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DIGITAL CLOSE RANGE PHOTOGRAMMETRY FOR 3D BODY SCANNING FOR CUSTOM MADE GARMENTS

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Abstract

Among several biometric applications, one of those currently attracting great interest is the possibility of carrying out 3D digitization of human individuals to analyze their physical characteristics. These characteristics can be used for several purposes, such as security, medicine and tailoring for custom-made clothing. In recent years, although the development of on-line 3D scanning systems has been accelerating fast, little work has been devoted to off-line systems, that are particularly suitable for textile industries.

In the present research the author presents a properly designed low cost off-line 3D body digitizer, based on Digital Close Range Photogrammetry. A specifically designed photogrammetric 3D scanner of the human body is presented, featuring automatic image processing procedures. The scanning system consists of 8 cameras with a resolution equal to 5 Mpixels, equipped with 16 mm wide angle lenses; there are 4 white light illuminators, of 100 W each. Tests on entire dummy and human bodies are reported, demonstrating the profitability of the technique for textile applications. The digitizations performed on human bodies generally yield worse results than the corresponding ones on the dummy and full body digitizations are worse than corset digitizations due to the lower points density and targets distortion. Nevertheless, the results are satisfactory for tailoring applications that do not require high accuracies.

KEYWORDS: 3D Body Scanning, Digital Close Range Photogrammetry, textile industry.

INTRODUCTION

The production of custom-made clothes involves continual fitting sessions, long delivery times and often prohibitive costs. In this field one of the most interesting challenges is to automate some parts of the process in order to obtain a competitive product in terms of both quality and cost. By using Concurrent Engineering and promoting the integration between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), it is possible to reduce the time to market and to enhance the quality and lower the cost of completely customized garments. The first step to be accomplished in order to automate the production of customized garments is to perform 3D digitization of the customer. In this way Reverse Engineering (RE) can be used to achieve a Computer Aided Design (CAD) model of the customer. The CAD model can sent to the CAM interface to automatically generate paths to cut textiles but also to perform the virtual fitting session in order to correct any undesired features before the final production, thus reducing the number of fitting sessions with the customer. The virtual simulation can avoid the need for physical prototyping, that is currently used in the textile industry, thus resulting in remarkable savings of time and money (Chittaro and Corvaglia, 2003). The development of a 3D CAD model reconstruction of the human body could represent a dramatic improvement in mass customization of clothes, accelerating e-commerce thanks to the use of virtual mannequins (Cordier et al., 2001). Several examples can be found in literature, reporting advanced methods of manufacturing clothes from 3D scanned body data (Kim and Park, 2007) (Au and Yuen, 1999) (Kim and Kang, 2002) (Kang and Kim, 2000). In the present paper the most important 3D human body scanners suitable for use in the textile industry are listed, pointing out features such as costs, ease of use, and diffusion potential. In this paper the author discusses an experimental photogrammetric scanner, that can easily be converted into a commercial, cost-effective one, just by replacing the video-cameras with consumer cameras.

BACKGROUND

3D digitization of human bodies is used in several knowledge domains; this use can be divided into two main groups: a) the first group is mainly related to visual results: the cinematographic industry, computer games, art and virtual reality; b) the second group focuses on the quantitative aspect of the results, using the 3D information to carry out measurements. These anthropometric data are used in several disciplines: ergonomics, medicine, clothes industry, etc.

As regards textile applications, the most commonly used digitizing systems can be classified on the basis of the technologies used: laser scanning, structured light projection, image elaboration and modeling, microwaves. X-ray body scanners are not included in this context as they are currently applied exclusively in the security field. For an exhaustive analysis of several 3D scanning technologies, the reader should refer to (D’Apuzzo, 2009).

Laser Scanning

Systems based on laser triangulation allow 3D sizes to be obtained by means of a simple apparatus consisting of a laser emitter and two CCD cameras. Recent research involving the use of laser scanning to digitize the human body has focused on a wide variety of applications such as anthropometric data collection (Lu and Wang, 2008), (Li et al. 2008), ergonomics (Lu et al. 2010), medical applications (Kovacs et al., 2006), sport training (Chong and Croft, 2009) and garment fitting simulation (Cho et al. 2010), etc. To scan the human body the laser beam must be projected onto the entire region of interest. The number of laser sources depends on the size of the body part to be digitized. Several scanners are currently available on the market for digital acquisition of the surface of the entire human body, based on the same triangulation technique. They differ mainly in terms of the way they project the laser beam and the way the image is captured. The majority of scanners (Cyberware, Vitronic, TecMath, Hamamatsu) project horizontal strips on the body and exploit the vertical movement of the laser head. Other scanners (Hamano Engineering) work with two rotary mirrors projecting vertical strips over the body.

