A new approach to obtain metric data from video surveillance: Preliminary evaluation of a low-cost stereo-photogrammetric system

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ABSTRACT:

Using an interdisciplinary approach the authors demonstrate the possibility to obtain reliable anthropometric data of a subject by means of a new video surveillance system.

In general the use of current video surveillance systems provides law enforcement with useful data to solve many crimes. Unfortunately the quality of the images and the way in which they are taken often makes it very difficult to judge the compatibility between suspect and perpetrator.

In this paper, the authors present the results obtained with a low-cost photogrammetric video surveillance system based on a pair of common surveillance cameras synchronized with each other.
The innovative aspect of the system is that it allows estimation with considerable accuracy not only of body height (error 0.1-3.1 cm, SD 1.8-4.5 cm) but also of other anthropometric characters of the subject, consequently with better determination of the biological profile and greatly increased effectiveness of the judgment of compatibility.

KEYWORDS: forensic science; video surveillance; CCTV; photogrammetry; identification; anthropometry; height.

1. Introduction

Video surveillance systems have become very diffuse in recent years and are now used to monitor a large number of urban areas and public sites. In many cases the images taken by such systems are the major, if not only, source of evidence for the identification of perpetrators. The best solution for this purpose is facial recognition, provided the images are sharp enough. If the image quality is insufficient or the people are masked, other elements must be analyzed, such as stature, gait, behavior, clothing, etc.

In addition to attempted facial recognition, the estimation of stature is often required to assess the compatibility between the suspect and the perpetrator. The most efficient techniques to estimate stature are based either on perspective, knowing the size of objects in the scene [1], or on "inverse photogrammetry". In this case a 3D virtual model of the crime scene is realized in which a virtual camera is placed and oriented just as the real one. The virtual images provided by the virtual camera are superimposed to the original ones. The height measurements are then taken in the 3D model by means of cylinders [2] or virtual humans [3] [4] or by means of a 3D ruler [5]. Another method [6] makes use of a frame placed in the crime at the perpetrator's location in the video in order to calibrate the camera, although the measurement accuracy is too dependent on the correct position of the frame in the scene.

Many factors can reduce the accuracy of stature estimation: location, orientation, optical and electronic quality of the cameras, attitude, posture and camouflage of the subject in the context of the crime scene, operator skill, etc. [2] [7] [8] [9]. For example, if the perpetrator is walking, his/her height varies approximately 6 cm in the vertical direction, and the maximum size may not correspond to the static value of stature [1]; indeed the search for confidence intervals for this parameter are based on a relationship between a systematic component and a random one [9]. Moreover a significant limitation to the accuracy of the stature estimation is due to the fact that the above-mentioned methods are based on processing of images taken by a single camera. This is because the normal installation of video surveillance cameras aims to limit as much as possible the overlapping of images. In this way the number of cameras is reduced to a minimum, with the consequent decrease of the costs of installation, maintenance and management of the plant. Therefore only rarely is the subject recorded by multiple cameras. Unfortunately this is a drawback because it prevents application of the algorithms of analytical photogrammetry and thus an accurate 3D determination of stature. Interesting results have been obtained in forensic studies with the simultaneous use of multiple cameras, but at least three cameras are required to achieve good accuracy [10]. Other multiple-camera applications different from surveillance [11] [12] [13] [14] regard the identification of an object moving in the scene. Similarly, in the fields of medicine and sports (mainly athletics, skiing, golf, rugby), there is now a widespread use of multiple cameras to perform anthropometric measurements and reconstruct the trajectories of human gestures (often for the prevention of accidents) [15] [16]. Therefore, considering the metrological potential of modern digital stereo-photogrammetry, the low cost of the sensors, the simplicity of use of image processing software, and the promising results of previous tests carried out in a simulated static crime scene [17], we decided to make and test a stereo-photogrammetric video surveillance device (SPVD) based on the acquisition of two simultaneous images of a subject. The surveillance system consists of two simple coupled cameras with parallel axes and a commercial photogrammetric software for the processing of digital images.

After clarifying the anthropometric significance of the terms "stature" and "height" (often incorrectly used as synonyms), we will describe the experimental study aimed at verifying whether the proposed low-cost sensor significantly reduces the error in the determination of height and, at the same time, if it can provide the values of other anthropometric characters for a much more effective assessment of compatibility [18].

2. Materials and Methods

The SPVD consists of a pair of digital cameras set up with their optical axes parallel at a distance of 40 cm from each other. The cameras, with a CMOS sensor (2MP, 1/3.2", zoom 2.8-8.2 mm, F 1.4, video 1600x 1200 px, 14 fps), were fixed to a horizontal bar that was in turn fixed to the wall with a bracket. An IR projector was located at the center of the bar (Fig 1a). To assess the accuracy of the measurements, an indoor test site was set up in an atrium of the Engineering Department (Fig. 2).

The stereo device was fixed at a height of 2.65 m above the ground and the optical axes were slightly inclined with respect to the horizontal (Fig. 1a). Thirty-nine Control Points (CPs) were placed on the walls and on the floor and were surveyed with a Topcon GPT-3100N total station in order to determine their 3D coordinates in a local reference system (Fig. 1b).

