Forensic Sci Med Pathol (2009) 5:167–173
DOI 10.1007/s12024-009-9094-8

ORIGINAL ARTICLE

Facial recognition and laser surface scan: a pilot study

Niels Lynnerup · Maja-Lisa Clausen · Agnethe May Kristoffersen · Henrik Steglich-Arnholm

Accepted: 30 April 2009 / Published online: 9 June 2009

Abstract Surface scanning of the face of a suspect is presented as a way to better match the facial features with those of a perpetrator from CCTV footage. We performed a simple pilot study where we obtained facial surface scans of volunteers and then in blind trials tried to match these scans with 2D photographs of the faces of the volunteers. Fifteen male volunteers were surface scanned using a Polhemus FastSCAN Cobra Handheld Laser Scanner. Three photographs were taken of each volunteer's face in full frontal, profile and from above at an angle of 45° and also 45° laterally. Via special software (MIMICS® and Photoshop®) the surface scans were matched with the photographs in blind trials. The matches were graded as: a good fit; possible fit; and no fit. All the surface scans and photos were matched correctly, although one surface scan could be matched with two angled photographs, meaning that the discriminatory value was 86.7%. We also tested the surface scanner in terms of reliability in establishing point measures on skulls, and compared with physical measurements performed by calipers. The variation was on average 1 mm for five cranial measures. We suggest how surface scanning might be applied in forensic facial identification.

Keywords Identification · Face recognition · Photography · Forensic

N. Lynnerup · M.-L. Clausen · A. M. Kristoffersen · H. Steglich-Arnholm
Laboratory of Biological Anthropology, Institute of Forensic Medicine, University of Copenhagen, Copenhagen, Denmark

N. Lynnerup (✉)
Laboratory of Biological Anthropology, The Panum Institute, Blegdamsvej 3, 2200 Copenhagen N, Denmark
e-mail: nly@sund.ku.dk

Introduction

Face recognition is often used in forensic science. For example, one scenario may be a bank robbery, where the perpetrator has been filmed on video, and where his face can be seen. Comparisons may then be made with one or more suspects. Another scenario is when facial photographs in visas or passport documents are scrutinized and compared with the holder [1–4]. At our unit we have had several of the latter cases, and we find that there is a need to further develop and test the techniques used to perform these analyses. Specifically, we find it important to address the difficulties in comparison between a two-dimensional facial photograph in a document with the holder either directly or, as is often the case, with (another) photograph of the holder taken by the immigration authorities. Not only may there be major differences in the quality and acquisition standards of the two photographs, but there may also be differences in how the face of the person is photographed, e.g., full frontal or more laterally [1–3]. Using a surface scanner instead of procuring another two-dimensional photograph, may potentially circumvent these problems.

We have previously investigated whether photogrammetry software might be useful to acquire definite three-dimensional models of a persons' face, and then overlay such a model (either as a wire-mesh or a point cloud) with a photograph [5]. We found that this was possible, but it did require several steps, and it also required careful selection of facial features which could be reliably identified on the photographs; for instance eye- and mouth-corners, ear lobes etc.

Newer methods include a full surface scan of the face, and then orienting the scan to align it with a facial photograph before checking for overall and specific congruence of facial features [6, 7]. We have recently acquired a laser surface scanner, Polhemus FastScan Cobra, and now plan to introduce laser surface scans as routine when asked to compare a person with a facial photograph. The aim of this study was thus to investigate validity and reliability of surface scanning, and to establish the value of matching photographs to facial scans and finally facial recognition.

We first checked the accuracy of the surface scan. This simply involved a direct comparison between physical craniometric measures obtained with standard calipers and as obtained by post-processing the surface scans of human skulls. The latter measurements do not in themselves actually entail performing full surface scans, as the scanner has a stylus function, which allows inputting only points as x, y, z coordinates. However, since we would be working with the facial surface scans in MIMICS®, we also included craniometric measurements as determined by using this software, i.e., by identifying the landmarks solely based on the surface scans. Using skulls for the accuracy test also assures that the measuring points are absolutely stable and well-defined, while at the same time within an overall three-dimensional size as a face.

