RESULTS FROM 3D-FORENSICS - MOBILE HIGH-RESOLUTION 3D SCANNER AND 3D DATA ANALYSIS FOR FORENSIC EVIDENCE

This paper was published in 10th Future Security, Security Research Conference;
Berlin, September 15 -17, 2015; Proceedings; Jürgen Beyerer, Andreas Meissner, Jürgen Geisler (Eds.) (ISBN 978-3-8396-0908-8) page 113

RESULTS FROM 3D-FORENSICS - MOBILE HIGH-RESOLUTION 3D-SCANNER AND 3D DATA ANALYSIS FOR FORENSIC EVIDENCE

Stephen Crabbe[1], Peter Kühmstedt[2], Roland Ramm[3], Andre Hendrix[4], Peter Smolders[5], Willem van Spanje[6], Boreas Hesselink[7], Giorgio Maria Vassena[8], Matteo Sgrenzaroli[9], Max Lucas[10] and Marc Oberholzer[11]

[1] *stephen.crabbe@crabbe-consulting.com*
Crabbe Consulting Ltd, Allerheiligenstr. 17, 99084 Erfurt (Germany)

[2] *peter.kuehmstedt@iof.fraunhofer.de,* [3] *roland.ramm@iof.fraunhofer.de*
Fraunhofer IOF, Albert-Einstein-Straße 7, 07745 Jena (Germany)

[4] *andre.hendrix@zeeland.politie.nl,* [5] *peter.smolders@zeeland.politie.nl*
Politie Zeeland-West-Brabant, Bezoekadres Ringbaan West 232, 5038 KE Tilburg (Netherlands)

[6] *wvspanje@delfttech.com,* [7] *bhesselink@delfttech.com*
DelftTech BV, Motorenweg 12, NL-2623CR Delft (Netherlands)

[8] *giorgio.vassena@gexcel.it,* [9] *matteo.sgrenzaroli@gexcel.it*
GEXCEL Srl, via Branze 45, I-25123 Brescia (Italy)

[10] *max.lucas@lucas-jena.de*
LUCAS Instruments GmbH, Hermann Lons Straße 2, 07745 Jena (Germany)

[11] *marc.oberholzer@enclustra.com*
Enclustra GmbH, Technoparkstr. 1, CH-8005 Zurich (Switzerland)

Abstract

This paper presents the latest results of the 3D-Forensics project to develop a mobile high-resolution 3D scanning system for the recovery and analysis of footwear and tyre impression trace evidence left at crime scenes towards the end of the project's completion. The prototype 3D-scanner and analysis software are presented together with the test and evaluation methodology and the results of laboratory and field testing to date.

Keywords: forensics; crime scene; footwear impressions; tyre impressions; 3D; scanning; fringe projection; digital data.

1 INTRODUCTION

The 3D-Forensics project is developing a mobile high-resolution 3D scanning system for forensic evidence recovery at crime scenes, specifically for footwear and tyre impressions. The traditional techniques to capture these traces are typically photography or plaster casting but both techniques have disadvantages e.g. photographs contain no depth information and plaster casting is very time-consuming. Our technological approach is designed to overcome such disadvantages. Footwear and tyre impressions as well as profiles are recorded and analysed in 3D and colour enabled through optical scanning technology. 3D data analysis and processing software tools have been developed for both the investigation of crime scenes and prosecution of criminal suspects. This paper will present the prototype scanner and analysis software realised and the results of the prototypes' test and evaluation and end user feedback to date.

2 PROTOTYPE 3D-SCANNER

The first part of the developed system is a 3D-scanner that is used directly at crime scenes. It captures footwear and tyre impressions quickly. The scanning technique is based on "fringe projection" combined with high resolution colour images. A sequence of fringe patterns is projected onto the scene while two cameras capture them from slightly different positions. This technical approach enables the calculation of a highly resolved 3D point cloud of the scene [1]. Colour images are taken by an attachable high resolution camera simultaneously with the 3D measurement. They can be later mapped onto the 3D point cloud to distinguish between characteristics in the impression trace and distortions such as small stones or leaves. Fig. 1 shows the complete prototype scanner with attachable high resolution camera.