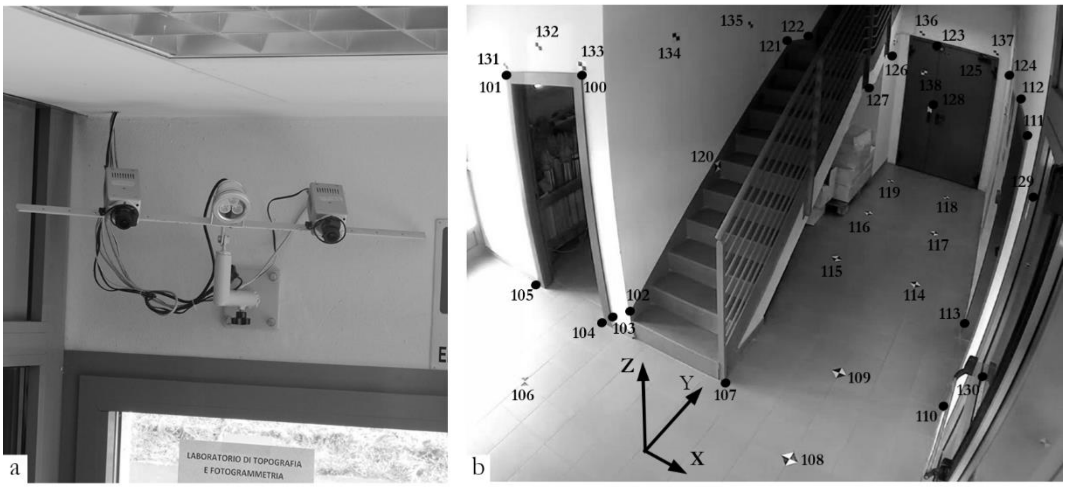

Fig. 1. The test site: the stereo photogrammetric video-surveillance device (first prototype of SPVD) fixed to the wall (a) and an image of the site with the CPs (100-138) provided by one of the cameras (b).

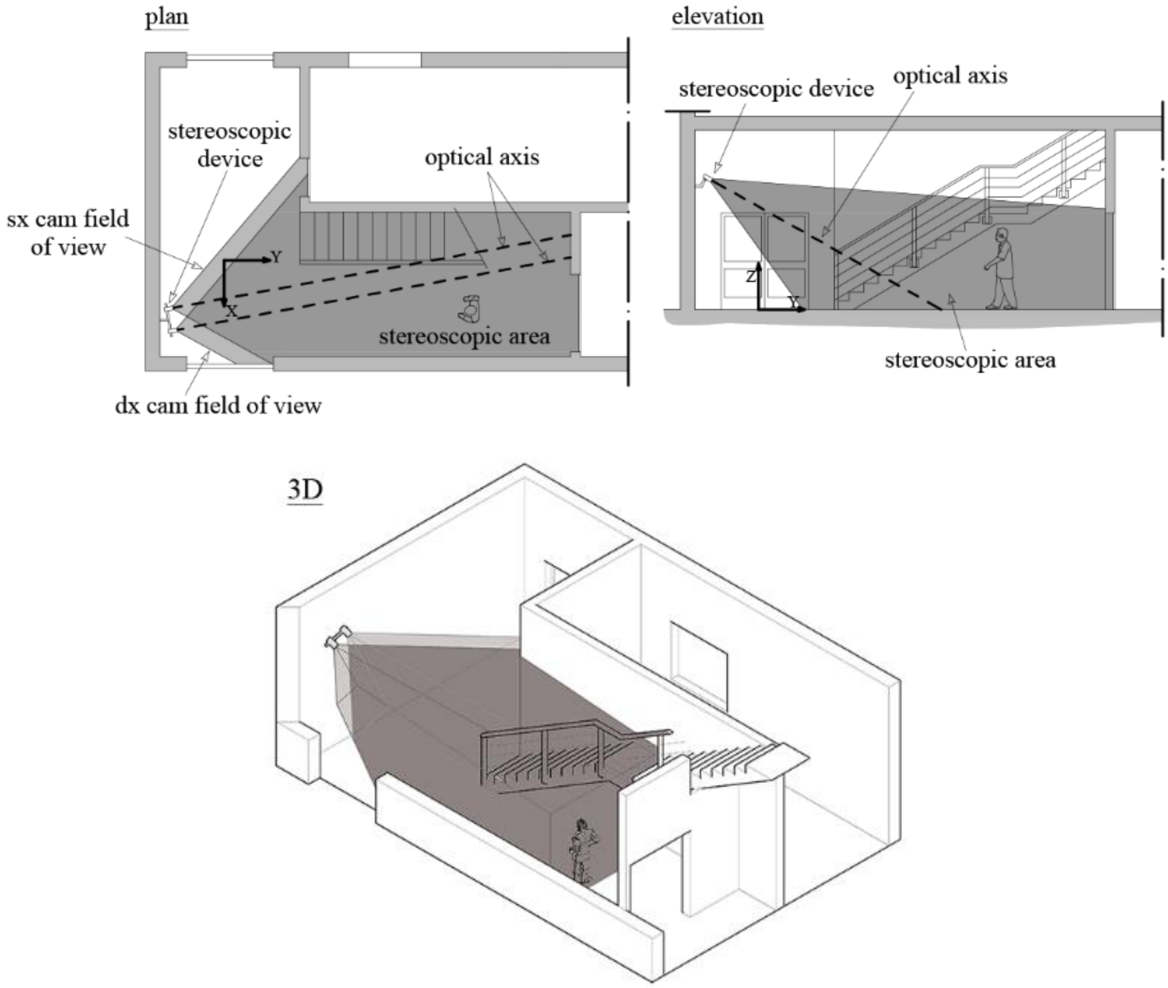

Fig. 2. Schematic representation of the indoor space (test site) controlled by the device (SPVD).