To optimize scanning time and quality, it is very important (Daanen et al., 1997) to block the subject's head; in this case scanning errors are reduced by approximately 50%, while the scanning time is reduced by about 30%. The scanning time of commercial laser scanners can vary between 5 and 20 seconds. Obviously, medical scanners have much better performances than those required by the clothes industry, achieving an accuracy equal to approximately 0.2 millimeters and an acquisition time equal to approximately 0.3 seconds. However, the costs of these technologies are still very high and this is reflected in the selling price of body scanners, that can reach several hundreds of thousands of Euro. The high price of this type of scanner is a strong disadvantage, as it severely limits the spread of this technology in the textile field.

Structured light projection

3D body scanners based on structured light projection are stimulating a great research effort, as reported in (Pribanic et al. 2010), (Yang et al, 2008) and (Yu and Xu, 2010). As compared to laser scanning, structured light allows one-step acquisition of the shape, with a remarkable saving of time. Indeed, laser scanning takes 5 to 20 seconds, while the projection of strips employs only about one second. The advantage of the short scanning time lies in the reduction of errors related to uncontrolled movements made by the subject. On the other hand, when the surface to be scanned is wide, it is necessary to employ several units, consisting of a light projector and CCD sensors, in order to work correctly. Interferences among them must be avoided by activating the projectors in series, increasing the scanning time. Another possible solution is to increase the distance between the subject and the projector; in this case the overall dimension of the system is very high.

Such scanners are competing with laser beams, especially because natural light is safer than laser. Other advantages are the low sensitivity to colors, the ease of use and easy maintenance due to the absence of moving parts.

Image Processing

In this section image processing techniques employed to achieve 3D models of the human body, using only digital images, are described.

Silhouettes extraction

The extraction of different silhouettes is based on a set of images taken of the person using several cameras, a single rotating camera or a single camera and a rotating platform. The images are subsequently processed to extract 2D profiles that when combined, yield the 3D model (D'Apuzzo, 2002). The volumetric representation of the human body is obtained from the intersection of the visual cones obtained by projecting each silhouette on the corresponding viewpoint (Bottino and Laurentini, 2000). This method can yield unconnected volumes or protrusions that do not correspond to real parts of the body, because the resulting geometrical shape is very complex.

Digital photogrammetry

Instantaneous 3D imaging systems are based on photogrammetry, where complete 3D information is gained thanks to the acquisition and matching of several images. These methods are particularly suited to digitization of human body data because of their insensitivity to slight body movements. In order to create a model of the body, the 3D information on the person can be directly acquired or a generic pre-existing model of the face may be employed, and then adapted to the specific individual. Actually, photogrammetry is not currently much employed to scan the human body, as this is usually done by means of laser or structured light-based scanners (Simmons, 2001). However, the costs of such scanners are still high and they do not facilitate the capillary spread of these useful technologies, whereas the adoption of photogrammetry would dramatically lower costs. The use of consumer cameras for accurate photogrammetric applications is reported in several papers such as (Chandler et al., 2005) where the potential of low-cost digital cameras for close range surface measurement using feature-based image matching methods is examined. This is achieved through extracting digital elevation models (DEMs) and comparing accuracies between three low-cost consumer-grade digital cameras. Another interesting research effort is concentrated on the development of new and more accurate calibration techniques (Chong et al., 2009), especially for medical applications.
Moreover, several works are available in literature that have analyzed the quality of data obtainable by proprietary software, such as Photomodeler by Eos systems, for similar applications. In (Larsen et al. 2008) the authors have quantified the inter- and intra-observer variability of bodily measures of clothed individuals in two different poses and examined whether body segment lengths could be used to distinguish between people of similar stature. For example, stature was reproduced within +/-1.5 cm in both the intra- and inter-observer study. In (Tasdemir et al., 2008), veterinary body measures are achieved with a similar accuracy, using a low resolution camera and no targets on the body.

The use of targets for applications related to human facial digitization dramatically improves the accuracy of measures with Photomodeler, as described in (Deli et al, 2009), where sub-millimetre accuracy is achieved when comparing the photogrammetric technique to laser digitization by the Minolta Vivid 910i.

Microwaves Body Scanner

One of the most recent systems is based on millimeter-waves scanning (Kim and Forsythe, 2010), mainly used for the garment industry (Petrova and Ashdown, 2008). It exploits low power electromagnetic waves, defined as millimeter-waves, in order to create a 3D model of the human body. Microwaves frequency varies between 1 and 30GHz, while the millimeter-waves range between 30 and 300GHz; they can be used for anthropometric applications due to their biocompatibility at low power levels. The process lasts about 10 seconds, digitizing hundreds of thousands of points, and its accuracy is about 6 millimeters. However, the disadvantages are the low accuracy of the measurement, and the fact that people are understandably reluctant to be bombarded by radio waves. Moreover, also in this case the costs are very high. In the author view, the photogrammetric technique introduces the best margins of improvement, owing to its intrinsic characteristics such as very low scanning times, low cost equipment and no intrusiveness.