Thus we compared three sets of cranial measures obtained by: (1) direct physical measurements on the skulls; (2) using a stylus to input the craniometric landmark coordinates directly from the skulls; and (3) identifying the landmarks on the surface scans and then calculating the distances. After this test of accuracy we then tested whether facial surface scans could be correctly paired with facial photographs in blind trials.

Methods and materials

Accuracy test

Ten human skulls were surface-scanned. Nine craniometric landmarks were selected in order to produce five craniometric measures (cf. [1]): basion–bregma (BA–BR); nasion–nasospinale (N–NS); maxillofrontal breadth (FM–FM); frontomalar breadth (EC–EC); basion–alveolare (BA–ALV). The measures were selected so as to reflect three dimensions and varying distances. We first measured the distances by using a spreading caliper and a digital caliper (data set termed "caliper"). Then, using the scanner stylus function, the craniometric landmarks were input as x, y, z coordinates onto the surface scans (Fig. 1). The x, y, z coordinates were then exported in a simple spreadsheet, and the above measures were then calculated directly from the coordinates (data set termed "stylus"). Finally, the surface scans were exported as STL files to MIMICS®, where the same craniometric landmarks were identified, and the same measurements were taken directly by the software (Fig. 2, data set termed "scan"). Bland and Altman statistics [8] were used to analyse agreement, and a table with summary statistics comparing the datasets "stylus" and "scan" against "caliper," respectively (the "caliper" dataset was used as gold standard), was produced.

Pilot study on facial recognition

Fifteen male volunteers were photographed using an ordinary digital camera (Canon G7). The facial photographs were taken as full frontals, profiles and from 45° above and 45° laterally (Fig. 3), respectably. Three-dimensional surface scans were also produced (Fig. 4). We then transferred the scans as STL files to MIMICS®. The photos and the surface scans were then compared in blind trials by two researchers (MJC and AMK). The comparisons were carried out in two stages. First, the surface scans were oriented so as to show the face in full frontal, in profile and from above laterally. These views were then compared directly with the photographs in the same orientation (Fig. 5). Secondly, the surface scans were overlaid

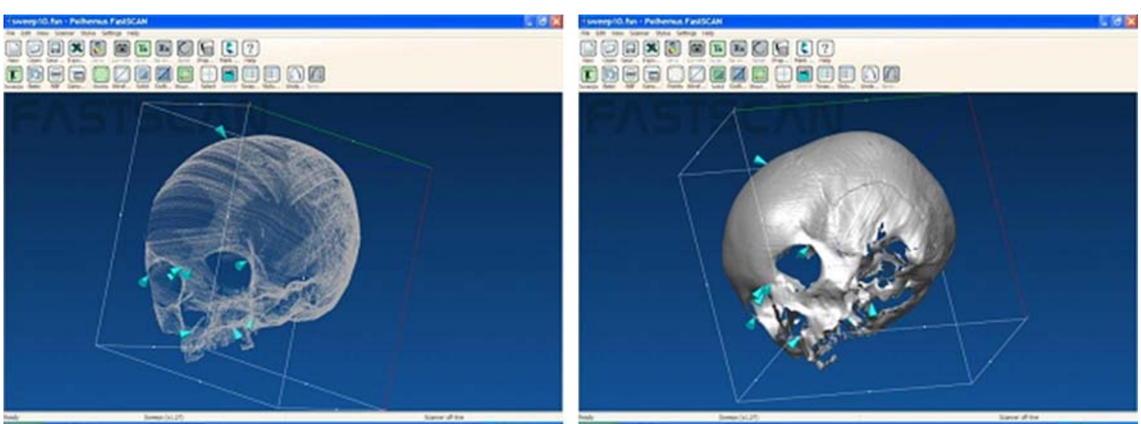

Fig. 1 Screen picture showing the surface scan and localisation of craniometric landmarks with stylus