The two cameras were calibrated using the photogrammetric software PhotoModeler (EOS Systems Inc., v.6) to determine the focal distance, the main point of auto-collimation and the coefficients of the mathematical model of radial distortion. Hence it was possible to correct all the individual frames for the effect of distortion, as shown in Fig. 3.

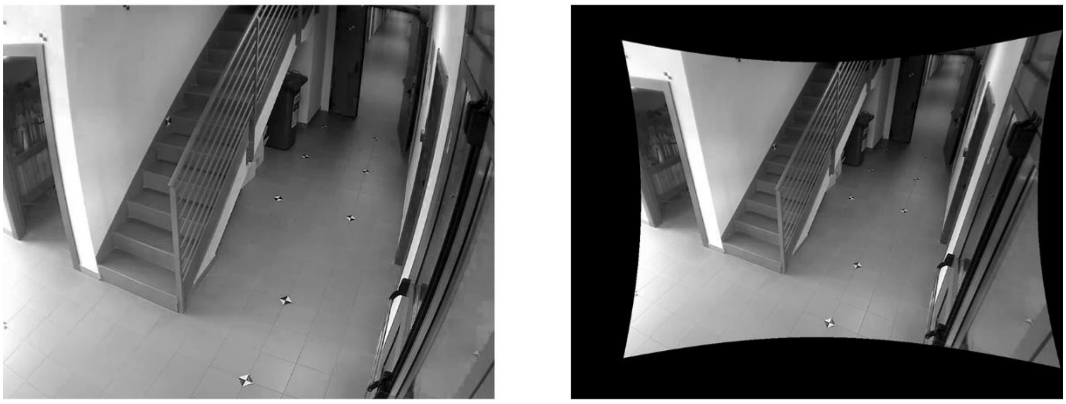

Fig. 3. Calibration of the cameras: an original image of the scene (left) and the same image without the effect of the radial optical distortion (right).

Subsequently the coordinates of the perspective centers of the cameras and the orientation of the optical axes in the local reference were determined by means of the CPs visible in both frames.

Testing of the video surveillance system was carried out on 11 volunteers (males of different body size, aged between 25 and 50 years) who were asked to walk naturally within the scene while being recorded by the cameras. Each of the volunteers walked along the hallway and stairs and back four times in one minute, providing hundreds of stereo-coupled images to be used for the metrological tests (Fig. 4).

Fig. 4. Examples of frames extracted from video recordings

The video recordings provided by the two cameras were synchronized and many stereo pairs of images were extracted. In the selected pairs of images the subjects were framed in front and from behind, in the more upright position possible and in different areas of the scene.

Significant anthropometric landmarks in each pair of images were identified and positioned by means of PhotoModeler (Fig. 5). It is necessary to specify that it is unlikely to detect the individual's stature in such circumstances. The stature is the distance between *vertex* and *planta* on a subject stretched vertically to the fullest extent and with the head positioned in the Frankfurt plane [19], which passes through *tragion* (above the top of the ear canal) to *orbitale* (the lowest point on lower orbital arch). The same measurement done without extension of the spine can be called "unstretched stature". When the orientation of the head is lacking, it should be called height of the head or total body height (below simply reported as Height). In the case of images, we will draw the distance between the highest and the lowest point of the body in a subject in standing position. Nevertheless, also in this case we can obtain different sizes depending on the position of the subject and the inclination of his head.

Numerous heights are possible from different anthropometric landmarks. From the X,Y,Z coordinates of the specific anthropometric landmarks (if detectable), the values of eight anthropometric characters were obtained in this study: 1) Height (distance from the ground of the highest point of the head, with the landmark taken along the median sagittal plane of the head in an upright position), 2) shoulder height (distance of *akromion* from the ground), 3) forehead height (distance of *trichion* from the ground), 4) eye height (distance of *ectocanthion* from the ground with the head in an upright position), 5) ear height (distance of *tragion* from the ground with the head in an upright position), 6) eyes breadth (*ectocanthion* - *ectocanthion*), 7) shoulder breadth 1 (*akromion* - *akromion*), 8) shoulder breadth 2 (bideltoid breadth) [20][21].

Measurements of the characters 2, 5, 7, and 8 were carried out on both right and left sides by averaging the corresponding values when the landmarks were both visible in the stereo pair of images.

For each character we wished to obtain at least 20 determinations. Therefore it was necessary to extract a higher number of images from the video recordings (between 40 and 55), mainly because of the difficulty in detecting eyes and ears which were not always visible on the selected images.

The photogrammetric procedure (Fig. 5) is performed as follows: the operator selects a pair of strictly contemporaneous images. On each of them he identifies the position of the same anthropometric landmark, making use of the epipolar straight line. The software then computes the X,Y, Z coordinates of the selected landmark in the local reference system.

From such coordinates it is simple to obtain the anthropometric characters:

$$\text{Height} = Z_v - Z_f,$$

where Z_v is the elevation of the selected landmark and Z_f is the elevation of the floor along the vertical through the landmark, while the breadth is obtained from

$$\text{Breadth} = \sqrt{[(X_l - X_r)^2 + (Y_l - Y_r)^2 + (Z_l - Z_r)^2]}$$

where l and r mean left and right landmark respectively.