Fig. 1 Complete prototype 3D-scanner

Fig. 2 3D-Scanner prototype in travelling case

The prototype comes equipped with an outdoor travelling case including reserve batteries, recharging devices and calibration pieces (Fig. 2). The 3D-scanner is used handheld or mounted on a tripod. Fig. 3 shows the handheld usage of the scanner. For bright outdoor conditions the scanner can be combined with a quickly assembled shadow box to avoid interference (Fig. 4).

Fig. 3 Handheld scanning with the 3D-scanner

Fig. 4 Scanning with the 3D-scanner using tripod and shadow box under bright outdoor conditions

The measurement volume of a single 3D-scan is 325 x 200 x 100 mm^3. The lateral resolution is determined by a point pitch distance of 0.17 mm. A height resolution of 0.04 mm is achieved. The high level of detail in the 3D-scan is shown in Fig. 5.

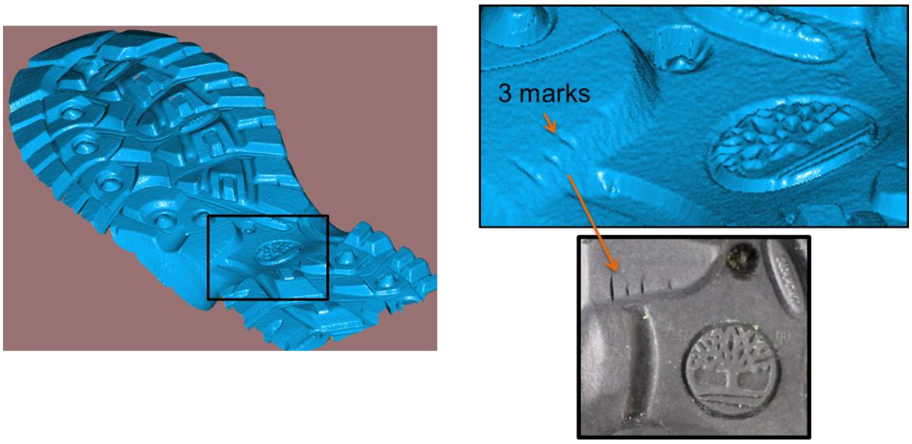

Fig. 5 High level of detail allows the detection of identification marks in 3D-scans

The 3D scanner can be used outdoors for approximately 40 minutes using rechargeable batteries which are integrated into the sensor head. For each measurement, the 3D scan result is processed and presented after some seconds in a preview. The captured colour image is presented as well. All scans are saved in a project structure, including further meta-information such as time and date, user name and brightness settings. The data from the scanner is transferred password protected and by USB-stick to the analysis software.

3 ANALYSIS SOFTWARE PROTOTYPE

The second part of the developed system is the 3D analysis software “R^3 Forensic” which is used by forensic experts in the office. The data import is realized simply by opening a dedicated project file i.e. a file for the crime scene. All scans and colour images taken in that project are opened in the correct structure. Once the data from the 3D-scanner has been uploaded to the analysis software in a first step it is prepared for the subsequent analysis step. Different shading variants are calculated which are later used to emphasize marks in the 3D-data. Optionally, if an impression was larger than the single field of view of the scanner, such as from a tyre, then multiple scans can be “stitched” together with a cloud to cloud registration process (Fig. 6).