EXPERIMENTAL SETUP

In this paper a specifically designed photogrammetric 3D scanner (**Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.**) of the human body is presented, featuring automatic image processing procedures. The scanning system is composed of 8 cameras uEye UI-1480 from IDS with a resolution equal to 5 Mpixels, equipped with 16 mm wide angle lenses FUJI DF6H-1B; there are 4 white light illuminators, of 100 W each. These cameras have been chosen as experimental equipment, due to their high flexibility, easy management of multiple live views by the PC operating system and, for the purposes of further studies, their capability of capturing

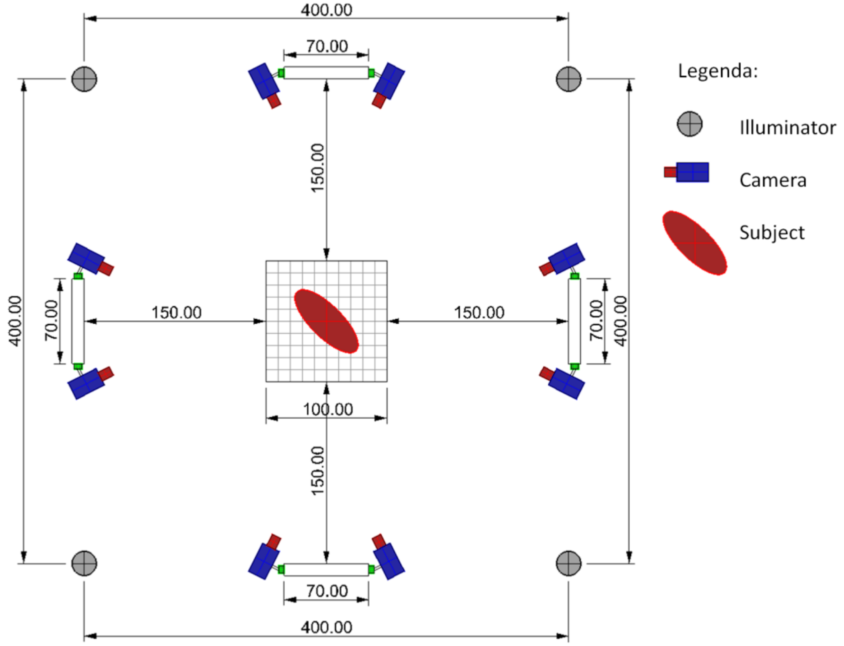

Fig. 1: The designed photogrammetric 3D scanner

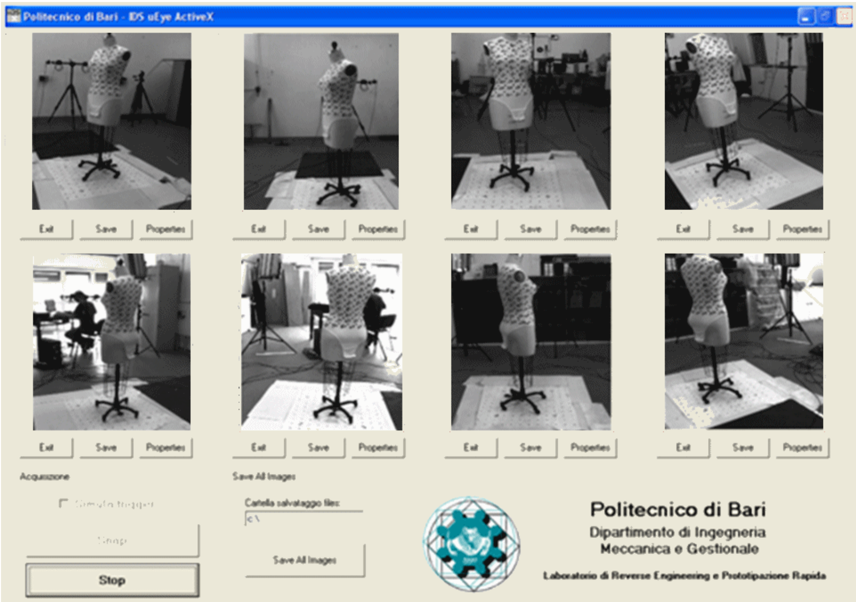

Fig. 2: Software Interface for image acquisition

and studying motion. Possible industrial applications.could be more profitably performed using commercial digital cameras that feature several advantages such as lower cost, a larger format, higher resolution and ease of operation. The eight cameras are software-triggered, while the female subject was asked to collaborate by limiting as far as possible her movements. The positions of the cameras with respect to the trunk are vertical and follow a convergent design, so as to produce 4 couples. The internal angle of each couple is 30 degrees, while the angle distance between two consecutive cameras, not belonging to the same couple, is 60 degrees. This configuration allows a high overlap of the front and rear part of the body, avoiding the presence of illuminators in front of the cameras while assuring a uniform, sufficient illumination of the subject. Image processing is done with Photomodeler 6.0 software by Eos Systems. Calibration of the system has been performed using a 12 x 12 points grid with 4 coded points, printed on a bidimensional 90 cm x 90 cm format. The application for garments does not require a high accuracy, so a 2-D calibration grid is sufficient (Fraser, 1997). Six images per camera were used, for a total of 48 photos. This phase, devoted to computing the lens distortion