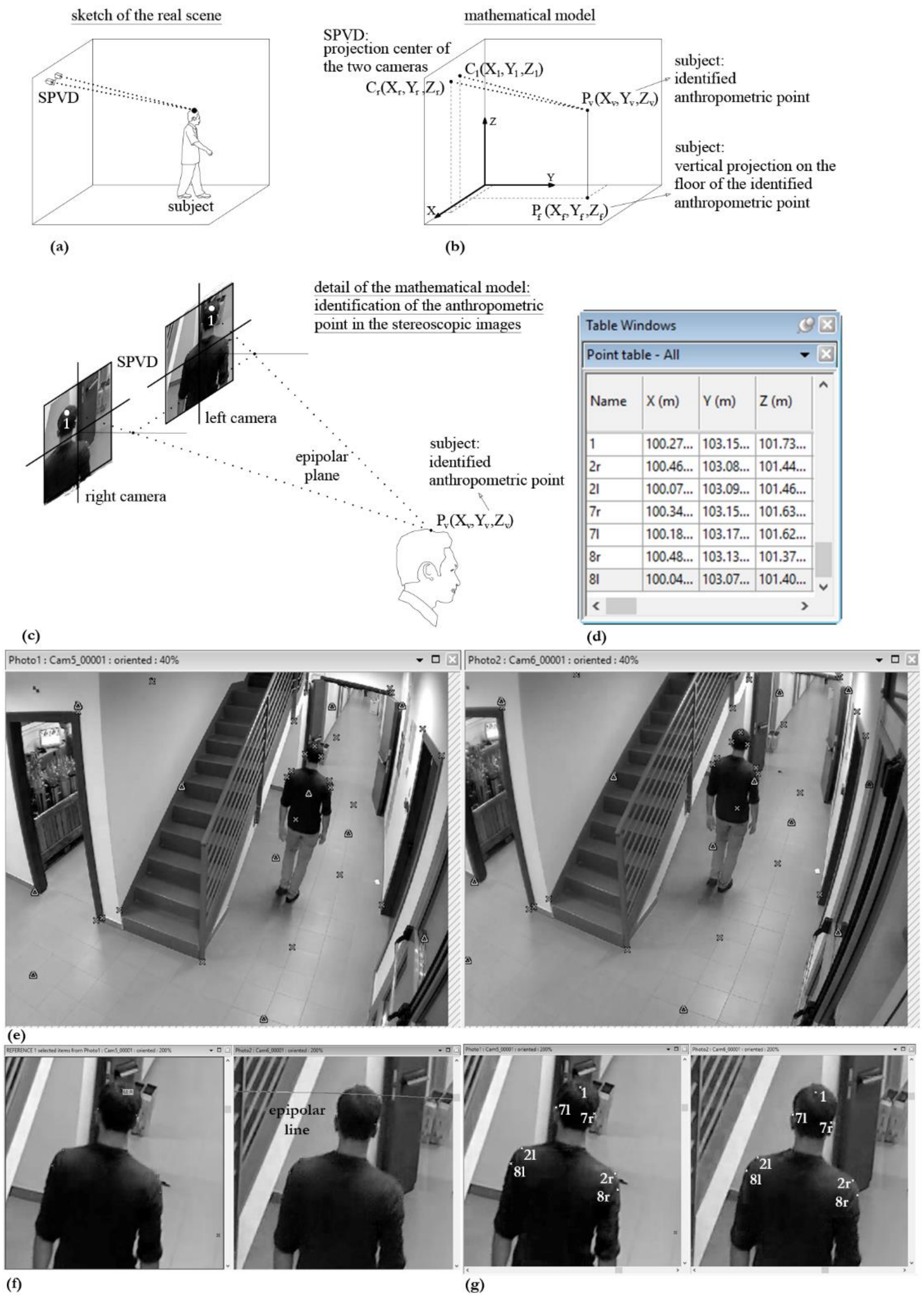

Fig. 5. Layout of the photogrammetric procedure: survey of the 3D position of an anthropometric point (a),(b),(c); selected pair of contemporaneous images and identified anthropometric landmarks (e), (f),(g) whose coordinates are reported in (d).

The photogrammetric measurements were compared with the corresponding direct ones carried out with anthropometric equipment in the laboratory. A stadiometer (Magnimeter, Raven Equipment Ltd., UK) was used to measure stature, unstretched stature and all other required heights (forehead, eye, ear and shoulder heights). The eye breadth (*ectocanthion-ectocanthion* distance, points at the outer commissure of the eye fissure) was measured with a sliding caliper. The biacromial and bideltoid breadths were measured with a caliper for chest measurements (a large sliding caliper). All measurements were taken to the nearest 0.1 cm by trained operators according to the standard procedures [19][20][21] immediately before or after the video recordings. For characters 1 to 5 the height of the shoes of each individual was added later to obtain values comparable with those estimated by the video surveillance system.

The first step of the procedure consisted in evaluating the accuracy of the SPVD. For this purpose the coordinates of some points in the scene were determined both by photogrammetry and by high-precision topographical surveying. The comparison between these coordinates provided a first indication of the accuracy of the video surveillance system. Moreover an object of known size and shape was placed in different positions of the test site in order to determine the discrepancies between the photogrammetric measurements and the true values.

In the second step, anthropometric landmarks of 11 subjects were collected independently by two operators, with multiple repetitions (40 on the average) of measurements for the same subject in different positions in the scene (videograms). The mean anthropometric measurements on images collected by the video cameras were calculated and compared with the “true” measurements (evaluated in the anthropometric laboratory with traditional equipment). The reference value (true value) for the Height detected on the images was the unstretched stature. The stature measurement was used to evaluate the mean difference in the comparison with unstretched stature.

Descriptive statistics were used to report inter-observer differences and differences in anthropometric characters as measured with anthropometric instruments and from images.

3. Results

3.1. Preliminary metrological tests

Prior to the anthropometric measurements, the SPVD was validated from a metrological point of view. For this purpose the external orientation of the cameras was performed using 12 targets of the 39 previously surveyed. The coordinates of another 10 targets (Control Points, CPs) were then determined by photogrammetry and compared with those already surveyed with the total station. The results reported in Table 1 show a remarkable accuracy of the system and of the procedure.