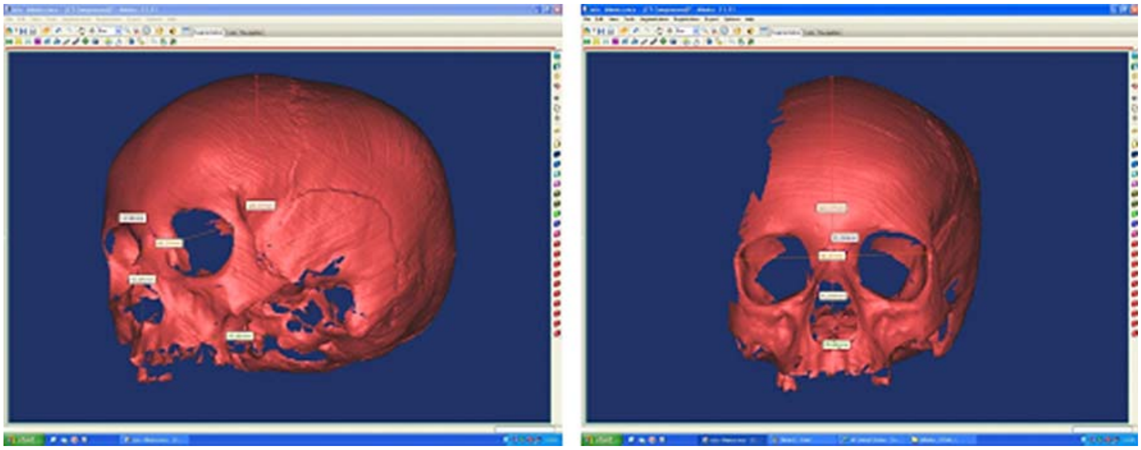

Fig. 2 Surface scan viewed in MIMICS®. Craniometric landmarks have been identified, as distances are given directly by the program

Fig. 3 Facial photographs showing the three settings: full frontal, profile, and above and from the side

Fig. 4 Surface scan as produced by FastScan Cobra, and viewed in MIMICS®

onto the photographs in Photoshop® (Fig. 6). Each of these matches was scored arbitrarily as either good match, possible match or no match.

Results

We produced Bland and Altman plots for all three sets of measurements (caliper versus stylus; caliper versus scan). The plots consisted of a "line-of-agreement" plot and a plot of mean difference (see Fig. 7 for an example). The summary statistics, generated from all the plots, are shown in Table 1, and these show that the mean difference between the different measuring techniques is ca. 1 mm or less (using the manual caliper data as Gold standard). We thus find the accuracy of the laser scanner, including subsequent visualization and measurement in MIMICS®, to be high.

We had planned to compare all scans with all photographs for the frontal, lateral and 45° views, respectively. However, it was quickly realized after a few cases that the scans and the photographs for the frontal and profile views were easily and correctly matched. We therefore present only the results of the above-lateral photographs and scans. Table 2 shows the overall results. All 15 scans were matched correctly with the 15 photographs (equal to a true positive rate of 100%). However, in two cases (P7 and P9), two scans were chosen to be "good matches" by overlay (equal to a false-positive rate of 86.7%), although for P9 the side-by-side comparison yielded a "possible match."

We finally looked at how often the match was deemed "possible match" (Table 2). There was one case where the scan was found to match only one photograph, 12 cases where the scan matched four or more photographs, five