parameters, yielded the results in terms of repeatability shown in Table 1: the overall residual RMS for each camera ranged between 0.05 and 0.07 pixels, and the maximum residual for each camera between 0.29 and 0.44 pixels. The estimated accuracy for a project obtained with this configuration is about 1:5000, as declared by Eos Systems.

Table 1: Overall RMS and Max Residual in computing parameters of lens distortion (units are pixels).

	Cam 1	Cam 2	Cam 3	Cam 4	Cam 5	Cam 6	Cam 7	Cam 8
Overall RMS	0.0495	0.0565	0.0668	0.0613	0.0668	0.0593	0.0575	0.0715
Maximum Residual	0.3197	0.3866	0.4315	0.3404	0.4398	0.3245	0.3429	0.2881

RESULTS

The scanner was preliminarily validated in several tests, described in the present paper, in the form of tests on only dummy and human busts, or the entire dummy and human body, all Italian size 42 (corresponding to American size 8). The busts were dressed with specially designed corsets (Fig. 3:), while the human bodies have been dressed in special suits. Several tests have been conducted of the corsets. For the sake of brevity in the present paper only three different typologies are reported: (i) coded targets with an external radius equal to 3.5 cm and an internal radius equal to 1 cm; (ii) hybrid coded-non coded targets where the coded targets are equal to case (i) and non coded targets with a diameter equal to 1 cm; (iii) hybrid coded-non coded targets where the coded targets are equal to cases (i) and (ii) and the non coded targets diameter is equal to 0.5 cm.

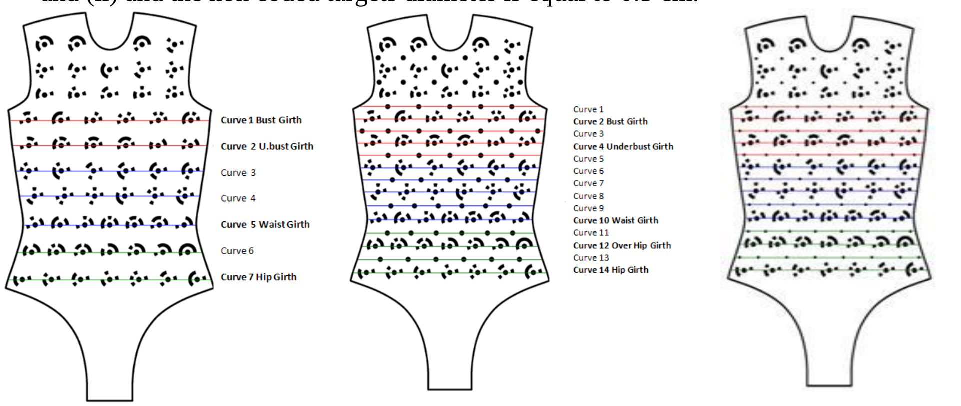

Fig. 3: (i) coded targets (ii) hybrid, larger non coded targets (iii) hybrid, smaller non coded targets

Tests on the bust

The corset (i) allows seven curves to be measured from the bust to the waistline. The use of non-coded targets allows the digitizable curves to be doubled and up to 200 points to be digitized to gain a more detailed CAD model. The measurable curves are shown in Fig. 3 and Fig. 4 for the three bodies; the curves cited by norm EN 13402, the European standard for labelling clothes sizes, are in bold type. In Fig. 4 curves interpolating the digitized points are shown for each corset.

