Int J Legal Med (2007) 121:489–492
DOI 10.1007/s00414-007-0176-4

TECHNICAL NOTE

New method for height estimation of subjects represented in photograms taken from video surveillance systems

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Received: 28 November 2006 / Accepted: 7 May 2007 / Published online: 1 June 2007

Abstract The article describes a method developed and applied by the authors for the purpose of determining the height of subjects taped on video surveillance systems. The determination of height is obtained by developing a virtual telecamera having the same characteristics of the video surveillance system with which the images have been shot. The results demonstrate that height is a parameter that can be accurately estimated with the method proposed, in the experimental conditions described, and consequently, can be utilized in probatory inquiry.

Keywords Personal identification · Height · Video surveillance · 3-Dimensional modelling

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Introduction

When investigating a crime, it is becoming a routine procedure to compare images of a suspect with those obtained from surveillance films, paying special attention to the morphological characteristics of some peculiar anatomical parts of the head, which are the most discriminant. Among new search topics in forensic anthropology [2–7], identification of the living is, therefore, more frequently asked and performed by anthropologists [1]. Some authors have based [8] their identification judgment on facial indices calculated on 2-D photographs of the videotaped subject and of the suspect [9]. At present, there is a growing interest for "at a distance" identification systems, such as systems of analysis and recognition of gait [10–13] and/or the estimate of stature.

These systems presuppose the analyses of sequences of gait, a factor which makes their application difficult within the limits of video surveillance, in which usually few useful photograms of persons, taken during a generic walking phase, are available.

Instead, height appears to be a more effective parameter, at least in proving the compatibility between the subject on tape and the suspect or in excluding the suspect as the perpetrator.

Izumi and Uerki [14] proposed a stereoscopic telecamera surveillance system mounted on the ceiling to estimate the distance between the head and the telecamera and, therefore, to deduce the height of the person.

BenAbdelkader et al. [11] demonstrated an increase in effectiveness of personal identification when, in the procedure, the estimate of the height is also included along with the quantification of the biometric parameters of gait.

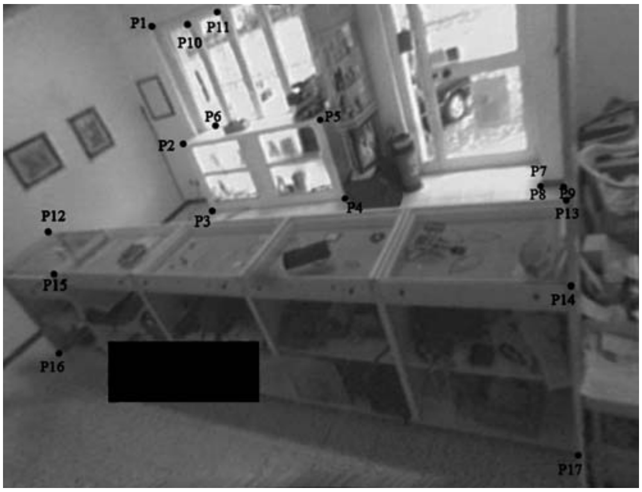

Fig. 1 Example of the selection of a reference system and of significant points

Criminisi et al. [15] reached similar conclusions: They state that height is a valid exclusion instrument, crucial when the height of the suspect is evidently different from the estimated one.

The scope of the present pilot study is to present a method for estimating the height of subjects taped in an erect posture.

Materials and methods

The measurement of the height of a subject recorded by a surveillance video camera includes a series of operations culminating in the 3-D reconstruction of the scene and in the superimposition of the virtual environment and the related starting 2-D image. This last phase is functional to the insertion in the scene of a virtual probe in correspondence to the contact point of the feet with the floor. In this way, the probe top is made to coincide with the top of the head, and stature of the filmed person can be deduced by probe height.

Clips considered "significant" for the purpose of determining the stature are chosen according to one of the following criteria:

– The clip is useful for the parameterization of the shooting system: It must contain at least six noncoplanar points whose 3-D coordinates can be recorded with an inspection of the shooting environment (Fig. 1, the shooting environment is clearly visible).
– The clip is useful for height determination: It must contain the subject in its entire shape in the most vertical posture possible (Fig. 3 where the entire figure of the subject is taken).