Table 1
Mean differences between the coordinates of CP’s determined by SPVD and by total station.

	DX	DY	DZ
Mean difference (m)	-0.003	0.006	-0.002
Standard deviation (m)	0.007	0.008	0.008

A second test based on an easily recognizable object of known size was performed to assess the calibration of the system (Fig. 6). For this purpose a target was used with three significant points (P1, P2, P3) placed on a bar of constant and known height (Fig. 6b). The target was placed at seven different locations (from S1 to S7) in the room (Fig. 6a), at each of which the height of the three points from the ground was determined by photogrammetry.

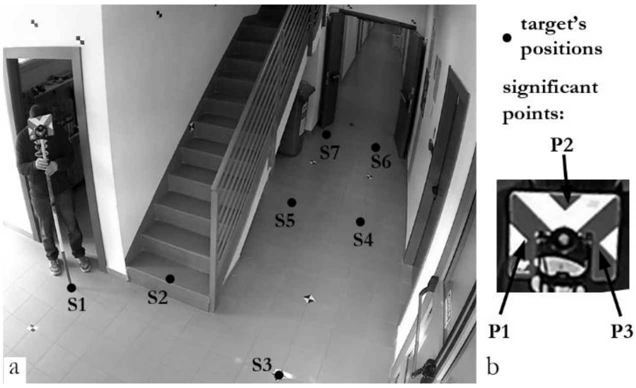

Fig. 6. The seven positions used for the test in the scene (a) and the target with three significant points (P1, P2, P3) (b).

The average height of points P1 and P3 was 1.568 ± 0.007 m (1.570 m true value), while the average height of the point P2 was 1.633 ± 0.007 m (1.631 m true value). The small differences between the measured and true values indicate that the orientation parameters calculated in the previous step were correct.

3.2. Anthropometric measurements

In this step a sample of 11 persons was surveyed. The video recordings were analyzed by two operators who acted independently of one another. For each subject located in a generic position in the scene, each operator manually identified the landmarks visible at that location in each pair of images, determining the X,Y,Z coordinates in the local reference system and the values of the corresponding characters (about 40 repetitions per character).

For each character we determined the mean, standard deviation and the difference between the photogrammetric measurement and the direct measurement previously collected by anthropometric instruments, regarding the latter as the reference value or “true” value. As an example, the results obtained for one subject of the sample are reported in Tab. 2. Different Height values calculated on the videograms for the same subject are also shown in detail in Figure 7.

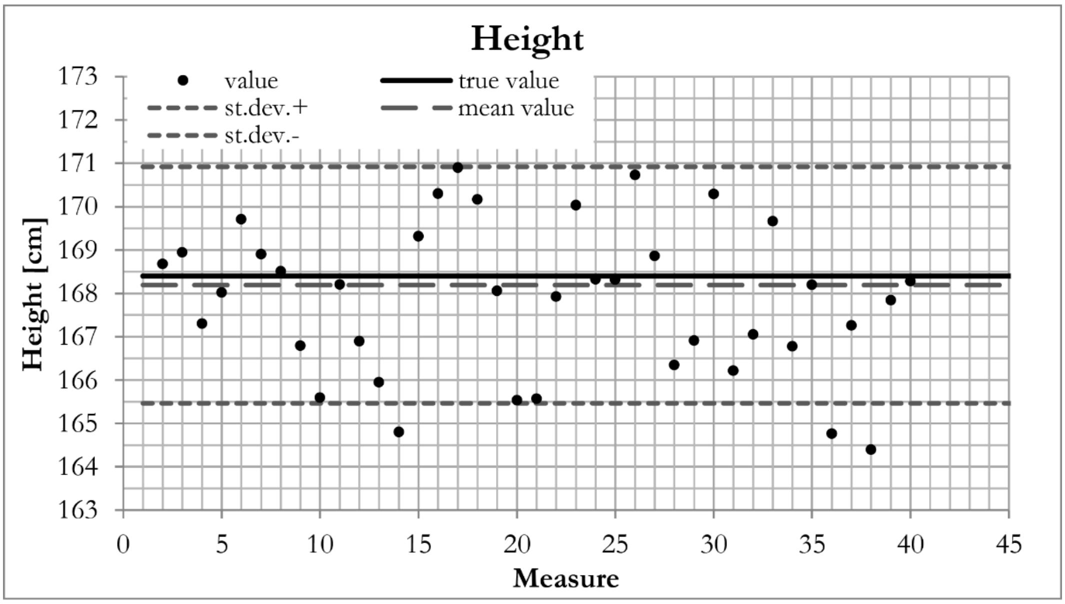

Fig. 7. The dispersion of 40 measures of the Height in one of the 11 subjects. The mean, standard deviation and true value are reported.

