.U. Thompson*, P. Norris

*School of Science, Engineering and Design, Teesside University, Borough Road, Middlesbrough TS1 3BX, United Kingdom*

ARTICLE INFO

*Keywords:*
Forensic evidence
Footwear impression
Non-contact scanning
Structured light
Rapid prototyping
Digital transformation

ABSTRACT

Footwear impressions are one of the most common forms of evidence to be found at a crime scene, and can potentially offer the investigator a wealth of intelligence. Our aim is to highlight a new and improved technique for the recovery of footwear impressions, using three-dimensional structured light scanning. Results from this preliminary study demonstrate that this new approach is non-destructive, safe to use and is fast, reliable and accurate. Further, since this is a digital method, there is also the option of digital comparison between items of footwear and footwear impressions, and an increased ability to share recovered footwear impressions between forensic staff thus speeding up the investigation.

## 1. Introduction

Footwear marks and impressions are a common form of evidence left at a crime scene [21]. Although the majority of casework will involve two-dimensional recording methods, the potential of using three dimensions is great. Traditional methods used to recover three-dimensional (3D) footwear impressions involve taking two-dimensional (2D) colour photographs [6,16], and creating a physical cast off the impression. These photographs can capture unique features of the impression but they do not adequately provide metric depth measurements of these features [13]. Further, the quality of the photograph, the type of camera film used, and the presence of shadows cast across the impression can reduce their usefulness [6]. A physical cast, in contrast, can overcome these issues and be an effective supplement to the analysis of these characteristics.

Nonetheless, there are some considerations that need to be taken into account before producing a cast, such as the need to ensure the correct technique for making the casting material and then subsequent produce the correct consistency of casting material, and the fact that evidence is often destroyed during the actual casting process [1,23]. It has been noted generally that there is little substantive research investigating the most appropriate practice in the field [4]. Some substrates such as sand and snow can prove to be particularly problematic substrates to recover impressions from [20], since sand is very fragile and snow melts during the exothermic reaction of the casting material. One approach to this has been to spray the impression with a fixative to highlight the detail before the dental stone can be poured in [4,14], while another has been to use foam blocks [20]. Both approaches demand physical intervention with the impressions which ultimately reinforces the notion that there is only one chance to recover an impression – regardless of how significant it is to the investigation.

Due to these factors, practitioners have been looking to alternative methods of recovering footwear impression evidence. Studies have been conducted into the use of 3D laser scanners (e.g.: [8,13,15]), and other techniques of 3D imaging (e.g.: [2]). Digital and 3D scanning approaches offer several potential benefits to practitioners, including greater efficiency in contexts with multiple overlapping footwear impressions since once the scan data has been acquired, it is then possible to segment the image to highlight the individual footwear impressions. Although these digital laser scanning techniques have shown promise, they do come with their own sets of caveats. These have included the questionable accuracy of measurement, the missing data, incomplete 3D models, and unacceptable levels of noise when used on dark or reflective/metallic surfaces [8]. This last point is a function of beam absorption or reflectance on these surfaces [3].

Nevertheless, non-contact scanning seems to offer great potential due to its non-destructive nature. Therefore, this research introduces the use of an alternative method – that of structured light scanning. Structured light scanners are already being used successfully in other areas of research, such as anthropology and architecture (see for example, [5,9,18,19,22]). In addition to collecting 3D morphological data, structured light scanners capture colour information during the acquisition process. In contrast, laser scanners often require colour to be mapped onto the 3D data during the subsequent processing stage [11]. Other potential advantages of structured light scanning include cheaper equipment and high resolution combined with high efficiency.

* Corresponding author.
*E-mail address:* t.thompson@tees.ac.uk (T.J.U. Thompson).

https://doi.org/10.1016/j.scijus.2018.02.001
Received 29 June 2017; Received in revised form 21 December 2017; Accepted 1 February 2018

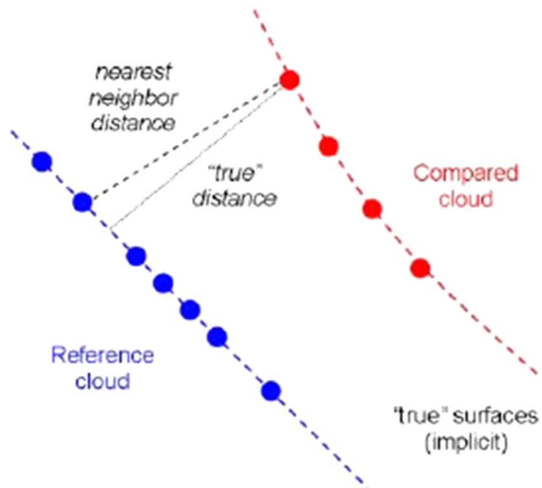


**Fig. 1.** Cloud-Cloud distances are computed by using the default "nearest neighbour distance" http://www.danielgm.net/cc/.

Structured light scanners like the one used in this research are also portable.