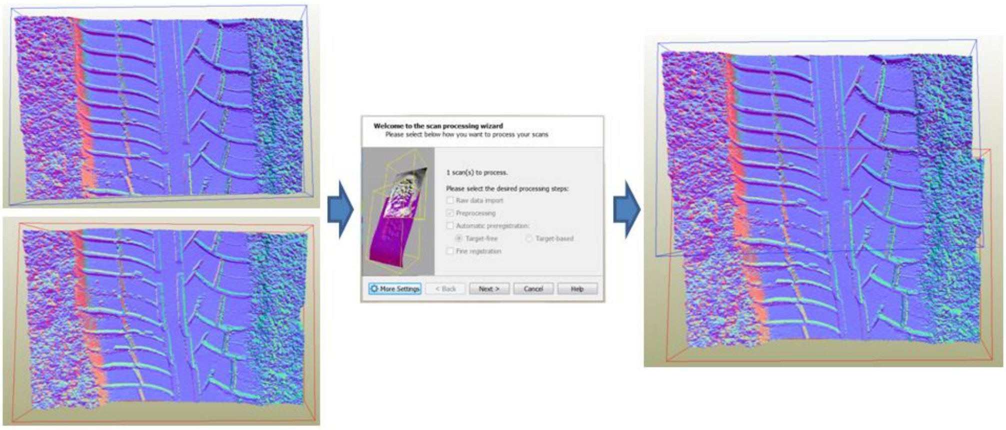

Fig. 6 Wizard guiding the user in the registration process of two scans covering two partially overlapping areas of the same tyre impression

In a further step the high resolution colour data is mapped onto the 3D data (Fig. 7).

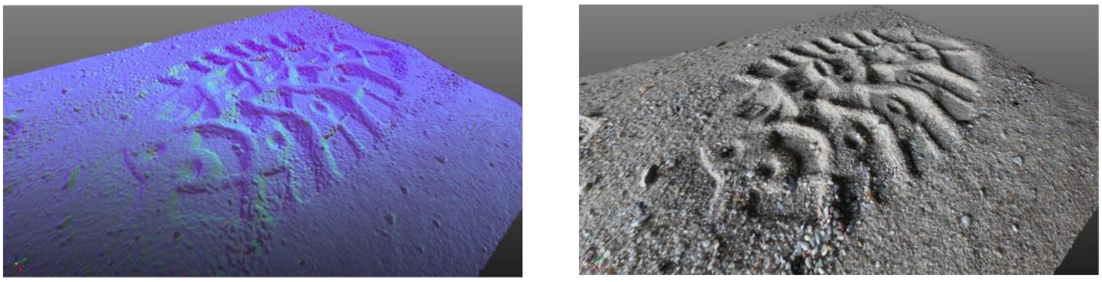

Fig. 7 Left image showing the pure 3D-data and right image with projected colour information showing that small rises are small stones from the underground and not a part of the impression trace itself

The integrated 3D measurement and colour data can then be analysed with the software to investigate characteristics of the footwear and tyre impressions. Class characteristics are determined by the user by comparing the impression with images from manufacturers’ or other databases. Individual identification characteristics can be marked by the user with an annotation tool (Fig. 8). The set of possible individual marks is defined by the forensic experts beforehand according to the special rules in their country or region.

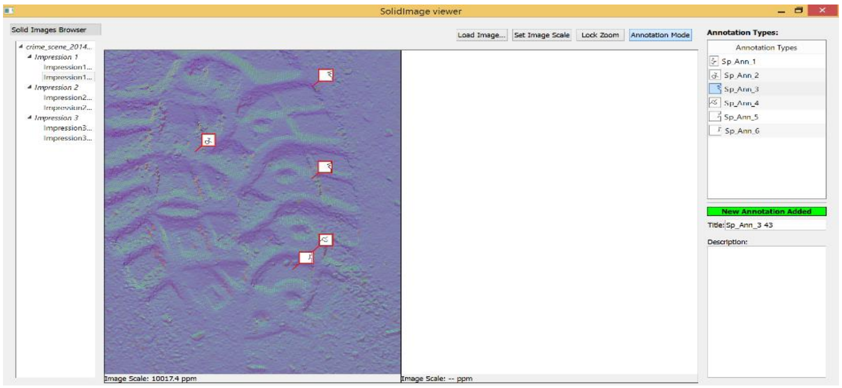

Fig. 8 Annotation tool of the R3 Forensic software which can be tailored by the users

There are further tools that allow the comparison of footwear and tyre impressions with suspects’ shoes and/or vehicle tyres and other crime scenes. Two 3D-scans can be presented in two opposite windows. The user can move and zoom through both scans to identify similarities or differences (Fig. 9).