Table 2
Summary of the results achieved from all measurements in one of the 11 subjects (SD: standard deviation; Δ: difference mean-true value; Δ/true: relationship between Δ and the true value expressed in percent) (*r*: right side; *l*: left side)

Character	Number of measurements*	True value [cm]	Mean [cm]	SD [cm]	Δ [cm]	Δ /true [%]
Height	40	168.4	168.2	2.7	0.2	0.1
Shoulder height, *r*	39	133.8	137.0	2.7	-3.2	-2.4
Shoulder height, *l*	39	133.8	137.3	2.5	-3.5	-2.6
Mean shoulder height	38	133.8	137.1	1.9	-3.3	-2.5
Shoulder breadth (*akromion*)	38	40.5	37.6	2.2	2.9	7.2
Shoulder breadth (bideltoid)	37	45.0	44.5	2.0	0.5	1.2
Forehead height	27	165.2	165.6	2.9	-0.4	-0.3
Eye height, *r*	23	158.2	158.5	2.7	-0.3	-0.2
Eye height, *l*	25	158.2	158.5	2.1	-0.3	-0.2
Mean eye height	21	158.2	158.5	1.5	-0.3	-0.2
Eyes breadth	21	9.5	10.8	2.6	-1.3	-14.1
Ear height, *r*	30	157.7	158.2	2.4	-0.5	-0.3
Ear height, *l*	31	157.7	157.6	1.7	0.1	0.1
Mean ear height	21	157.7	157.9	1.6	-0.2	-0.1

*differences in the measurements number for each character depend on the position of the subject (in front or from behind) and on the availability of reliable frame pairs

With particular reference to Height, the results obtained for each subject of the sample are listed in Tab.3. Although not used in these comparisons, the mean stature of the examined subjects was 0.9 cm greater than the mean unstretched stature, used as the reference measurement in the comparisons with the Height evaluated on images.

Table 3
Summary of the results achieved from measurements of the Height in 11 subjects (SD: standard deviation; Δ: difference mean-true value; Δ/true: relationship between Δ and the true value expressed in percent, and the value of stature).

Character	Subject	Number of measurements	True value [cm]	Mean [cm]	SD [cm]	Δ [cm]	Δ /true [%]
Height	1	53	173.4	173.3	3.7	0.1	0.1
	2	43	178.9	175.8	4.5	3.1	1.7
	3	40	168.4	168.2	2.7	0.2	0.1
	4	56	165.6	163.1	2.1	2.5	1.5
	5	41	174.8	171.8	3.5	3.0	1.7
	6	42	180.5	179.3	2.4	1.2	0.7
	7	48	168.0	165.5	2.4	2.5	1.5
	8	45	177.6	174.2	2.5	3.4	1.9
	9	47	184.4	182.6	2.3	1.8	1.0
	10	43	184.8	182.6	2.7	2.2	1.2
	11	50	172.5	169.9	3.7	2.6	1.5

More in general, the differences between the photogrammetric and direct anthropometric measurements of all detected characters for each subject are provided in Table 4.

Table 4
Values and standard deviation (cm) of the discrepancy Δ between photogrammetric and true value for all the characters and all the subjects (first operator) (*r*: right side; *l*: left side).

Character			Height	Shoulder height, *r*	Shoulder height, *l*	Mean shoulder height	Shoulder breadth (*akromion*)	Shoulder breadth (bideltoid)	Forehead height	Eye height, *r*	Eye height, *l*	Mean eye height	Eyes breadth	Ear height, *r*	Ear height, *l*	Mean ear height
Subject	1	Δ	0.2	0.4	-2.9	-1.2	0.1	-0.5	2.1	0.7	0.0	-0.1	-1.7	1.6	0.5	0.9
		SD	*3.7*	*4.5*	*4.1*	*4.0*	*4.7*	*6.1*	*3.1*	*3.7*	*3.0*	*2.4*	*3.8*	*3.7*	*2.8*	*2.9*
	2	Δ	3.1	2.0	2.4	1.4	-3.0	-1.5	3.0	3.5	1.3	1.9	-2.0	3.7	0.7	1.2
		SD	*4.5*	*7.3*	*6.2*	*4.7*	*12.4*	*8.1*	*4.4*	*4.7*	*3.3*	*2.9*	*3.5*	*5.0*	*2.3*	*2.5*
	3	Δ	0.2	-3.2	-3.5	-3.3	2.9	0.5	-0.4	-0.3	-0.3	-0.3	-1.3	-0.5	0.1	-0.2
		SD	*2.7*	*2.7*	*2.5*	*1.9*	*2.2*	*2.0*	*2.9*	*2.7*	*2.1*	*1.5*	*2.6*	*2.4*	*1.7*	*1.6*
	4	Δ	2.5	0.3	0.6	0.2	-3.4	-0.3	3.6	3.3	3.2	2.6	-3.5	3.5	2.0	2.7
		SD	*2.1*	*2.5*	*2.8*	*2.2*	*2.4*	*2.1*	*2.8*	*1.7*	*2.5*	*1.3*	*5.0*	*2.6*	*1.8*	-
	5	Δ	3.0	-0.5	0.6	-0.2	-0.6	2.3	5.5	5.2	4.3	3.9	-3.2	2.8	2.7	2.0
		SD	*3.5*	*3.9*	*3.0*	*2.4*	*3.3*	*4.0*	*4.3*	*4.4*	*3.1*	*2.5*	*4.1*	*3.9*	*2.3*	*1.9*
	6	Δ	1.2	0.3	-2.2	-1.0	-3.5	0.4	3.9	1.8	1.1	1.3	-1.5	1.2	1.1	0.8
		SD	*2.4*	*2.8*	*2.9*	*1.9*	*5.2*	*4.4*	*2.2*	*1.8*	*1.2*	*1.1*	*3.3*	*2.1*	*2.2*	*2.1*
	7	Δ	2.5	-0.6	-1.0	-0.8	1.3	-0.2	2.3	1.3	1.8	1.3	-1.0	2.8	1.2	2.0
		SD	*2.4*	*2.7*	*2.6*	*2.2*	*2.7*	*2.7*	*2.7*	*1.5*	*2.4*	*1.5*	*2.4*	*2.4*	*1.6*	*1.1*
	8	Δ	3.4	-0.8	-0.7	-0.8	1.0	-1.3	-	2.3	1.6	1.6	-3.4	2.9	1.0	2.1
		SD	*2.5*	*3.1*	*2.4*	*1.7*	*4.0*	*2.9*	-	*2.2*	*2.9*	*2.3*	*5.7*	*3.5*	*1.8*	*2.1*

