Research Journal of Applied Sciences, Engineering and Technology 4(22): 4928-4933, 2012
ISSN: 2040-7467

Submitted: July 05, 2012 Accepted: July 28, 2012 Published: November 15, 2012

A Photogrammetric Method for Stature Estimation: Reliability and Validity

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Abstract: The identification of subjects by means of image comparison has already been used in the past; however, the advent of new image elaboration software has provided a new impact and new resources useful for the application of techniques for the identification of the culprits. This study has been carried on at the Department of internal medicine and public health of the University of Bari, Italy, during the year 2011 to investigate the possibility of determining the stature of a subject by means of photogrammetry. Preliminarily, actual heights (in Cm) were obtained by measuring a selection of 288 people including subjects ranging from 150 Cm to 200 Cm with a metallic pole; they were all photographed while standing in a doorway, so as to simulate the images of subjects taken in the doorway of a bank. The selected subjects were measured by a standardized method. The frames obtained were elaborated (by another operator who was unaware of the actual heights) using professional software to determine the height of the people selected using a grid technique. The use of frames for forensic purposes can be considered useful only when the subject is filmed in a static position (i.e., inside the bank doorway). The mean differential values between the actual height and the height measured in people standing, ranging from – 0.90 Cm to + 1.24 Cm, confirm the reliability of the technique. The validity of the technique for the measurement in motion is unreliable, owing to the high variability between the actual heights and the measurements obtained by a professional image editing software (ranging from – 3 Cm to + 6 Cm).

Keywords: Forensic, photogrammetry, stature estimation

INTRODUCTION

The identification of subjects by means of image comparison has already been used in the past; however, the advent of new software for the elaboration of images has provided a new impact and new resources useful for the application of techniques for the identification of the culprits. As regards legal medicine the results of the investigations can orientate the judge towards a verdict of guilt or innocence, but reliable scientific methods necessary, without neglecting to highlight the possible limits (Introna *et al*., 1992; Goos *et al*., 2006; Zabjek *et al*., 1999; Lee *et al*. 2008; Lynnerup and Vedel, 2005). Few studies have been described in literature about photogrammetry for anthropometric purposes; (Attallah *et al*., 1986) considered the possibility of estimating the age of children of unknown age, by means of the measurement of different bone segments (sitting height, upper arm, forearm, leg, hand and foot length).

Halberstein (2001) compared an arrested suspect with a subject videotaped while carrying out the crime by using a series of discrete craniofacial and post-cranial proportions together with additional data as to earlobe structure, head and facial hair patterns, degree of chin eminence, presence or absence of tattoos, and various physical and corporeal dimensions such as height and weight estimations.

Fraser *et al*. (2003) used a 3D physiognomic rangefinder combined with a computer-assisted system of superimposition for the identification of suspects through surveillance images.

Ventura *et al*. (2004) studied the reliability of personal identification of living subjects through video-filmed images; no. 17 points of comparable similarity were identified on the face and right ear of the perpetrator of the crime and the same points of similarity were identified on the face of the suspect: right and left eyebrows, right and left eyes, glabella, nose, mouth, chin, fold between nose and upper lip, right ear, helix, tragus, “fossetta” (triangular o scaphoid fossa), concha and lobule.

Lynnerup (2005) and Larsen *et al*. (2008) used photogrammetry in forensic science to help identify

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perpetrators from crime scenes by way of surveillance video to examine gait and body measurements.

De Angelis *et al*. (2007) proposed a method to determine the height of subjects filmed on video surveillance systems: the height is obtained by creating a virtual camera, having the same characteristics as the video surveillance system with which the images have been taken. The results demonstrate that height is a parameter that can be accurately estimated using the proposed method, respecting the experimental conditions described, and that it can consequently be utilized in probatory inquiries. Galantucci *et al*. (2008) and Deli *et al*. (2010) have studied the possibility of applying photogrammetry to the measurement of facial indices in order to improve face reconstruction techniques. In addition stereo photogrammetry has been widely used to perform 3D difitizations of the entire human body (Percoco 2011). Moreover stereo photogrammetry and, more in general, 3D scanning techiques allow the use of Additive Manufacturing technologies such as Fused Deposition Modeling (Galantucci *et al*., 2010) very useful for replicating human parts (Galantucci *et al*., 2006) or studying human motion (Uva *et al*., 2011)..

These scientific studies have had a particular impact in Italy, where the identification of the culprit by means of the comparison between the images of the arrested suspect and those of the subject videotaped while carrying out the robbery is allowed.