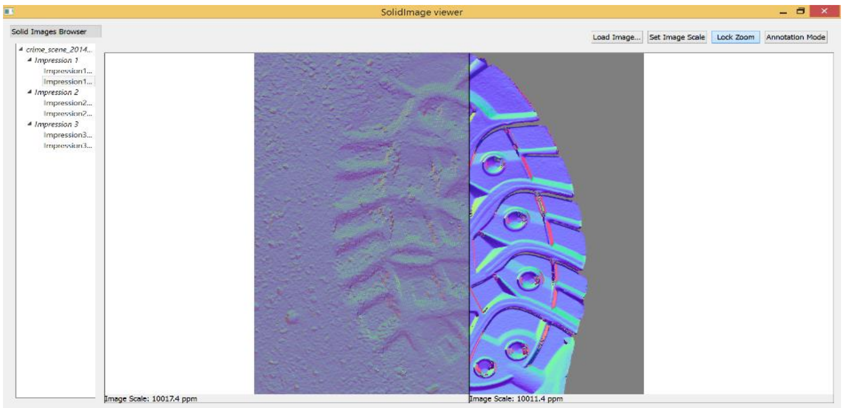

Fig. 9 An example of R3 Forensic software comparison tool

There are several possibilities to insert measurable annotations (profiles, 3D polylines), to export and to document analysis results for further reporting purposes. The data recording and analysis tools have been designed to ensure that the expert assessment obtained with the 3D-Forensics system will be admissible as expert evidence in court. The original raw data is never changed by the software. Each analysis step is logged and can be undone. A further focus in the development was simplicity and clarity of the software.

Fig. 10 provides an overview of the workflow of the 3D Forensics system. From left to right: scanning process, data processing, comparison analysis and specific analysis.

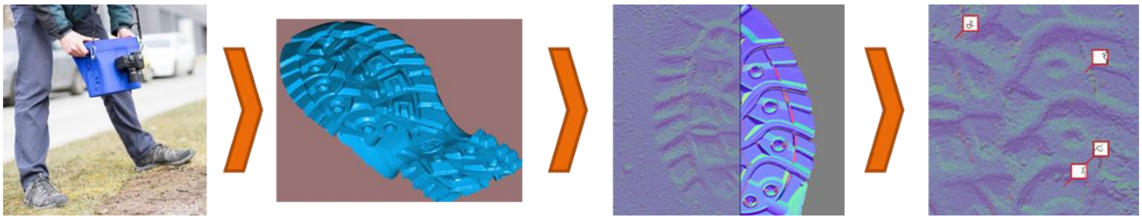

Fig. 10 Overall workflow of 3D Forensics system from scan to analysed impression traces that can be used in court

Prospectively the analysed data can be structured in a database, which contains information about each case and impression. This would allow easy research of footwear and tyre impressions that were present at different cases and can be used as a tool for forensic intelligence e.g. matching traces of the same footwear found at different crime scenes.

4 ORGANISATION OF TEST AND EVALUATION

The test and evaluation of the prototype system, consisting of the 3D-scanner and analysis software, has been organized in four phases.

In Phase I, “Technical characterization”, the basic characteristics of the system, both hardware and software, were documented by performing individual standalone tests. These tests were not dedicated to footwear or tyre impressions solely, but rather to define the operational functionality of the system.

In Phase II, “Reference testing”, the prototype scanner and its complementing software were used to scan and analyse actual footwear and tyre impressions. Within this phase, almost ideal conditions were simulated and used in an indoor laboratory environment. Impressions were also taken with dental cast and photographed in order to compare the results achieved with traditional methods of impression registration and analysis and those achievable with 3D-Forensics.

Phase III “Field testing” contains outdoor filed tests, test scenarios are being developed with representative footwear and tyre impressions, including varying environmental conditions. These tests though still under controlled conditions are enabling a good evaluation of the scanner and analysis software performance parameters in situations close to those expected at crime scenes. Here traditional techniques will also be compared to the results from the new system.