9	Δ	1.8	-1.1	-3.0	-2.3	0.6	-4.1	0.7	1.5	1.3	1.0	-1.1	1.0	0.6	0.4
	SD	*2.3*	*2.6*	*2.8*	*1.8*	*4.4*	*4.9*	*1.4*	*1.4*	*1.7*	*1.0*	*2.3*	*1.7*	*1.3*	*1.0*
10	Δ	2.2	-0.1	-0.2	-0.4	0.0	-5.7	3.3	1.2	2.3	1.4	-0.8	1.3	2.3	1.5
	SD	*2.7*	*4.0*	*3.9*	*2.5*	*5.8*	*5.3*	*3.5*	*2.7*	*3.7*	*2.4*	*2.1*	*2.5*	*2.3*	*1.7*
11	Δ	2.6	-2.5	-2.2	-3.2	2.5	-3.9	3.8	4.3	3.7	3.3	-1.7	2.0	1.8	1.6
	SD	*3.7*	*4.3*	*5.4*	*2.4*	*6.9*	*7.7*	*4.2*	*4.1*	*4.3*	*2.5*	*3.1*	*3.5*	*3.3*	*2.2*

As Fig. 7 and Tables 2-4 show, the discrepancy between the estimated and true value is reduced to a few centimeters by averaging many measures of the same anthropometric character. In particular, analyzing the whole set of data collected from 11 subjects, we obtained the following minimum/maximum discrepancies in absolute terms:

- Height (vs unstretched stature): from 0.2 cm (subject 1, 3) to 3.4 cm (subject 8);
- average shoulder height: from 0.2 cm (subject 4, 5) to -3.3 cm (subject 3);
- shoulder breadth (*akromion*): from 0.1 cm (subject 1) to 3.5 cm (subject 6);
- bideltoid breadth: from 0.3 cm (subject 4) to 5.7 cm (subject 1);
- forehead height: from 0.2 cm (subject 7) to 5.5 cm (subject 5);
- average eye height: from 0.1 cm (subject 1) to 3.9 cm (subject 5);
- eyes breadth: from 1.1 cm (subject 9) to 3.5 cm (subject 4);
- average ear height: from 0.2 cm (subject 3) to 2.7 cm (subject 4).

Moreover, the discrepancies between the mean values of the individual characters detected by the two operators were analyzed for the assessment of inter-observer error (Table 5).

Table 5
Inter-observer error: mean differences Δ (cm) between the values obtained from two operators for each anthropometric character of the 11 subjects (*r*: right side; *l*: left side).

Character	**Height**	**Shoulder height, *r***	**Shoulder height, *l***	**Mean shoulder height**	**Shoulder breadth (*akromion*)**	**Shoulder breadth (bideltoid)**	**Forehead height**	**Eye height, *r***	**Eye height, *l***	**Mean eye height**	**Eyes breadth**	**Ear height, *r***	**Ear height, *l***	**Mean ear height**
Δ (cm)	-0.8	-0.2	-0.7	-0.5	1.8	1.5	-1.0	-0.3	-0.2	-0.4	0.1	0.2	0.1	0.0
SD (cm)	*0.9*	*1.0*	*1.5*	*1.2*	*1.9*	*1.4*	*0.9*	*0.6*	*0.3*	*0.5*	*0.9*	*0.6*	*0.1*	*0.4*

The differences in mean values exceeded 1 cm only for two characters concerning the breadth of the shoulders. Indeed this was the most difficult character to estimate due to the uncertainty in identifying the landmarks in dressed individuals, thus making it more dependent on subjective interpretation. The standard deviation values were also greater than 1 cm, but less than 2, only in the measurements of the shoulders (heights and breadths).

4. Discussion

The proposed video surveillance system is simple, minimally invasive, low-cost and can be easily installed in place of existing video surveillance devices. Great care must be taken in the lighting of the scene and the calibration. The calibration must be performed only once and includes a 3D survey of the pavement and the determination of the external orientation parameters of the video cameras.

The data processing requires no special knowledge, being based on a commercial software for digital photogrammetry which is common and easy to use. However the data processing may take a long time, especially when using many pairs of images. This is not a serious drawback because the system should be employed only in the event of a crime or other rather rare situations. Undoubtedly the introduction of automatic matching algorithms would speed up the work.

The determination of anthropometric characters is performed by the photogrammetric survey of the 3D coordinates of significant points (landmarks). With regard to accuracy, the experimental test carried out on 11 individuals indicated that about 40 pairs of images are sufficient to obtain satisfactory results. In fact, by averaging many measurements of the same anthropometric character, the discrepancy between the estimated and true value is reduced to a few centimeters.

With regard to the inter-observer error, the measures show good congruence, the difference between the mean values of the same character measured by two separate observers ranging between -0.8 to 1.8 cm.
Such accuracy is due to the use of rigorous photogrammetry, the technical characteristics of the device and the processing of a large number of images, although only a few tens of the many hundreds of images were necessary.