This research project had two aims, which were explored using a controlled, laboratory-based set of experiments. The first is to assess the ability of structured light scanning to recover footwear impressions from different substrates. The second was to determine whether the 3D scan of the footwear impressions and the footwear outsoles could be compared using readily-available computer software. Although an assessment of the accuracy of this method for actual use in the courts was not an aim of this study.

## 2. Method

A PicoScan (4D Dynamics, Belgium) 3D structured light scanner, comprising a Cannon EOS 1100D camera and a vertically mounted Pico projector connected to a laptop, was used in this study. The PicoScan was chosen as it has been shown to be effective in recording and supporting the analysis of material of forensic interest and best practice guidance has been published [10,11]. The scanner must be calibrated using a geometrical calibration. In order to do this, intrinsic, extrinsic and radiometric properties have to be determined. This is a straightforward process that can be achieved in the laboratory or in the field. A checkerboard is used during the calibration process. The camera's optical focal length and the intensity of the projector will determine the size of the checkerboard to be used. During this study a checkered pattern of $21 \times 15$ squares of 11 $mm^2$ was used. An important aspect of recovering forensic evidence is the accuracy in which it is obtained [19], and this method of calibration has been demonstrated to provide a point accuracy of 0.1 mm [9].

Once the scanner has been successfully calibrated the footwear impression to be scanned can be put into the view of the camera. It is important that the projector and the camera's lens are not moved following the calibration procedure because it can affect the accuracy of the results. The mounted projector emits a known pattern of light resulting from this calibration process onto the footwear impression. The presence of the 3D impression deforms the pattern of light, which the camera then records and stores. The scanner must then be moved around the footwear impression (or vice versa) to ensure that the impression is imaged from all angles. After the acquisition of the scan data, the software 'Process' allowed the researcher to stitch together all of the individual scans taken from each angle to create one final watertight 3D model. Subsequently, noise (unwanted data caused by the reflection of light) that was created during the scanning process was removed. The final model was exported in a number of different standard file formats, including .ply, .obj and .stl. As the method is noncontact if a problem occurred during the scanning process, the process could simply be repeated.

Following export of the final models (which averaged a relatively small ~50 kb), the files were uploaded into CloudCompare (http://www.danielgm.net/cc/) and MeshLab (http://www.meshlab.net) for measurement and analysis. These software packages were chosen because they are freely available to download and therefore are available to all practitioners, regardless of budget. There are many functions

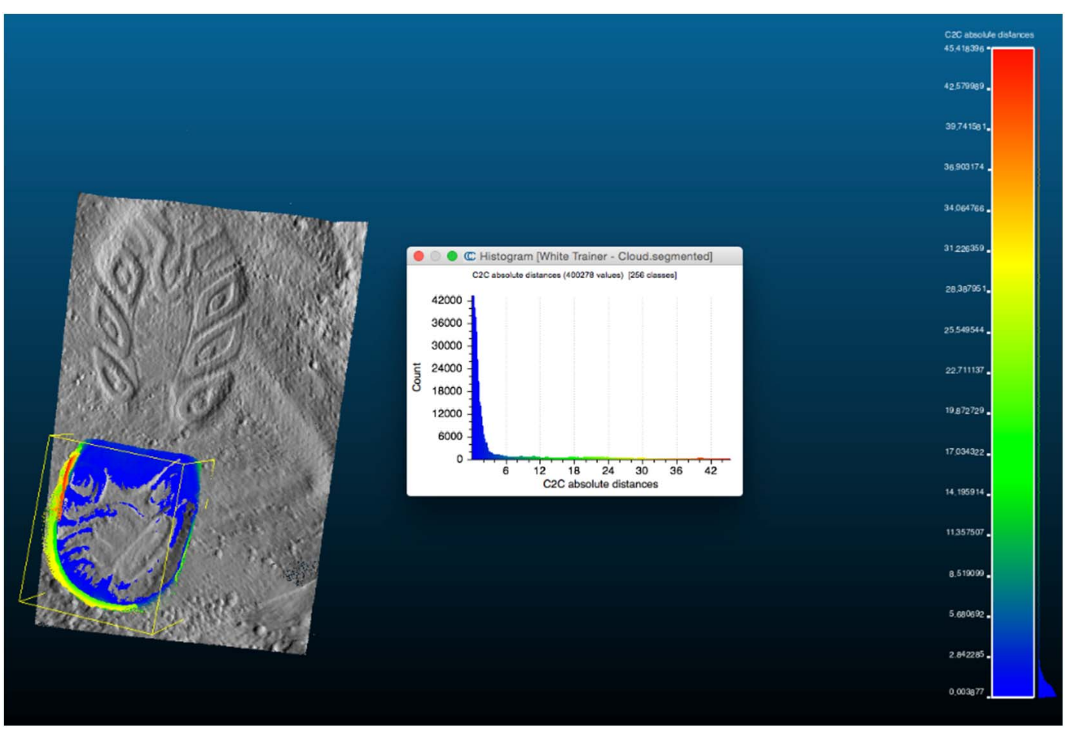


**Fig. 2.** Computed scalar field after alignment.