The virtual environment is free from distortions, which are instead frequently present in the digitized images at the start, because of shooting optics. In order for the procedure of reconstruction/superimposition between real and virtual environment to give positive results, the images of interest must present a negligible distortion. Otherwise, they must be corrected by removing the existing distortion. If the original shooting system is available, a sample image is obtained by placing a gauging grill, on which some markers on the plane are uniformly positioned perpendicularly to the optical axis of the camera. With the analysis of the distribution of the positions of the markers, it is possible to quantify the distortion introduced by the shooting system and remove it from the original images with the application of correction algorithms.

Once the six noncoplanar points are identified in the original 2-D frame, it is necessary to go to the shooting site and measure their relative position with the greatest possible

Fig. 2 "Camera matching": reconstruction of the virtual video camera (**a**); image taken with the virtual camera superimposed on a picture taken with the original camera (**b**)

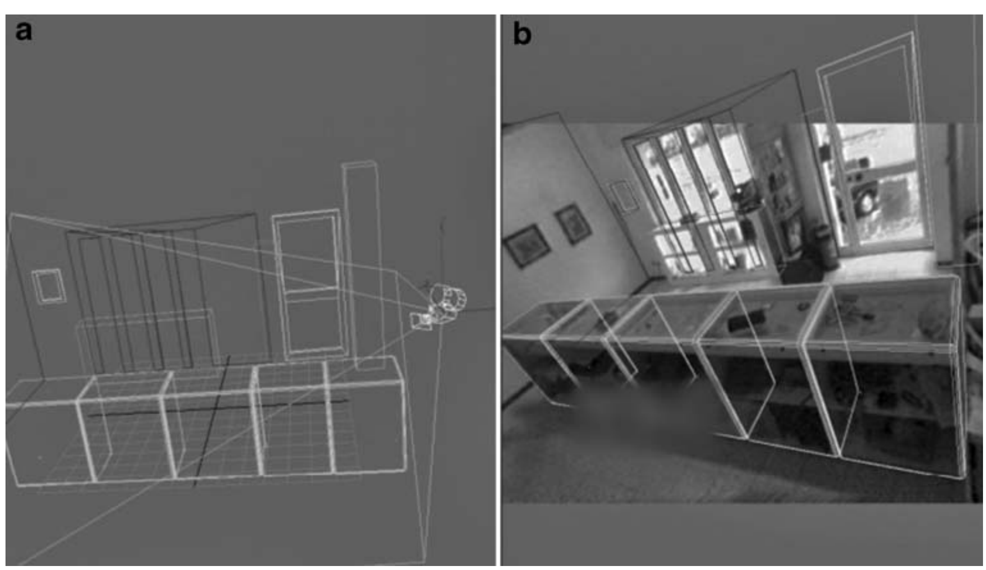

Fig. 3 Estimate of the height with an altimetric probe

accuracy. This is done with a LEICA TCR 1101 total station that can measure the 3-D coordinates of all points previously selected. Starting from these survey results, a simplified, but significant, environment of the telecamera shooting is modelled.

The simpler model is carried out by the authors using the special instruments of a commercial 3-D modelling program (Autodesk 3D Studio MAX). It is then possible to determine the position, the orientation, and the focal distance of the telecamera used for the shooting; clearly, this refers to an "ideal camera," as the procedure does not consider the imperfections of the real one; this, however, does not really represent a problem in view of the fact that probable important distortions existing on the real scene are removed before this point is reached.

The authors use a "camera match "procedure available from 3D studio MAX. The program enables in a simple way the superimposition of the reconstructed environment over the real one. To obtain such a result, it is sufficient to load in the background the real image, taken by the surveillance system, pinpoint the chosen reference points, and manually assign to each one of them their own 3-D coordinates. Once all information has been inserted, a virtual camera is created with all the characteristic parameters of the real system present in the original shooting.

