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Testing photogrammetry-based techniques for three-dimensional surface documentation in forensic pathology

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ABSTRACT

Three-dimensional surface technologies particularly close range photogrammetry and optical surface scanning have recently advanced into affordable, flexible and accurate techniques. Forensic postmortem investigation as performed on a daily basis, however, has not yet fully benefited from their potentials. In the present paper, we tested two approaches to 3D external body documentation – digital camera-based photogrammetry combined with commercial Agisoft PhotoScan® software and stereophotogrammetry-based Vectra H1®, a portable handheld surface scanner. In order to conduct the study three human subjects were selected, a living person, a 25-year-old female, and two forensic cases admitted for postmortem examination at the Department of Forensic Medicine, Hradec Králové, Czech Republic (both 63-year-old males), one dead to traumatic, self-inflicted, injuries (suicide by hanging), the other diagnosed with the heart failure.

All three cases were photographed in 360° manner with a Nikon 7000 digital camera and simultaneously documented with the handheld scanner. In addition to having recorded the pre-autopsy phase of the forensic cases, both techniques were employed in various stages of autopsy. The sets of collected digital images (approximately 100 per case) were further processed to generate point clouds and 3D meshes. Final 3D models (a pair per individual) were counted for numbers of points and polygons, then assessed visually and compared quantitatively using ICP alignment algorithm and a cloud point comparison technique based on closest point to point distances.

Both techniques were proven to be easy to handle and equally laborious. While collecting the images at autopsy took around 20 min, the post-processing was much more time-demanding and required up to 10 h of computation time. Moreover, for the full-body scanning the post-processing of the handheld scanner required rather time-consuming manual image alignment. In all instances the applied approaches produced high-resolution photorealistic, real sized or easy to calibrate 3D surface models. Both methods equally failed when the scanned body surface was covered with body hair or reflective moist areas. Still, it can be concluded that single camera close range photogrammetry and optical surface scanning using Vectra H1 scanner represent relatively low-cost solutions which were shown to be beneficial for postmortem body documentation in forensic pathology.

1. Introduction

Verbal description combined with two-dimensional photography presents the gold standard utilized throughout the entire process of postmortem examination, documenting corpse's state of preservation, the presence of unique somatic traits, external and internal injuries and/or pathological changes [1–3]. A careful and precise documentation of an original pre-autopsy state, perishable findings and sequential steps of an autopsy allows preserving forensic evidence and enables other specialists to revisit the original conclusions, prevent misdiagnoses and maintain a high level of quality control.

It has been well-established that 3D surface documentation surpasses 2D photography at various levels. For any physical evidence it offers a three-dimensional representation where all

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three dimensions are equally present without one of them being discarded or distorted. 3D surface data are fitted to be subjects of indirect measuring (body measurements, angles of penetrations), comparison of multiple types of forensic evidence, such as pattern injuries against injury-inflicting instrument in weapon analysis [4,5], bone injuries [6], identification [7–9] or advanced morphometric analysis [10].

Nowadays, three-dimensional surface documentation can be conducted by a variety of devices involving a reasonably long learning curve [11]. For human body, technologies based on laser or white light scanning, passive photogrammetry, video-imaging in conjunction with infra-red sensors, radio sources or contact measurement may be employed. Laser surface scanners are based on laser beams, which move slowly across the scanned surface and reflect back to a light sensor. For the majority of systems the process demands that the scanned object avoids any motion for a longer period of time. In the forensic setting this is plausible for examining crimes scenes [12], corpses and skeletal remains [13] or other forensic evidence, such as weapons (shotgun, knife) or personal belongings (accessories, dental prosthetics, dental casts, etc.) [14], but is not preferred for living persons [7]. It is one of the major shortcomings of laser scanning technology that resulting 3D digital models do not include information about original texture coloring unless a device is equipped with an optical camera system, e.g., NextEngine, or texture is transferred onto the surface using an appropriate editing application, e.g., Meshlab.