Phase IV “Expanded reference and field testing” will bring the knowledge gained from the previous tests together and simulated scenarios as close as possible to actual crime scenes will be tested up to the expected performance parameters of the system. Here traditional techniques will also be compared to the results from the new system.

At the time of writing Phases I and II have been conducted and Phases III is running and Phase IV will commence in July 2015. Phase I was carried out primarily by the technical developers Fraunhofer IOF, Lucas instruments, Enclustra and Gexcel and Phase II by DelftTech. DelftTech and the Police Zeeland-West-Brabant will primarily carry out the tests in Phases III and IV.

5 RESULTS

5.1 Phase I: Technical characterisation

The following Table 1 and Table 2 show the main characteristics of the 3D-scanner and an overview of the most important tools implemented in the analysis software.

Table 1 Main technical parameters of the 3D-scanner

Parameter	Value
Field of view	325 x 200 mm² (single field)
Measurement height	100 mm
Working distance	455 mm
Resolution	Lateral: 0.17 mm (point pitch distance) / Vertical: 0.04 mm
Accuracy	< 50 µm
Weight	3.6 kg (with attachable digital colour camera 4.4 kg)
Battery time	40 min
Time to scan	< 500 ms
Processing time	10 – 20 seconds
Colour quality	20 MPx / resolution ca. 0.08 mm

Table 2 Most important tools implemented in the 3D analysis software

Tool	Description
Alignment	▪ Semi-automatic stitching of multiple scans e.g. tyre track
Colour mapping	▪ Automatic projection of the external colour image onto the 3D point cloud
Class characteristics	▪ Loading images from manufacturer or other databases ▪ Comparison with actual scanned footwear or tyre impressions
Specific characteristics	▪ Creation of user defined identification marks e.g. scratch types ▪ Marking of identification mark positions within the scan data
Measuring tool	▪ Easy measuring of distances within the scan data e.g. shoe size and width
Distance map	▪ Coloured drawing of the height profile of the impressions e.g. to visualize the depth of the impressions
Annotation	▪ Inclusion of comments at defined positions inside the scan data
Section tool	▪ Visualizing of sections through the point cloud

5.2 Phase II: Reference testing

The reference testing was performed using two representative shoes and a single separate tyre. Impressions were created in boxes with different underground materials: sand, clay, soil and mortar (Fig. 11).

Fig. 11 Boxes with different ground materials, from left to right: sand, clay, soil & mortar

The surfaces are common at crime scenes and all have different structures and brightness. Tests were carried out indoors under controlled conditions. (Snow will be tested at an indoor snow slope later in the project.) Every underground was scanned by using different brightness settings and scan modes (scan modes correspond to different fringe pattern sequences). The handheld and tripod mounted operation modes for the 3D-scanner were also compared

Fig. 12 shows the comparison between the original shoe, the photographed impression in sand and the 3D data (with inclination shading) collected. The result for sand is very clear and has a high level of detail. The results of the other surfaces show that the quality of the impression itself is very much dependent on the surface structure. It is more difficult to obtain detailed impressions in clay and soil. When the impression has a good quality the 3D scan captures enough level of detail to perform a forensic comparison with the original shoe. The captured 3D and colour data was successfully uploaded into the dedicated "R³ Forensic" analysis software by importing the corresponding project file and it was successfully prepared for analysis. The analysis tools provided a convenient means for analysis of the data by forensic experts.