By showing the virtual environment reconstructed by this camera, its superimposition over the original image is obtained.

Determination of stature

The superimposition of the reconstructed environment on the 2-D image makes it possible to evaluate the height of the subject present in the scene.

The evaluation of height is done by comparison with a probe of variable height introduced in the virtual scene in correspondence with the subject. The representation of a virtual environment, "perfectly" compatible with the original 2-D image "seen" by the same shooting system, allows the insertion into the scene of virtual objects observed from the same perspective. In order to reach the height of the subject, a probe anchored to the floor plane and positioned in proximity of the feet of the subject, is introduced. At this point, the height of the probe is adjusted until it reaches the upper extremity of the head.

This last part of the procedure requires the direct intervention of the operator, and the quality of the result obtained also depends on experience. For this reason, the positioning of the probe was done several times, by different operators, to verify error and repeatability.

For this purpose, six subjects of known height, placed in the same environment, were photographed in ten different positions in the scene. To evaluate the accuracy of the method, the subjects were asked to hold an erect position (to minimize the sources of uncertainty deriving from posture) and to wear during the trial the same shoes worn during the

Table 1 Values obtained from 10 measurements (A–L) of the same subjects (1–6; in mm)

Measurements	Subjects					
	1	2	3	4	5	6
A	1,690	1,880	1,690	1,660	1,710	1,830
B	1,680	1,870	1,680	1,660	1,690	1,810
C	1,680	1,880	1,680	1,660	1,690	1,810
D	1,680	1,880	1,690	1,660	1,700	1,820
E	1,700	1,900	1,700	1,670	1,710	1,830
F	1,680	1,890	1,690	1,670	1,700	1,820
G	1,680	1,880	1,690	1,660	1,700	1,810
H	1,690	1,890	1,690	1,660	1,720	1,820
I	1,690	1,870	1,700	1,670	1,710	1,820
L	1,700	1,870	1,710	1,680	1,700	1,810
Real stature	1,700	1,880	1,700	1,680	1,720	1,820

measurement of the real height. Finally, the images were obtained by using a digital camera, which supplies images of better quality than those obtained by the normal system of video surveillance. Considering the good quality of the images and the use of a digital camera, in this specific application, it was not necessary to carry out the operation of digitalization and of distortion correction.

Results

The main phases necessary to represent the virtual environment and to estimate height are shown in Figs. 1, 2, and 3.

The results related to the six subjects are reported in Table 1, in which the measurements obtained and the real stature for each individual examined are compared.

Experimental data, to be intended as preliminary results to be completed with further investigations, show an average difference between estimated and real height of about 10 mm, together with a standard deviation of 10 mm and assess the validity of the method.

Conclusions and future developments

The method generates a virtual camera with parameters entirely equivalent to those of the camera that produced the original images. Once the camera has been generated, it is possible to insert into the scene an altimetric probe that extends from the base of the feet to the top of the head of the person.

The initial experimental results of this pilot study seem to show that, under ideal conditions (excellent quality images and subjects taken in erect position), it is possible to estimate the height of the subject and, therefore, it is possible to formulate a judgement of compatibility between the height of the shot subject and that of the suspect (whose real height is known).

Extrinsic sources of error consist of the posture of the subject which may not be perfectly erect; the subject is wearing heels, wig, and/or hat (if heels are clearly visible, they can be measured with the same probe used to estimate stature); evaluation errors related to gait [11, 15], and errors of reconstruction, associated to the method used.

Among the sources of error intrinsic to the shooting system, we include errors associated to the resolution of the image (pixel dimension), distortion phenomena related to the shooting system residual even after correction and telecamera positioning.

While it is rather difficult to quantify and to correct sources of extrinsic uncertainties (such as non-erect posture, existence of a wig or hat), it is instead possible to quantify (and therefore correct) the uncertainty sources related to the shooting system. Further developments will be directed to the study and modelling of such factors (particularly factors of a nature intrinsic to the shooting system) and their influence on the method's accuracy, thus shedding light on possible strategies to carry out to reduce the uncertainty.

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