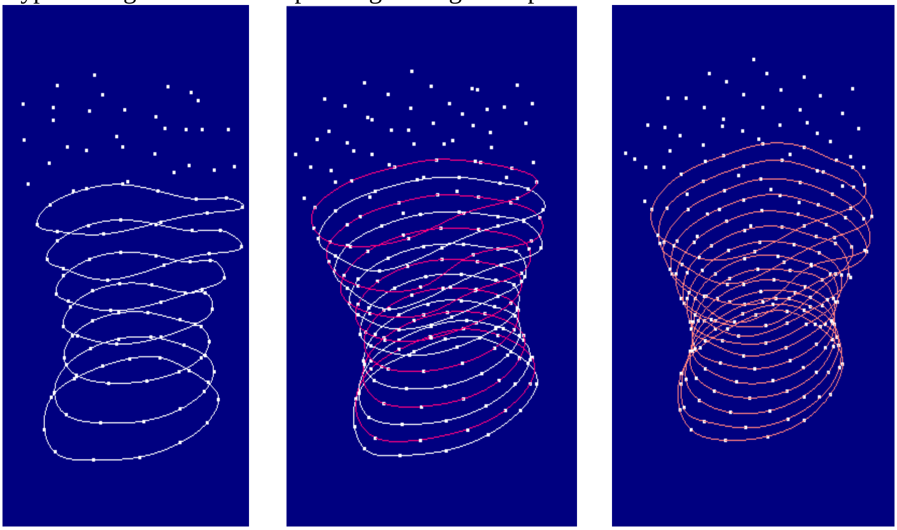

Fig. 4: Digitized curves with corset (i) Digitized curves with corset (ii) Digitized curves with corset (iii)

Each of these curves was measured using a classic tape-measure and the 3D digitizing system designed by the author.

The system is set up to minimize the need for human intervention: one operator is needed to guide the software photogrammetric elaboration. The images acquired are oriented, marked and processed with one-push-button procedures, leading to a point cloud. The points are then manually imported and joined into the corresponding curves with the aid of 3D CAD software.

Tailor's Dummy

The results are shown in Tables 2, 3 and 4, related to the measurements performed on the tailor's dummy with corsets (i), (ii) and (iii), respectively.

Table 2 Measurement on tailor's dummy with corset (i)

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*
Curve 1 Bust Girth	95.9	96.04	-0.14
Curve 2 Underbust Girth	93.3	92.97	0.33
Curve 3	82.7	83.5	-0.8
Curve 4	76.5	76.97	-0.47

Curve 5 Waist Girth	76.3	76.08	0.22
Curve 6	82.7	83.2	-0.5
Curve 7 Hip Girth	91.5	91.85	-0.35

The measured differences were computed as the mean absolute difference between manual and digital measurements. For corset (i) this was equal to 0.48 %, a satisfactory margin for tailoring applications. The highlighted curves are derived from the above mentioned UNI-EN standard. The hybrid corset (ii) (Table 2) introduces a mean difference equal to approximately 0.42% for 212 digitized points; however, this corset also introduces difficulties related to target marking during the image processing phase because the size of the uncoded targets was very similar to that of the ring codes, thus increasing the need for human intervention.

Table 3 Measurement on tailor's dummy with corset (ii)

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve 1	94.1	94.28	-0.18	-0.19
Curve 2 Bust Girth	96	95.55	0.45	0.47
Curve 3	95.5	95.2	0.3	0.31
Curve 4 Underbust Girth	91.1	91.14	-0.04	-0.04
Curve 5	86	86.05	-0.05	-0.06
Curve 6	81.2	81.44	-0.24	-0.30
Curve 7	77.2	77.85	-0.65	-0.84
Curve 8	75.5	76.25	-0.75	-0.99
Curve 9	74.6	75.11	-0.51	-0.68
Curve 10 Waist Girth	76.2	76.67	-0.47	-0.62
Curve 11	79.4	79.76	-0.36	-0.45
Curve 12 Over Hip Girth	85	84.92	0.08	0.09
Curve 13	89.4	89.18	0.22	0.25
Curve 14 Hip Girth	92.7	93.26	-0.56	-0.60

The results related to corset (iii) are shown in Table 3, showing a mean measurement error equal to 0.49%, measured on 225 digitized points. With this corset the marking and referencing phases were faster and more points could be digitized thanks to the smaller size of the uncoded targets.

Table 4 Measurement on tailor's dummy with corset (iii)

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve 1	94.6	94.93	-0.33	-0.35
Curve 2 Bust Girth	95.6	95.84	-0.24	-0.25
Curve 3	96.3	96.42	-0.12	-0.12
Curve 4 Underbust Girth	92.8	92.67	0.13	0.14
Curve 5	87.2	86.95	0.25	0.29

Curve 6	82.7	83.45	-0.75	-0.91
Curve 7	78.8	79.6	-0.8	-1.02
Curve 8	77.2	77.69	-0.49	-0.63
Curve 9	75.5	76.31	-0.81	-1.07
Curve 10 Waist Girth	76.5	77.03	-0.53	-0.69
Curve 11	79.3	79.56	-0.26	-0.33
Curve 12 Over Hip Girth	84.3	83.96	0.34	0.40
Curve 13	89.2	89.63	-0.43	-0.48
Curve 14 Hip Girth	92.5	92.68	-0.18	-0.19

Human

The tests performed on the tailor's dummy were preliminary to testing the performance of the system on the human body. For all the subsequent tests corset (iii) was used due to its better results. While the dummy is a static object, humans move continuously and imperceptibly. This phenomenon cold make target marking more difficult and less accurate. On the contrary, automatic target marking was achieved thanks to the designed system (Fig. 5) leading to the point cloud and the curves shown in Fig. 6