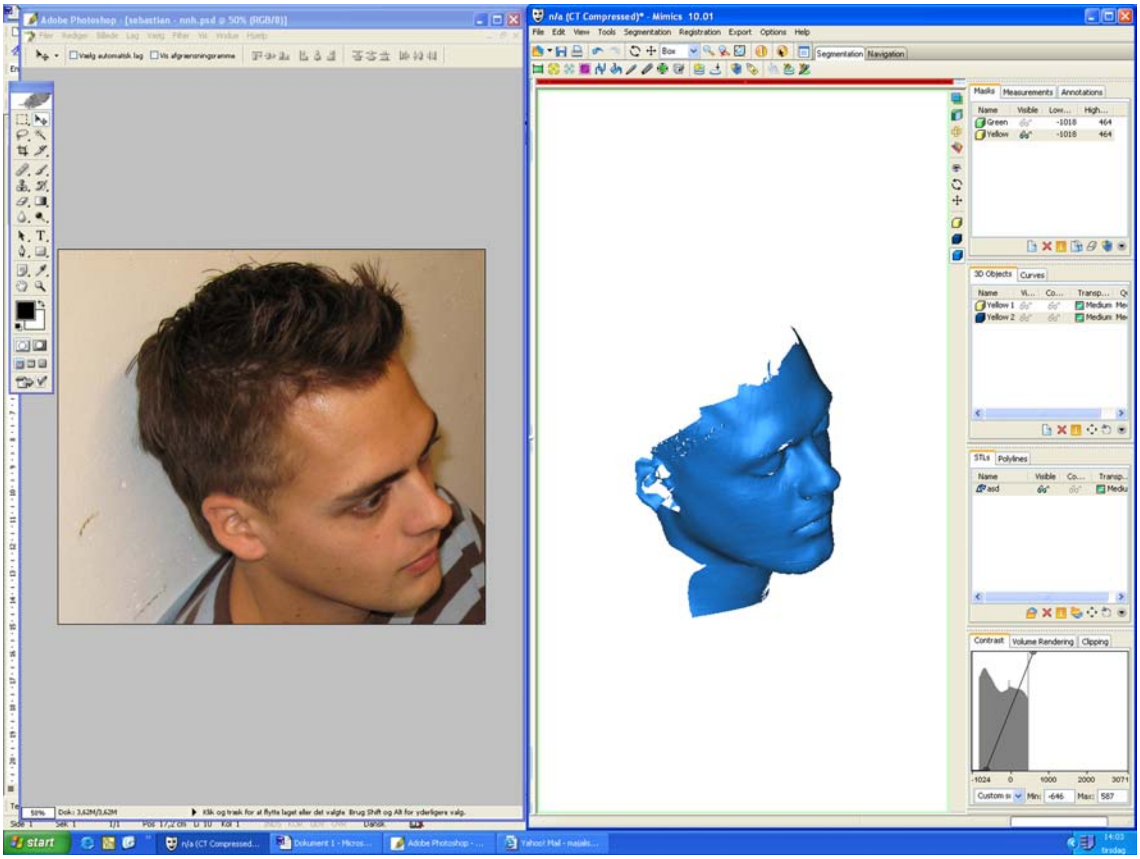

Fig. 5 Screen view showing how matching was made: surface scan rotated so as to mimic photographic angle

Fig. 6 Direct overlay of surface scan with photograph. Three different scans have been overlaid with the same photograph. The image to the left indicates good match; the middle image "possible match", and the right image "no match"

cases where the scan matched seven or more photographs, and one case where the scan matched nine photographs.

Discussion

Comparison of photographs of suspects with images of perpetrators on surveillance imagery or visa or passport documents is difficult due to the many different settings and differences in the equipment with which the persons face is captured on camera [1–3]. Customarily, single facial features are first sought out, e.g., moles, scars or ear morphology [9, 10]. Anthropometric variables may also be deduced from the imagery, although careful attention must be paid to the above issues of camera angles and distances [11–13]. General facial shape and profile has been studied also, especially in terms of trying to photograph a person from the same angles as in the photographs with which he or she is to be compared [14]. This is not easy, though, and there may be questions as to cooperation as well as legal issues [1, 15]. As such, full facial 3D scan, which may allow post-capture manipulation, e.g., viewing from a specific POV, under changed (simulated) lighting conditions, has gained much interest [16, 17].

We have previously found that wireframe models generated by photogrammetry may be of use in these situations

