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Corrigendum

Forensic 3D documentation of bodies: Simple and fast procedure for combining CT scanning with external photogrammetry data

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A B S T R A C T

This study presents a procedure for combining 3D models obtained from CT scanning (internal and external data) and photogrammetry (external data). 3D data were acquired at different times, without the support of reference points. The procedure has been tested on 30 injured areas caused by different wounding mechanisms. The alignment of the different 3D models was in most of the cases very precisely (mean distance around 1 mm, SD around or lower than 2 mm). Ad hoc procedures should be followed in case of injuries on the head, joints and back.

1. Introduction

Internal and external 3D documentation of the body enables precise and accurate recording of forensic pathological findings and, at the same time, the creation of permanent data sets that can be reviewed at any time [1]. A whole-body 3D model can be generated using Computed Tomography (CT) and Magnetic Resonance (MR) techniques introduced at several forensic medical institutes around the world [2–6]. 3D models of both internal and external structures can be created, but skin injuries, such as bruises or superficial wounds, are not adequately documented. A proper recording of skin injuries can be acquired using surface scanners [7] or photogrammetry [8–12].

In earlier studies, a procedure for whole-body internal and external 3D documentation has been demonstrated by the VIRTOPSY group [9,13–16]: internal and external data, obtained from CT and MR, were combined with external data, acquired using photogrammetry and structured light scanning. The obtained 3D models of the bodies are very detailed, accurate and precise and their usefulness in forensic investigations has been clearly demonstrated [12,17,18]. However, it is unlikely that the described approach can find wider use in forensic institutes, mainly because it requires that photogrammetry or surface scanning is performed during CT scanning [9,19,20]. The VIRTOPSY procedure also requires a thorough preparation of the body before scanning: clothing and any other objects need to be removed, the bodies cleaned and, if necessary, shaved [19]; then, reference points, i.e. radiographic and coded markers, need to be placed on and around the body, with particular attention to the lesions. Unfortunately, many forensic institutes do not have their own CT scanner and rely on machines in hospitals; this means that the bodies are often scanned in body bags before removing the clothing and cleaning the body.

Recently, a different approach has been proposed based on single-camera photographs for acquiring texture information of the injuries [21]; however, this approach does not provide 3D detailed information of the lesions, but only 2D images that can be combined with 3D models from CT scanning. Using a single camera, a detailed, to-scale, true-color 3D documentation of the skin can be created by means of photogrammetry, as recently demonstrated [8,10].

This study presents a simple and fast procedure for combining 3D models obtained from CT scanning (internal and external data) and photogrammetry data (external). 3D data were acquired at different times, without reference points on or around the body. The procedure has been tested on 30 injured areas caused by different wounding mechanisms.

2. Material and methods

2.1. Samples

The study sample included 30 body areas with injuries. The injuries were caused by: 10 blunt force traumas, 10 sharp force traumas and 10 gunshot traumas. The injured body regions were: limbs (12 lesions), head (9 lesions), thorax (7 lesions) and back (2 lesions). Detailed information about type of injury, location and dimensions of the injured area used for the alignment process is reported in Table 1.

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Table 1
Study sample, 30 cases in detail.