Fig. 5: Points marked on the female subject after image orienting and

marking

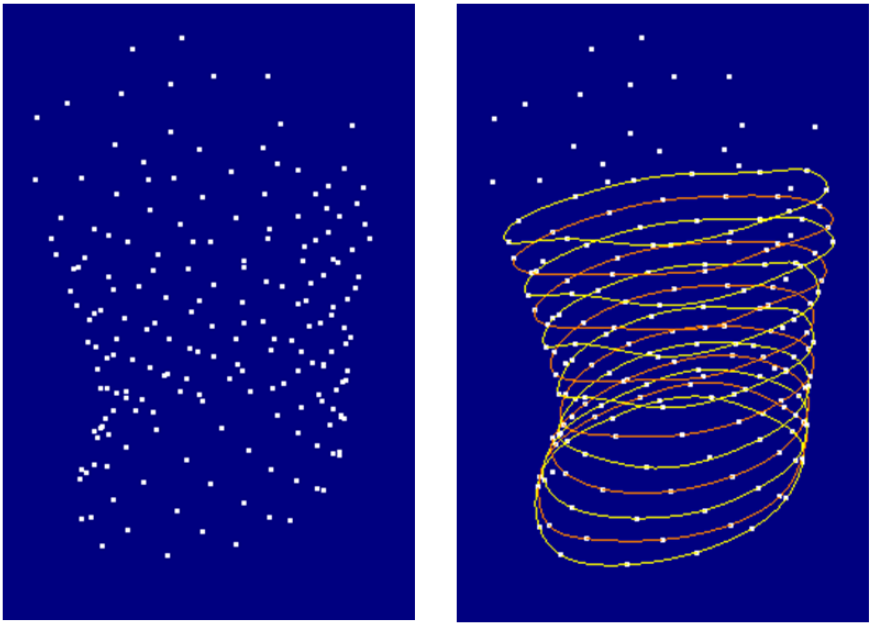

Fig. 6: 3D points and curves for the female subject

Table 5 Measurement on human body dressed in corset (iii)

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve 1	91.9	92.41	-0.51	-0.55
Curve 2 Bust Girth	92.8	92.36	0.44	0.47
Curve 3	92	92.25	-0.25	-0.27
Curve 4 Underbust Girth	90.6	90.05	0.55	0.61
Curve 5	87.3	86.91	0.39	0.45
Curve 6	83.5	84.36	-0.86	-1.03
Curve 7	80.8	81.4	-0.6	-0.74
Curve 8	79.7	80.4	-0.7	-0.88
Curve 9	80	80.3	-0.3	-0.38
Curve 10 Waist Girth	80.9	81.15	-0.25	-0.31
Curve 11	84.5	84.8	-0.3	-0.36
Curve 12 Over Hip Girth	88	88.5	-0.5	-0.57
Curve 13	91.3	91.96	-0.66	-0.72
Curve 14 Hip Girth	93.5	93.02	0.48	0.51

In Table 5 the results obtained are shown; at a first glance the results are worse than those with the dummy, with a mean error equal to 0.56%, computed on 193 points.

Full body tests

Tailor's Dummy

In Fig. 7 the suit used to measure the whole body is shown and the measured curves are indicated. The consistency of the texture is very important because of the possible deformation of the targets.

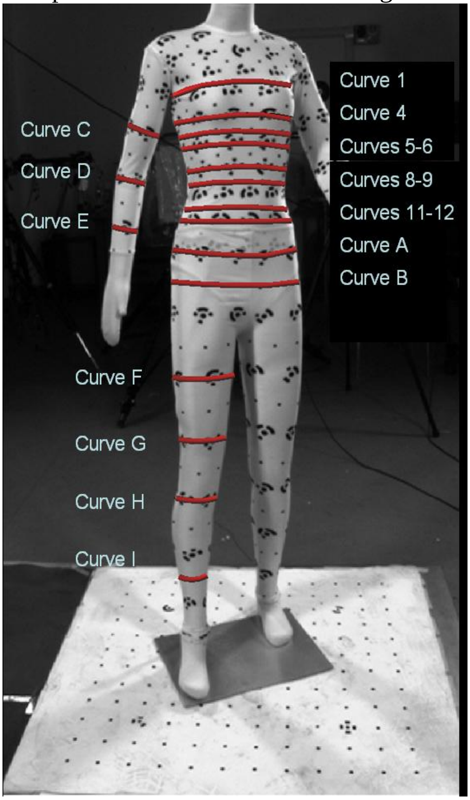

Fig. 7 the full body suit

BUST

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve 1	81.5	81.24	0.26	0.32
Curve 4	75.2	75.94	-0.74	-0.98
Curve 5	70.8	70.96	-0.16	-0.23
Curve 6	69	69.03	-0.03	-0.04