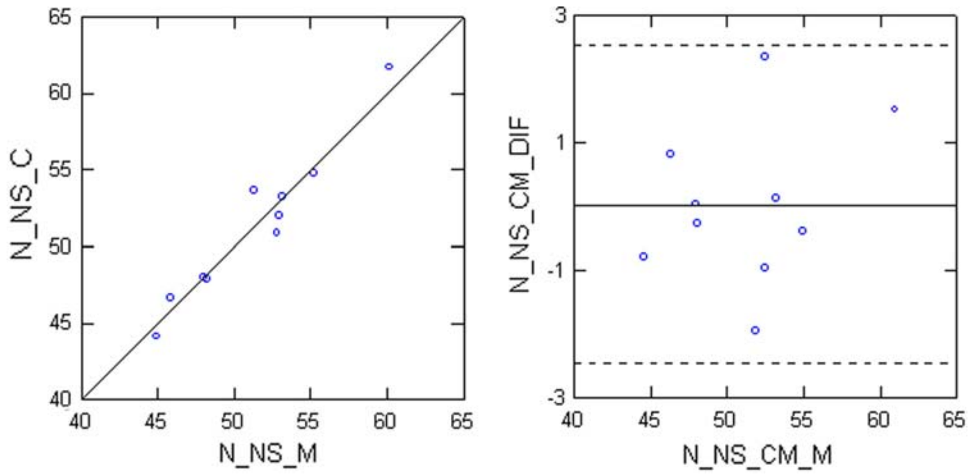

Fig. 7 Bland and Altman plots of agreement between nasion–nasospinale distance for ten skulls as measured by caliper and via MIMICS®, (scan). The *graph to the left* shows how the single measures cluster around the line of agreement, i.e., a line on which all measures would lie if they were completely identical. The *right graph* shows the level of agreement, i.e., the difference between the single measures plotted against their mean. *Hatched lines* indicate mean ± 2SDs (of the difference). See also Table 1. All measures in millimeters

Table 1 Summary statistics for differences between measuring techniques (SC: stylus versus caliper; CM: caliper versus scan) for five craniometric distances (BA_BR: basion–bregma; N_NS: nasion–nasospinale; MF_MF: maxillofrontal breadth; EC_EC: frontomalar breadth; BA_ALV: basion–alveolare). All measures in millimeters

	BA_BR SC	BA_BR CM	N_NS SC	N_NS CM	MF_MF SC	MF_MF CM	EC_EC SC	EC_EC CM	BA_ALV SC	BA_ALV CM
N	10	10	10	10	10	10	10	10	10	10
Minimum	0.000	0.350	0.160	0.040	0.120	0.100	0.120	0.130	0.180	0.250
Maximum	5.020	2.280	1.350	2.340	3.670	2.020	0.920	2.250	1.240	2.230
Median	0.750	0.690	0.525	0.795	0.780	0.605	0.320	0.810	0.575	0.470
Mean	1.176	0.800	0.593	0.918	1.033	0.738	0.474	1.000	0.556	0.623
1 SD	1.501	0.556	0.425	0.787	1.004	0.580	0.333	0.750	0.317	0.574

[5]. In this study we found that laser surface scan may be a good method by which to acquire the facial features and then use this three-dimensional visualisation for comparison with two-dimensional photographs. For example, the holder of a visa or a passport may be surface scanned, and the scanning then used to compare with a facial photograph in the visa or passport. The benefit of this is that the surface scan may be freely rotated and set in a position to align with the facial photograph. While this does not solve the problem of unknown settings for the shooting of the facial photograph, it does at least do away with taking another facial photograph of almost certainly different shooting settings for comparison. In terms of alignment, we also found that surface scanning does allow quite accurate pinpointing of specific facial features. This, obviously, does not address the problem of changing facial expressions. Indeed, others have investigated congruence by overlaying surface texture (from photos or scans) to substructures, which potentially may allow one to operate with differing expressions (e.g., [18, 19]), which may be very useful for biometric systems [20].

Interestingly, while our blind trial showed that good matches were performed correctly, we did notice that for some faces there were either very few or many possible matches. While we have not explored this further, mainly due to the small sample size, it may indicate, as also shown by Valentine [20] and Valentine and Bruce [21] that some faces, i.e., at least as pertains to general shape and size features, are much more distinct than others, and that some faces are more common than others. Clearly, a face with a condition such as a mandibular growth anomaly (either manifest hypoplasia or hyperplasia) will be much more unique than a face without this condition. In a legal setting this may mean that some suspects are more easily aligned with a perpetrator simply because their facial features are more average.