Lesion nr.	Wounding mechanism	Type of injuries	Location	Linear dimension of the aligned 3D models (in cm)
1	Blunt force trauma	Abrasion due to a mechanical chest compression device	Thorax: central area	30 × 30
2	Blunt force trauma	Avulsion	Lower limb: left anterior shin and knee area	34 × 12
3	Blunt force trauma	Avulsion	Lower limb: right anterior shin and knee area	28 × 11
4	Blunt force trauma	Contusion wound	Head: right temporal area	10 × 6
5	Blunt force trauma	Laceration	Head: nose-mouth region	11 × 11
6	Blunt force trauma	Contusion wound and abrasion	Lower limb: left anterior shin and knee	38 × 10
7	Blunt force trauma	Abrasion	Lower limb: right anterior shin and knee	36 × 14
8	Blunt force trauma	Abrasion and contusion	Lower limb: left anterior shin, knee and lower thigh	46 × 14
9	Blunt force trauma	Abrasion	Thorax: right side	10 × 7
10	Blunt force trauma	Abrasion	Upper limb: dorsal aspect left hand	6 × 6
11	Sharp force trauma	One stab wound	Thorax: right side, clavicle area	24 × 19
12	Sharp force trauma	One stab wound	Back: upper area	17 × 11
13	Sharp force trauma	One stab wound	Head: left temporal area, near the ear	10 × 10
14	Sharp force trauma	Five stab wounds	Lower limb: left thigh	14 × 10
15	Sharp force trauma	Five stab wounds	Lower limb: right thigh	10 × 11
16	Sharp force trauma	One stab wound and a bruise	Head: right cheek	10 × 9
17	Sharp force trauma	Two stab wounds and an incised wound	Thorax: left side	16 × 15
18	Sharp force trauma	One stab wound and a bruise	Upper limb: dorsal aspect right hand	6 × 6
19	Sharp force trauma	One stab wound	Thorax: right side	11 × 6
20	Sharp force trauma	One stab wound	Thorax: left side	20 × 16
21	Gunshot trauma	Bullet entry wound	Head: right temporal area	13 × 11
22	Gunshot trauma	Shotgun entry wound	Head: left frontal/parietal area	8 × 7
23	Gunshot trauma	Bullet entry wound	Head: right frontal area and eyes	16 × 10
24	Gunshot trauma	Shotgun entry wound	Upper limb: lower arm	15 × 7
25	Gunshot trauma	Bullet entry wound	Head: left temporal area	15 × 8
26	Gunshot trauma	Bullet entry wound	Back: right side	9 × 9
27	Gunshot trauma	Shotgun entry wound	Head: right side of the face	15 × 12
28	Gunshot trauma	Shotgun entry wound	Thorax: right side of the thorax and shoulder area	26 × 20
29	Gunshot trauma	Bullet entry wound	Lower limb: left hip area	28 × 13
30	Gunshot trauma	Bullet fragment entry wound	Lower limb: left thigh	13 × 12

2.2. 3D models from CT scanning (CT models)

The CT scans used to create the 3D models were acquired using a Siemens Somatom Definition using the following settings: 120 kV, 300 mAs, variable slice thickness (head: 2 mm; thorax, pelvis and legs: 3 mm), variable slice increment (head: 1.5 mm; thorax, pelvis and legs: 2 mm) and soft reconstruction algorithm (the soft reconstruction algorithm was selected to minimize the noise in the 3D models). The bodies were CT scanned in supine position. At our institution, homicide victims are scanned in body bags prior to autopsies and prior to the sampling supplementary evidence material, e.g. DNA or fibers. The body bag protects the body against contamination. Medical devices, foreign objects, jewelry and clothing could be present during CT scanning. 3D models of the bodies (skin, bones, bullets or surgical implants) were created using Mimics software v. 19 [22] and exported as .stl files. Manual removal of medical devices, foreign objects, jewelry and clothing was performed during the segmentation process in Mimics.

2.3. 3D models from photogrammetry (Photogrammetry models)

Photographs of the injuries were taken at a later time during the autopsies, after the clothing was removed and the body cleaned, using a Canon EOS 550D (5184 × 3456 pixels) with a focal length of 40 mm or a Canon EOS 5DS R (8688 × 5792 pixels) with focal length of 35 mm or 50 mm. A similar procedure as described in Villa [8] was followed in this study. No coded marker was applied on or around the body. No tripod was used. A centimeter ruler was present in photographs as scale reference. Photographs were taken from different points of view and with an overlap area of about 80%. A shutter speed equal or faster than 1/80 was used to avoid blurred photographs. An ISO setting equal to or lower than 800 and 1600 was used for the Canon 550D and for the Canon 5DS R, respectively. A variable aperture was obtained based on chosen shutter speed and ISO (minimum aperture f/4). The white balance was set in automatic mode for the Canon 550D, while it was manually set at the light temperature of the autopsy room (4500 K) in the Canon 5DS R. Photographs of the lesion and the surrounding area including the closest joint were taken to facilitate the alignment process. A variable number of photographs were taken based on the dimension of the region of interest, e.g. 15 for recording the right side of a face, or 134 for recording an entire leg.

PhotoModeler UAS v. 2017 [23] was used for processing the photographs (see Villa [8] for further technical details). 3D models (mesh surface) were created and saved as .objfiles.

2.4. Alignment process and distance calculation between meshes

The alignment process of the 3D models (CT models of the skin and photogrammetry models) was performed using Cloud Compare v. 2.8 [24], an open source software. The CT model was used as reference model in the entire process. The following steps were performed to align the injured areas, using the default values if not otherwise indicated:

1) A rough alignment of the two meshes, using the function *"aligns two clouds by picking (at least 4 points) equivalent points pairs*" or the manual alignment tool "*Translate /rotate"*.
2) Fine alignment using the function *"finely registers already (roughly) aligned entities (clouds or meshes)"* with final overlap value equal to 50%.
3) Manual removal of the "not overlapping area" using the function

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