3D optical surface scanning systems, in contrast, are two or more optical camera units that capture the flash light reflection of the object's surface at different angles (passive photogrammetry). Digital images taken by converged cameras then enable to recompose surface depth information by computing 3D surface points following basic triangulation rules and to include high-resolution texture. Or, they compose of a camera system and a projection unit emitting structured light, i.e., a pattern or multiple patterns, which images on the surface are then recorded. Distortion of the light pattern and camera calibration parameters are the sources of depth information. The stereo-photogrammetry process requires for the scanned object to remain motionless for only a second or two which is easily achievable in deceased human bodies, but also represents minimum issues or discomfort for documenting living persons. Conversely, structured light-based devices, such as ATOS scanners, require more controlled conditions while producing high-resolution surface data of various volumes. This becomes beneficial in forensic pathology, where needs for documenting an entire body or for instance subtle impressed cranial fracture [6] may occur on a daily basis.

Of other techniques, RGB-D sensors, e.g., PrimeSensor/Microsoft Kinect, register depth information together with surface coloring. Such systems feature an RGB camera and infra-red projector. Rapid processing of data at a low resolution allows capturing real-time actions. The noisy, incomplete and low resolution outcomes are, however, the main obstacles for a more general utilization in forensics, apart from real-time surveillance and biometrics, such as face recognition [15].

Ultimately, it has been shown that medical imaging technologies (CT, MRI, μCT) which have the capacity to visualize both outer and inner body structures are helpful in cases such as gunshot injuries [12,7] or traffic accidents [16,17]. The quality of the external body documentation remains, however, inferior to traditional photography due to the lower resolution of cross-sectional 2D CT images (and their subsequent 3D volume reconstructions) and more importantly due to the lack of color information.

In last few years a rise of single camera photogrammetry could be detected in several scientific fields, mostly as a reaction to affordable high resolution digital cameras and equally accessible commercial, open-source or freeware applications (123D Catch, PhotoScan, etc.) capable of processing high-resolution digital data in a consistent and accurate manner. For instance, photogrammetry allowed Ege et al. [18] to evaluate topography of the articular surface of human radii. Lerma et al. [19] and De Reu et al. [20] applied close range photogrammetry while documenting archeological excavation sites. Multiple medical applications were reviewed by Mitchell and Newton [21].

By definition, photogrammetry allows determining the three-dimensional coordinates of discrete points (i.e., surface point clouds) by measurements made in a series of photographs taken from varying viewpoints [22]. For its simplicity, inexpensiveness and relatively trivial technical requirements photogrammetry represents the easiest manner to create a textured 3D surface model. For forensic purposes, however, utilization of modern-day photogrammetry has been discussed rather scarcely, e.g. [23]. As an exception, Brüschweiler and colleagues published several case studies using a protocol based on 3D/CAD-supported photogrammetry, e.g., matching skin abrasions to injury-causing weapons [4,5,24], or vehicles [25].

It has been generally acknowledged that forensic postmortem examination as performed in the standard settings on a daily basis has not developed the full potential of the advances made in 3D technologies. Although progress has been made in diagnostics where examinations are performed on a basis or with assistance of medical imaging technology [8,26–29] or advanced robotic prototypes [30], body surface documentation is still far behind of what currently available techniques can offer.

Here, we present two optical surface documentation techniques, single digital camera photogrammetry combined with commercial software and stereophotogrammetry-based handheld scanner. For the purpose of forensic postmortem examination their feasibility and effectiveness was tested on two forensic cases and a living volunteer.

2. Materials and methods

Three human subjects were selected to conduct the study; a living person (a volunteer) and two cases admitted for postmortem examination at the Department of Forensic Medicine, Medical Faculty of Charles University and University Hospital Hradec Králové, Czech Republic.

3. Data acquisition

3.1. Living person

A 25-year-old female, 170 cm in height was photographed from multiple viewpoints in a circle-like manner using a digital camera Nikon 7000, Tokyo, Japan (AF-S NIKKOR 18–105 mm) handheld with the flash disabled. A series of 27 images was taken while the subject lied on her back on a raster desk in a supine position. Shortly after, the subject was scanned in the approximately same position with Vectra H1 (VH1) handheld scanner (Canfield Scientific, Inc., Fairfield, NJ). Accessorized with a large built-in lens the device resembles a professional digital camera in both appearance and control. The lens, however, composes of two synchronized optical systems enabling it to capture the surface from two converged points of view in capture volume of 270 mm (height), 165 mm (width) and 100 mm (distance). The optimal distance for capturing desired portions of an object is controlled by two green light pointers projected on the scanned surface. The body surface (except for the parts in contact with the desk) was captured with 59 partial scans. No specific protocol to capture the entire surface was followed. The entire process was highly intuitive aimed at recording the scans with reasonable overlaps.