Table 2 Matching of 15 facial scans with 15 facial photographs (oblique angle)

P/S	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
P1	−/−	+/−	−/−	−/−	−/−	−/−	++/++	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
P2	+/+	−/−	−/−	−/−	−/−	+/−	−/−	++/++	−/−	+/−	+/−	−/−	−/−	−/−	−/−
P3	−/−	+/−	+/+	−/+	+/−	−/+	−/−	−/−	−/−	+/−	−/−	−/−	−/+	++/++	−/−
P4	−/−	−/−	−/−	+/+	−/−	−/−	−/−	−/−	−/−	+/+	+/+	−/+	++/++	−/−	+/+
P5	−/−	+/−	+/−	−/−	++/++	−/−	−/−	−/−	−/−	−/−	−/−	+/−	−/−	−/−	+/−
P6	+/−	+/−	+/+	−/+	−/+	−/−	−/−	−/−	−/−	+/+	−/+	+/−	−/−	−/−	++/++
P7	−/−	+/−	−/−	+/−	+/−	−/−	−/−	+/−	−/−	++/++	++/++	−/−	+/+	−/−	+/+
P8	++/++	−/−	−/−	−/−	−/−	−/−	−/−	−/−	+/+	−/−	+/−	−/−	−/−	−/−	+/−
P9	−/−	−/−	−/−	++/+	−/−	−/−	−/−	−/−	−/−	+/−	−/−	++/++	+/+	−/−	+/+
P10	−/−	−/−	−/−	−/−	−/+	++/++	−/+	−/−	−/−	−/−	−/−	−/−	−/+	−/−	+/−
P11	−/−	++/++	+/−	−/−	−/−	−/−	+/+	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
P12	−/−	−/−	−/−	+/+	−/−	−/−	−/−	−/−	−/−	−/−	++/++	−/+	+/+	−/−	−/+
P13	−/+	−/−	−/−	−/−	+/−	−/−	+/−	−/−	++/++	−/−	−/−	−/−	−/−	−/−	−/−
P14	−/−	−/−	−/−	++/++	−/−	−/−	−/−	+/−	−/−	−/−	+/−	−/−	−/−	−/−	−/−
P15	−/−	+/−	++/++	−/−	+/+	+/+	−/−	−/−	−/−	−/−	+/+	−/−	−/−	−/−	+/+

Matching was made by side-by-side comparison (cf. Fig. 5) and by direct superimposition (cf. Fig. 6). The first marking before the slash indicates whether there was a good match (++); a possible match (+); or no match (−) for the side-by-side comparison. The marking after the slash indicates the same but for the superimposition. All the photographs were matched correctly with the scans (a "++/++" result), although in two cases (P7 and P9) two scans were chosen to be good matches by superimposition

Conclusion

Surface laser scanning may potentially be a technique whereby a three-dimensional rendering can be made of the face. This rendering can then be manipulated so as to be overlaid onto facial photographs with which one wants to compare, instead of comparing two-two-dimensional facial photographs, each acquired with probably very different camera settings and angles. We found that even a low-end hand held scanner had a good resolution, and that craniometric landmarks could be reliably identified on the surface scans (as compared to direct physical measurements on the skull). In a pilot study involving 15 male volunteers, we were able to allocate the surface scans to the photographs correctly. We will now start to implement surface scanning in our routine work. Interestingly, we found, as has been reported before, that some faces are much more distinct than others, while some faces are much more "average." While our material is too small to analyse this further, it does indicate that one should be cautious when pronouncing if congruence is highly specific or not in real cases.

Key points

1. Surface laser scanning may be a technique whereby an accurate and precise three-dimensional rendering can be made of the face.
2. The resolution of even a low-end hand held scanner is such that craniometric landmarks can be reliably identified on the surface scans.
3. Surface scans can be correctly allocated to facial photographs, although some faces are much more distinct than others.
4. This may indicate that one should be cautious when pronouncing if the congruence (between imagery and faces) is highly specific or not in individual cases.

Acknowledgments We thank the participating medical students for volunteering for the study. Permission has been obtained to use the facial photographs and scans.