The application of such techniques, however, requires the permission of the suspect to be filmed by the bank surveillance system; besides, the images filmed during the robbery need to be of excellent quality (Introna *et al*., 1992).

When this permission is denied and then it is not possible to perform a complete face superimposition, it might be useful to collect the information regarding the robber's stature from the images taken during the robbery itself.

In this study the possibility of determining the stature of a subject by means of photogrammetry has been investigated.

MATERIAL AND METHODS

Materials: As a 1st step, the heights (in Cm) were obtained measuring, with a metallic pole, a selection of 288 people including subjects with heights ranging from 150 Cm to 200 Cm; they were all photographed while standing in a doorway, so as to simulate the images of subjects taken in the doorway of a bank.

To simulate a surveillance camera used in European banks, the images were acquired using DSLR cameras set in video-camera mode.

The materials used to realize this project were: Nikon D80® digital camera (10,2 mega pixels; elaboration module for high resolution images, up to 2.5 inch (230.000 points) high resolution LCD monitor), AF-S NIKKOR 18-135 mm Lens set on 18 mm, AutoCAD ®© 2008 version.

AutoCAD (CAD stands for "Computer-Aided Design") is a professional design software used in architecture and engineering to achieve bi- or three-dimensional models. However any low cost bidimensional CAD software can be used for this method.

Methods: To apply the proposed technique, the subjects must be filmed near a reference (i.e. the height of a door can be used as reference in an image of a person that walks through it).

For the subjects filmed using the camera of the surveillance system, the height of the bank door can be used as a reference distance, because the camera is pointed normally to the subject standing still in front of the closed automatic door, before entering the bank.

In order to standardize the video recording, a digital camera was positioned on a fixed tripod located at a height equal to 236 Cm from the ground and at a distance of 538 Cm from the centre of the doorway; the height of the door (ground-upper door frame) was equal to 219 Cm. The selected subjects were measured using a standardized method. They were photographed, without shoes, positioned both standing still and in motion; another operator measured the actual height using a metric pole, standing still (without shoes). The frames were elaborated (by another operator who was unaware of the actual heights) using AutoCAD to determine the height of the people selected using the grid technique. As concerns the assessment of the height of a person during motion, the measurement has been made when the subjects were placed with their centre of gravity lying on the perpendicular line to the door threshold (fig.1). Once the 576 images were obtained, 288 photographs of people standing still and 288 in motion the construction of the grids using the software AutoCAD was performed.

The grids were realized drawing 4 lines, the first passing through the upper door frame, the 2nd passing through the floor (on which the subject stands), the third passing through the left door frame and the fourth passing through the right door frame. The intersection points of the horizontal and the vertical lines create 4 vertices, the conjunction of which form the 4 sides of the grid, where the subject is positioned. The line passing through the upper door frame is prolonged to infinity and the same goes for the line passing through the floor. The intersection point of the 2 lines is defined as the *horizontal vanishing point* (F^1). Subsequently the procedure prescribes that the diagonals are drawn inside

Fig. 1: Subjects placed in a “dynamic” position

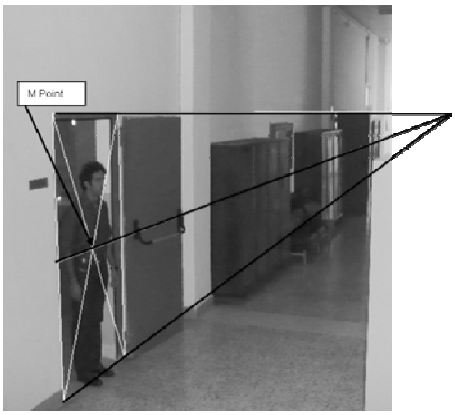

Fig. 2: First step of technique

Fig. 3: Second step of technique

the grid. The intersection of the 2 lines always coincides with the centre of the grid; in this way this point (M) is equidistant to the plane passing through the floor and the plane passing through the upper door frame. Then, a line is traced towards the horizontal vanishing point which is prolonged up to the line passing through the right door frame: in this way, respecting prospective, the grid is divided into 2 halves,