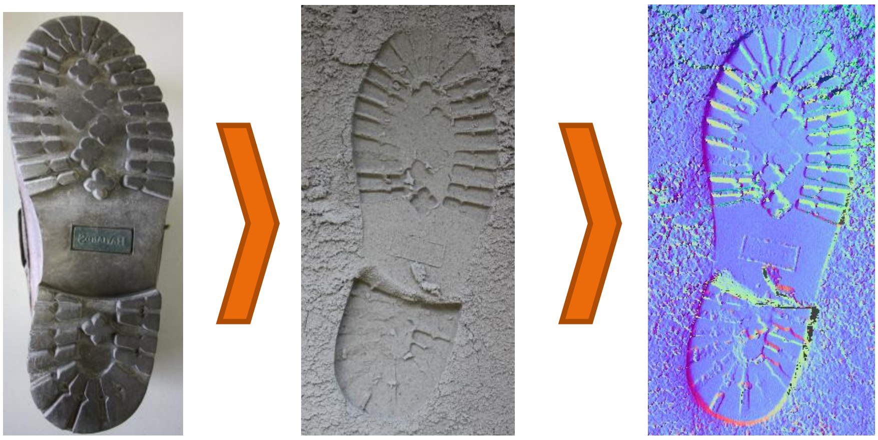

Fig. 12 Comparison of shoe, photograph and 3D data of impression in sand under laboratory conditions

5.3 Phase III: Field testing

The field testing is being performed with the same underground materials as the reference testing before. At the time of writing the first experiments have started under outdoor conditions.

Fig. 13 shows the comparison between an original shoe, the photographed impression in clay, the plaster cast and the 3D data (with inclination shading) collected.

Fig. 13 Comparison of shoe, photograph, plaster cast and 3D data of impression in clay under field conditions

The comparison between the plaster cast and the 3D data shows that the 3D data has more fine details that match with the original shoe. The 3D data also looks less irregular than the plaster cast. The outdoor experiments have also confirmed that the amount of surrounding light is an important disturbing factor. Using a shadow box reduces interferences strongly and improves the scan results. Forensic experts are able to compare and analyse the captured 3D data using the dedicated "R³ Forensic" under the more difficult circumstances of the testing in Phase III compared to Phase II.

5.4 Assessment of results to date

The tests carried out together with discussions with forensic experts are the basis for the following assessment. Forensic experts are very interested in having a 3D-scanner to obtain data from footwear and tyre impressions as they expect a number of operational advantages (detailed in [1]), but particularly faster recovery and analysis of the traces and because there is a general move to storing evidence digitally. In the past, the resolution of 3D-scanners which could be used at crime scenes was not enough to capture the tiny identification marks in the impressions. The tests indicate that the resolution of the 3D-Forensics system achieves this requirement. The software "R³ Forensic" dedicated to this application is a further advantage. It allows an analysis of the new 3D data in a way in which forensic experts are used to working with traditional techniques.

6 OUTLOOK

Test phases III and IV must prove the usability of the system in the field environment. As a next step, the prototype would be engineered into a product and commercialised. The main barrier to commercialisation is expected to be financial risk in connection with the investment to engineer a product without the certainty that police forces have the capital resources to procure the product. Commercialisation of the product would be supported through its validation within a relevant certified process. Future development activities could include, for example, extended functionality to enable automatic comparison of 3D data as an optional filtering support for forensic experts.

7 CONCLUSION

Optical 3D-scanning enables quick and contactless capturing of impression traces with detailed information. The analysis of digital 3D-data instead of plaster casts will ease the work of forensic experts and will enable increased linking of data from different crime scenes. 3D-Forensics has delivered a 3D-scanner prototype with integrated analysis software. The technical characterization results indicate that the technical requirements derived from the user requirements have been achieved. Reference and filed testing to date indicate that the system can provide finer 3D details than traditional techniques but that when surrounding light is strong a shadow box must be used. Further field testing and evaluation was on-going at the time of writing.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°. 312307, http://www.3D-Forensics.eu. The project started in 2013 and ends in August 2015.

REFERENCES

[1] Crabbe, S., Kühmstedt, P., Vassena, G. M., van Spanje, W., and Hendrix, A. (2014). *3D-Forensics – Mobile High-Resolution 3D Scanner and 3D Data Analysis for Forensic Evidence*. 9th Future Security - Security Research Conference; Berlin, September 16 -18, 2014; Proceedings; Klaus Thoma, Ivo Häring, Tobias Leismann (Eds.) (ISBN 978-3-8396-0778-7) pp 215-222.