References

1. Knussman R. Methoden des morphologischen Vergleichs in der forensischen Anthropologie. In: Knussman R, editor. Anthropologie. Stuttgart: Gustav Fischer; 1988. p. 386–407.
2. Thomas CDL. Quantification of facial shape and form. In: Clemet JC, Ranson DL, editors. Craniofacial identification in forensic medicine. London: Arnold; 1998. p. 165–76.
3. Iscan MY. Introduction of techniques for photographic comparison: potential and problems. In: Iscan MY, Helmer RP, editors. Forensic analysis of the skull. New York: Wiley-Liss; 1993. p. 57–70.
4. Oxlee G. Facial recognition and imagery analysis. In: Thompson T, Black S, editors. Forensic human identification. Boca Raton: CRC Press; 2006. p. 257–70.
5. Lynnerup N, Andersen M, Lauritsen HP. Facial image identification using photomodeler®. Leg Med. 2003;5(3):156–60. doi:10.1016/S1344-6223(03)00054-3.
6. Yoshino M, Matsuda H, Kubota S, Imaizumi K, Miyasaka S. Computer-assited facial image identification system using a 3-D physiognomic range finder. Forensic Sci Int. 2000;109:225–37. doi:10.1016/S0379-0738(00)00149-3.
7. Goos MIM, Alberink I, Ruifrok ACC. 2D/3D image (facial) comparison using camera matching. Forensic Sci Int. 2004;148:113–20.

8. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;8476:307–10.
9. Porter G, Doran G. Facial comparisons from ID photographs. In: Clement JC, Thomas CDL, editors. Proceedings of the 7th scientific meeting of the international association for craniofacial identification. Melbourne; 1998. p. 69–80.
10. Hoogstrate AJ, Van den Heuvel H, Huyben E. Ear identification based on surveillance camera images. Sci Justice. 2001;41:167–72. doi:10.1016/S1355-0306(01)71885-0.
11. Halberstein RA. The application of anthropometric indices in forensic photography: three case studies. J Forensic Sci. 2001;46:1438–41.
12. Porter G, Doran G. An anatomical and photographic technique for forensic facial identification. Forensic Sci Int. 2000;114:97–105. doi:10.1016/S0379-0738(00)00290-5.
13. Farkas LG. Photogrammetry of the face. In: Farkas LG, editor. Anthropometry of the head and face. New York: Raven Press; 1994. p. 79–88.
14. Lynnerup N, Sejrsen B, Vedel J. Identification by facial recognition, gait analysis and photogrammetry: the Anna Lindh murder. In: Brickley M, Ferllini R, editors. Forensic anthropology: case studies from Europe. Springfield: Charles C. Thomas; 2007. p. 232–44.
15. Freckelton I. Identification and the law. In: Clemet JC, Ranson DL, editors. Craniofacial identification in forensic medicine. London: Arnold; 1998. p. 257–66.
16. Lú X, Jain AK, Colbry D. Matching 2.5D face scans to 3D models. IEEE Trans Pattern Anal Mach Intell. 2006;28(1):31–43. doi:10.1109/TPAMI.2006.15.
17. Kovacs L, Zimmerman A, Borckmann G, Baurecht N, Schwenzer-Zimmerer K, Papadopulos NA, et al. Accuracy and precision of the three-dimensional assessmenet of the facial surface using a 3-D laser scanner. IEEE Trans Pattern Anal Mach Intell. 2006; 25(6):742–54.
18. Lu X, Jain A. Deformation modelling for robust 3D face matching. IEEE Trans Pattern Anal Mach Intell. 2008;30(8):1346–57. doi:10.1109/TPAMI.2007.70784.
19. Lai Z, Hua J. 3D surface matching and registration through shape images. Medical image computing and computer-assisted intervention: MICCAI. International Conference on Medical Image Computing and Computer-Assisted Intervention 2008, 11:44–51.
20. Valentine T. A unified account of the effects of distinctiveness, inversion, and race in face recognition. Q J Exp Psychol. 1991;43A:161–204.
21. Valentine T, Bruce V. The distinctiveness in recognising and classifying faces. Perception. 1986;15:525–35. doi:10.1068/p150525.