Curve 8	65.1	65.58	-0.48	-0.74
Curve 9	64	64.25	-0.25	-0.39
Curve 11	69.5	69.68	-0.18	-0.26
Curve 12	74	73.5	0.5	0.68
Curve A	81	80.66	0.34	0.42
Curve B	83	82.67	0.33	0.40
ARMS				
Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve C	22.3	21.82	0.48	2.15
Curve D	22	22.03	-0.03	-0.14
Curve E	18.2	18.42	-0.22	-1.21
LEGS				
Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve F	42	41.62	0.38	0.90
Curve G	32.1	31.74	0.36	1.12
Curve H	32	31.78	0.22	0.69
Curve I	26	26.21	-0.21	-0.81

Table 6 Measurement on tailor’s dummy dressed in suit

The results are similar to those obtained with the corset, and the difference between the tailor’s measure and the digital measure is never above 1 centimetre. The mean difference is equal to 0.67% (0.3 centimetres), on 389 digitized points, due to the presence of distorted coded targets on the legs and arms.

Full human body

Subsequently, the analysis was made on a woman (Fig. 8) to test the methodology in a real case, using the same settings as in the tailor’s dummy case.

Fig. 8:Photogrammetric suit on the human body

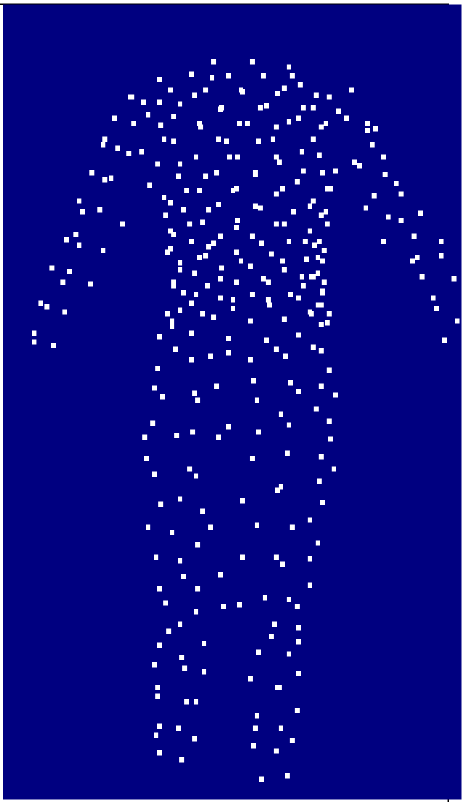

Fig. 9:Resulting point cloud

The point cloud has been made of 348 points, shown in Fig. 9, while the difference between tailor and digital measures is shown in Table 7.

BUST

Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve 1	92.8	93.7	-0.9	-0.97
Curve 4	90.6	90.09	0.51	0.56
Curve 5	86.8	85.22	0.81	1.02
Curve 6	83.5	83.23	0.27	0.32
Curve 8	79.7	80.51	-0.81	-1.02
Curve 9	80	80.56	-0.56	-0.70
Curve 11	84.5	84.67	-0.17	-0.20
Curve 12	88	88.73	-0.73	-0.83
Curve A	94.7	95.23	-0.53	-0.56

Curve B	99	99.23	-0.23	-0.23
ARM				
Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve C	24.4	25.1	-0.7	-2.87
Curve D	26.8	27.32	-0.52	-1.94
Curve E	26.4	26.26	0.14	0.53
LEG				
Measured Sizes	*Tailor measure (cm)*	*Photogrammetric Measure (cm)*	*Difference (cm)*	*Difference %*
Curve F	46.3	46.49	-0.19	-0.41
Curve G	39.4	39.12	0.28	0.71
Curve H	34	34.47	-0.47	-1.38
Curve I	27.9	28.37	-0.47	-1.68

Table 7: Measurement on a woman dressed in the suit

The results are similar to the test on the dummy, all the differences being lower than 1 cm, and the percentage difference is equal to 0.97 %, on 349 digitized points. Legs and arms are more difficult to digitize due to the higher distortion of the targets. The graph in Fig. 10 summarizes the performance of the various measurements in terms of percentage differences. The digitization performed on the human being is generally worse than the corresponding digitization on the dummy. Three measurement repetitions have been performed on each curve for both the mannequin and the woman and the values shown in the tables are the means. In order to investigate whether human movement is the cause of discrepancies, for each curve the F-test of the hypothesis that the two populations have the same variance, was carried out, using a confidence level equal to 90%. The F-test resulted in rejection of the null hypothesis, as no significant difference was demonstrated between variances for any curve. As a consequence, it cannot be claimed that movement is the cause of the worse behaviour of the scanner with humans. Further investigations of this aspect are needed.