The methods used in this study can be applied in forensic cases to determine possible matches in identities by comparison of measurements of a perpetrator to those of a suspect. In fact a significant advantage of the system is the detection of several anthropometric characters in addition to the traditional use of body height to get a reliable assessment of compatibility. Although stature (measured during forced extension of the body according to precise anthropometric standards) and the total body height detectable on video frames are different measurements, the latter character was very similar to the unstretched stature. As recently observed by Yang et al [22] for eye height, all the examined heights (body, eye and ear) were unaffected by a possible lack of orientation in Frankfurt plane probably due to the numerous repetitions considered and the careful choice of frames by the operators, who were well trained in anthropometric landmarks. Our results indicated that the Height of a walking person was smaller on average than his/her unstretched stature (static measurement), in accordance with the literature [8], but that the difference was less than 1 cm on average. The good results for the Height assessment obtained in this study may be partly due to use of the direct measurement of the heel height of the shoe instead of a generic correction factor as used previously [8]. Moreover the availability of numerous pairs of images allows estimation of precision on a statistical basis and elimination of the problem of variations in Height due to motion and posture [1].

Of course some improvements of the system can be obtained by using high-resolution cameras to reduce the error in identifying homologous points, by automation of the process through matching algorithms, and by studying the parameters that influence accuracy: the number of pairs of images to be used, the distance between cameras, the inclination of the optical axes, protection of the device against atmospheric agents and dust.

5. Conclusions

This study describes a new low-cost stereo-photogrammetric system that provides interesting prospects for future applications in forensic cases. A reliable assessment of several anthropometric characteristics of the perpetrator is obtained directly from the video images of this security system, providing a more detailed anthropometric profile and contributing to his/her identification.

References

[1] A. Criminisi, A. Zisserman, L. Van Gool, S. Bramble, D. Compton, New approach to obtain height measurements from video, SPIE Proceedings, Investigation and Forensic Science Technologies 3576 (1998) 227-38.

[2] B. Hoogeboom, I. Alberink, M. Goos, Body height measurements in images, J. Forensic Sci. 54 (2009) 1365-75.

[3] G. Edelman, I. Alberink, Comparison of body height estimation using bipeds or cylinders, Forensic Sci. Int. 188 (2009) 64-67.

[4] D. De Angelis, R. Sala, A. Cantatore, P. Poppa, M. Dufour, M. Grandi, C. Cattaneo, New method for height estimation of subjects represented in photograms taken from video surveillance systems, Int. J. Legal Med. 121 (2007) 489-92.

[5] J. Lee, E.D. Lee, H.O. Tark, J.W. Hwang, D.Y. Yoon, Efficient height measurement method of surveillance camera image, Forensic Sci. Int. 177 (2008) 17-23.

[6] A.K. Chong, A rigorous technique for forensic measurement of surveillance video footage, Photogramm. Eng. Rem. S 668 (2002) 753-59.

[7] P.K. Larsen, E.B. Simonsen, N. Lynnerup, Gait Analysis in Forensic Medicine, J. Forensic Sci.. 53 (2008) 1149–1153.

[8] N. Ramstrand, S. Ramstrand, P. Brolund, K. Norrell, P. Bergstrom, Relative effects of posture and activity on human height estimation from surveillance footage, Forensic Sci. Int. 212 (2011) 27-31.

[9] I. Alberink, A. Bolck, Obtaining confidence intervals and Likelihood Ratios for body height estimations in images, Forensic Sci. Int. 177 (2008) 228-37.

[10] P.K. Larsen, L. Hansen, E.B. Simonsen, N. Lynnerup, Variability of bodily measures of normally dressed people using PhotoModeler Pro 5, J. Forensic Sci. 53 (2008) 1393-99.

[11] K.H. Bae, J.S. Koo, E.S. Kim, A new stereo object tracking system using disparity motion vector, Opt. Commun. 221 (2003) 23-35.

[12] Z. Cui, A. Li, A novel binocular vision system for surveillance application. J. Multimedia 8 (2013) 307-14.

[13] J.H. Ko, E.S. Kim, Stereoscopic video surveillance system for detection of target's 3D location coordinates and moving trajectories, Opt. Commun. 266 (2006) 67-79.

[14] J. Ko, J. Lee, Stereo camera-based intelligence surveillance system. J.A.C.E. 3 (2015) 253-57.

[15] A.K. Chong, Exploiting HD camcorders for close-up human movement applications, Photogramm. Rec. 27 (2012) 227-37.

[16] A.K. Chong, H.G. Kroft, A photogrammetric application in virtual sport training. Photogramm. Rec. 24 (2009) 51-65.

[17] P. Russo, A. Furini, E. Gualdi, Low cost photogrammetry for morphometric human detection in video surveilance. Proceedings of the 18th International conference on Virtual Systems and Multimedia; 2012 Sep 2-5; Milan, Italy: IEEE Xplore Digita Library (2012) 599-602.

[18] P.K. Larsen, E.B. Simonsen, N. Lynnerup, Use of photogrammetry and biomechanical gait analysis to identify individuals, Proceedings of the 18th European Signal Processing Conference (EUSIPCO-2010); 2010 Aug 23-27; Aalborg, Denmark: EURASIP (2010) 1660-64.

[19] J.S. Weiner, J.A. Lourie, Human Biology - A Guide to Field Methods, Blackwell Scientific Publications, Oxford, 1981.

[20] F. Facchini. Antropologia. Evoluzione, Uomo, Ambiente. UTET, Torino, 1999.

[21] ISO 7250. Basic human body measurements for technological design. 1996.

[22] S.X.M. Yang, P.K. Larsen, T. Alkjær, B. Juul-Kristensen, E.B. Simonsen, N. Lynnerup, Height estimations based on eye measurements throughout a gait cycle, Forensic Sci. Int. 236 (2014) 170-174.