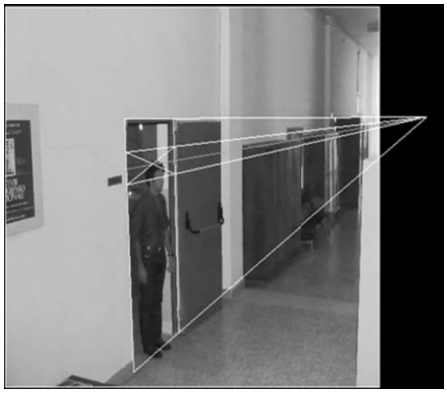

Fig. 4: Third step of technique

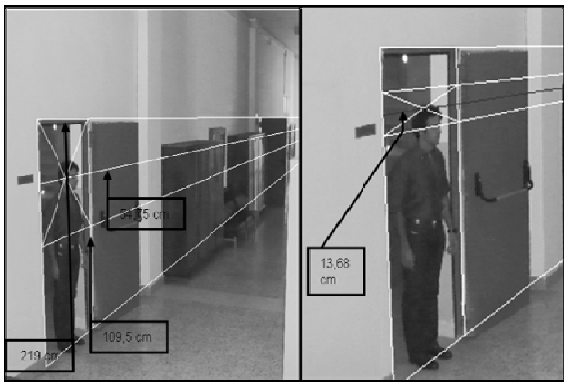

Fig. 5: Determination of height

upper and lower, so obtaining two specular panels of the same dimensions (Fig.2). The use of the same camera in standard position removed the distorsion.

Inter and intra-observer error was assessed involving 2 operators locating lines and construction of the grid at two different times. The differences in the results of the comparisons carried out by 2 different operators were not significant. Thus, given that the door height is 219 Cm, it is possible to calculate the height of the M Point equal to 109.5 Cm.

Using this technique it is possible to divide each rectangle into squares and each square is then divided in half following the same procedure (Fig.3).Then it is then possible to detect the height of a suspect, with subsequent divisions of the grids, in order to obtain a tangential line just touching the top of the suspect’s head (Fig. 4). The general height of the filmed suspect is obtained by adding up the various partial heights obtained from each grid (Fig. 5). Isn’t possible to determine before how many divisions are necessary. The estimate of the height was obtained by a blind experiment, in that the operator is unaware of the actual height of the subjects.

RESULTS AND DISCUSSION

Images were gathered for each suspect, both in the standing position and in motion. The AutoCAD software was then used to determine the height from each image therefore, obtaining a height estimate for each subject, both in the standing position and in motion.

The set of values collected from the height estimation of the 288 people with AutoCAD was then compared to the 1 obtained by measuring the same 288 people with the metric pole (actual height). This procedure was executed for the heights both in the standing position and in motion. The results obtained were then divided into the following classes which refer to the difference between the height measured in a subject standing still and the actual height obtained by using a metric pole, taking into consideration the number of the people included into each single class:

- ± 0.5 Cm: 126 subjects out of 288 (43.7%)
- ± 1 Cm (except class 1): 91 subjects out of 288 (31.6%)
- ± 1.5 Cm (except classes 1 and 2): 35 subjects out of 288 (12.15%)
- ± 3 Cm (except classes 1, 2 and 3): 25 subjects out of 288 (8.6%)
- – 3.13 e + 4.75 Cm (except classes 1, 2, 3 and 4): 10 subjects out of 288 (3.48 %)

From a first analysis it is possible to ascertain that the heights of the 288 people obtained using the AutoCAD program varied for both the positive and negative values compared with the corresponding actual heights obtained using the metal pole. In 22 cases (7.6%) the height estimated by AutoCAD in people standing still corresponded perfectly to the actual height. In 43.7% of the cases the height estimation presented a discrepancy ranging ± 0.5 Cm. In 31.6% of the cases the height estimation presented a discrepancy ranging between -0.5 Cm/- 1 Cm and + 0.5 Cm/+1 Cm. In 12.15% of the cases the height estimation presented a discrepancy ranging between -1.5/-1 Cm and +1 Cm/+ 1.5 Cm. Finally, the last 35 cases (12.08%) ranged from – 3 to + 4.75 Cm (Fig.6).

Taking into consideration all the people (100% of the cases), the height estimation measured using AutoCAD moved from the actual height to a value ranging from – 3.13 to + 4.75 Cm. The same procedure was carried out for measuring the heights in motion. The results obtained were divided into the following classes which refer to the height measured in motion compared with the corresponding actual heights obtained using the metal pole, taking into consideration