Full body digitization resulted worse than corset digitization due to the lower points density and targets distortion on legs and arms. Nevertheless, the results are still satisfactory for tailoring applications. In particular legs and arms are critical areas also for automatic target marking due to shadow zones with low contrast. In this case it is very important the orientation of the subject. In Fig. 11 red circles highlight unmarked targets due to a combined effect of distortion and low contrast: in a different subject orientation or manual marking is required.

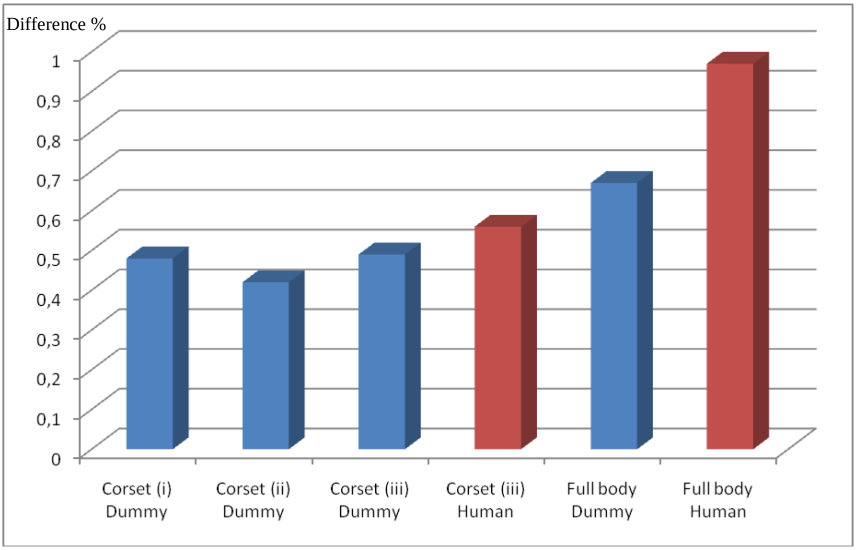

Fig. 10 Percentage Difference between tailor's measure and 3D scanner

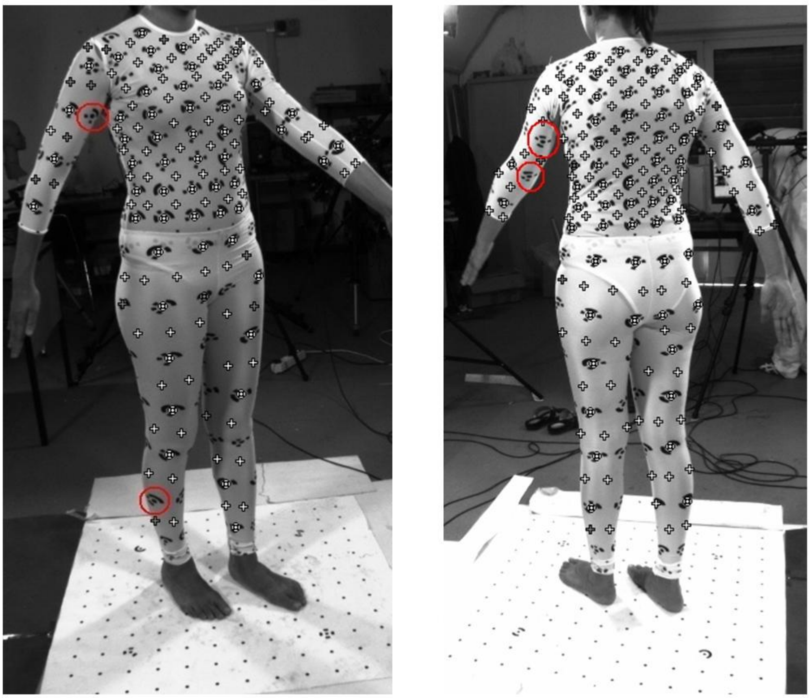

Fig. 11: Points marked on the female subject after image orienting and marking

CONCLUSIONS

The experimental 3D scanner presented in the present paper confirms the usefulness of photogrammetry using coded targets to digitize human bodies. The 3D information on the subject is correctly obtained and curves necessary for tailors to cut custom-made garments are successfully extracted. The analysis has been conducted considering two different dummies and two different human subjects, pointing out that tailor measurements can be obtained thanks to the use of properly designed corsets. In order to increase the performance of the process, further studies will be focused on combining photogrammetric applications with infra-red light and retro-illuminated targets to improve points recognition. Better accuracies can easily be achieved by using a highly redundant sensor network, increasing the number of cameras and increasing the sensor resolution. The system is economic, easy and has the potential for extensive use in the textile industry. The use of 3D technology in this field could represent a dramatic improvement in mass customization of clothes, also for e-commerce.

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