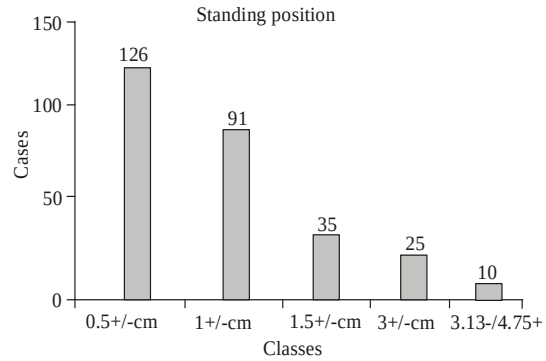

Fig. 6: Representation of the results for the standing height using CAD estimate

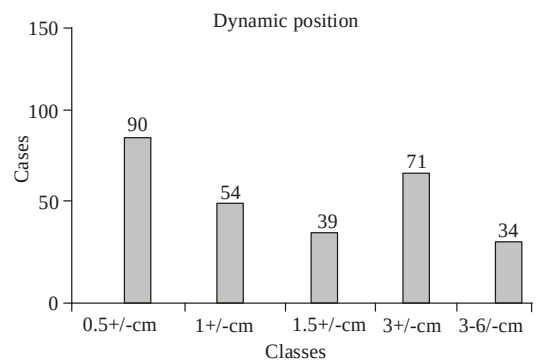

Fig. 7: Representation of the results for the height in motion using CAD estimate

the number of the people included into each single class (Fig. 7):

- ± 0.5 Cm: 90 subjects out of 288 (31.25 %)
- ± 1 Cm (except class 1): 54 subjects out of 288 (18.75 %)
- ±1.5 (except 1 and the 2 class): 39 subjects out of 288 (13.6 %)
- ± 3 (except classes 1, 2 and 3): 71 subjects out of 288 (24.6 %)
- -3.1 + 6 (except classes 1, 2, 3 and 4): 34 subjects out of 288 (11.8 %)

From a first analysis it is possible to ascertain that the heights of the 288 people obtained using the AutoCAD software varied for both the positive and negative values compared with the corresponding actual heights obtained using the metal pole. In 14 cases (4.4%) the height estimated by AutoCAD in people standing still corresponded perfectly to the actual height. In 31.25% of the cases the height estimation presented a discrepancy ranging ± 0.5 Cm. In 18.75% of the cases the height estimation presented a

discrepancy ranging between -0.5 Cm/- 1 Cm and + 0.5 Cm/+1 Cm. In 13.6% of the cases the height estimation presented a discrepancy ranging between -1.5/-1 Cm and +1 Cm/+ 1.5 Cm. Finally, the last 105 cases (36.40%) ranged from – 3 to + 6 Cm.

CONCLUSION

The use of this technique for forensic purposes can be considered useful only *when the subject is filmed in a static and "erected" position* (i.e. inside the bank doorway). The mean differential values between the actual height and the height measured in people standing still using AutoCAD, ranging from – 0.90 Cm to + 1.24 Cm, confirm the reliability of the technique. This result could be, in authors' opinion, further improved by means of a more standardized measurement during the height estimation, both standing still and "dynamic" position.

However, the validity of the technique for the measurement in dynamic position is unreliable, owing to the high variability between the actual heights and the measurements obtained with AutoCAD; such variability is due to the difficulty of obtaining a dynamic position which is actually "natural", because the dynamic position with both soles firmly on the ground assumes a physiological "stooping" in comparison with the actual height; this has to do with an obvious discrepancy which was expected, taking into consideration the physiological stopping with respect to the standing position obtained by the widening of the support base; on the other hand, the position of the head projected towards the anterior sole entirely on the ground and the posterior 1 lifted, brings the dynamic height nearer to the actual one. Therefore, the estimation of the position in dynamic position must be carried out, when using the technique under examination, taking into account that there is a major discrepancy to consider, given that the 88.50% of the estimate (255 out of 288) differed from the actual value by +/- 3 Cm. Taking the entire selection of people (100% of the cases) into account, the height estimation in dynamic position, when elaborated by AutoCAD, differed from the actual height by a value ranging between - 3 and + 6 Cm. Finally, the standard deviation between the estimated height, the dynamic height and the actual height turned out to be – 1.5970.

In the future, it will be necessary to assess the importance of shoes, headwear, wigs and other accessories worn by the individuals photographed. These items could be responsible for the major discrepancies between the heights obtained using AutoCAD and the actual heights.

An issue in the application of the method can be represented by the volume of the hair which could affect the measured stature of the subject. To try to overcome this problem, it is possible to modulate the technique according to the needs: for example, if the robber (filmed in a video shot) is wearing a hat, it is possible to take into account and provide to determine the height excluding the "added" hair. In conclusion, the technique permits evaluation of the stature of the filmed subject, but must also take into account the variables determined by the hair and shoes.

ACKNOWLEDGEMENT

Thanks to prof. Mikael Kolk, English native speaker, for article translation.

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