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3D body scanning technology for fashion and apparel industry

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ABSTRACT

This paper presents an overview of 3D body scanning technologies with applications to the fashion and apparel industry. Complete systems for the digitization of the human body exist since more than fifteen years. One of the main users of this technology with application in the textile field was the military industry. In fact, body scanning technology is being successfully employed since many years in military bases for a fast selection of the correct size of uniforms for the entire staff. Complete solutions were especially developed for this field of application.

Many different research projects were issued for the exploitation of the same technology in the commercial field. Experiments were performed and start-up projects are to time running in different parts of the world by installing full body scanning systems in various locations such as shopping malls, boutiques or dedicated scanning centers. Everything is actually ready to be exploited and all the required hardware, software and solutions are available: full body scanning systems, software for the automatic and reliable extraction of body measurements, e-kiosk and web solutions for the presentation of garments, high-end and low-end virtual-try-on systems. However, complete solutions in this area have still not yet found the expected commercial success. Today, with the on-going large cost reduction given by the appearance of new competitors, methods for digitization of the human body becomes more interesting for the fashion and apparel industry. Therefore, a large expansion of these technologies is expected in the near future.

To date, different methods are used commercially for the measurement of the human body. These can be divided into three major distinguished groups: laser-scanning, projection of light patterns, combination modeling and image processing. The different solutions have strengths and weaknesses that profile their suitability for specific applications.This paper gives an overview of their differences and characteristics and expresses clues for the selection of the adequate method. A special interest is given to practical examples of the commercial exploitation of human body digitization with applications to the fashion and apparel industry.

Key words: 3D surface scanning, laser scanning, white light projection, human body

1. INTRODUCTION

Complete systems for the digitization of the human body exist since more than fifteen years. One of the main users of this technology was the movie industry. Its visual effects had to appear more and more realistic and this was not possible any more by using computer graphics only. A new idea stuck: replace the real actors with virtual ones. A representative example is the movie *Teminator 2*, which was turned in 1991, already fifteen years ago. At that time, the cost of a full body scanner was still over 400'000 US$. The military industry had also these equipments, but its application was primarily ergonomics: seats of combat airplanes could, for example, be fitted exactly to pilots.

New methods and techniques were continuously developed for the digitization of the human body and new tools were introduced for a more efficient use of the resulting data. The number of available solutions increased. With the possibility of a massive cost reduction given by the new technologies, human body digitization became interesting also to other fields of application. With the time, the different solutions profiled themselves more clearly with their strengths and weaknesses. For the selection of the adequate solution for a specified application, it is therefore important to know deeply their characteristics and differences.

Nowadays, 3D scanning technologies are applied to different parts of the human body and systems are commercially available for the measurement of practically any surface area of the human body. Figure 1 shows some examples of results achieved by applying 3D surface scanning.

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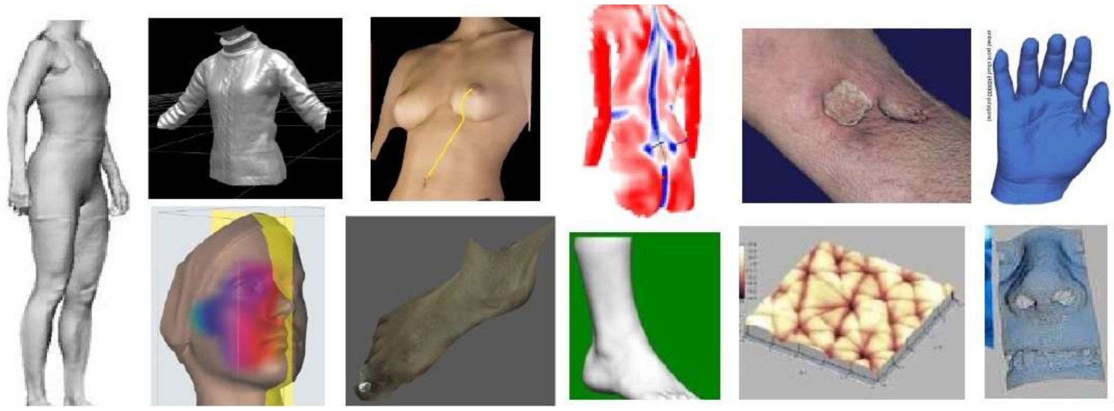

Fig. 1. Examples of digital measurements of the surface of the human body: full body, half body, chest, back, arm, hand, face, foot, leg, skin, nose.

The fields of possible applications of 3D scanning technologies are also of various nature. Some examples of domains where the human body digitization is already successfully exploited are, as shown in Figure 2, animation, computer games, art and sculpture, ergonomics, medicine and forensic, cosmetics and dermatology, anthropology, biometry and security, fitness and sport, fashion and beauty, communications.

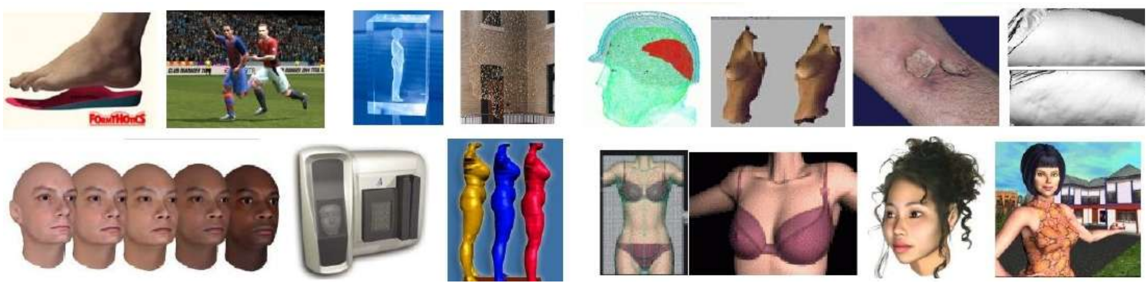

Fig. 2. Examples of applications of digital measurements of the surface of the human body. Form left to right top to bottom: animation, computer games, art and sculpture, ergonomics, medicine and forensic, cosmetics and dermatology, anthropology, biometry and security, fitness and sport, fashion and beauty, communications.

2. ACTUAL STATE OF TECHNOLOGY

Technologies used commercially for the digital measurement of the human body can be divided into five different groups: (a) laser scanning, (b) projection of white light patterns, (c) combination modeling and image processing, (d) digital manual measurement, (e) technologies based on other active sensors.
Table 1 and the Figure 3 show the distribution of all the existing companies developing systems for the measurement of the human body. These are divided into three major groups: systems based on laser scanning, systems employing white light projection and the rest.

Table 1. Number of companies developing and producing systems for the 3D measurement of the human body.

	Laser scanning	White light projection	Other	Total
North America	7	7	5	19
Europe	0	22	7	29
Asia	4	3	0	7
Total	11	32	12	55

The systems and products for human body measurement are developed and produced in the three regions North America, Europe and Asia. The majority of white light projection based systems are developed in Europe: mainly in Germany and UK. Whereas, laser scanning systems are developed and produced in north America and Asia.

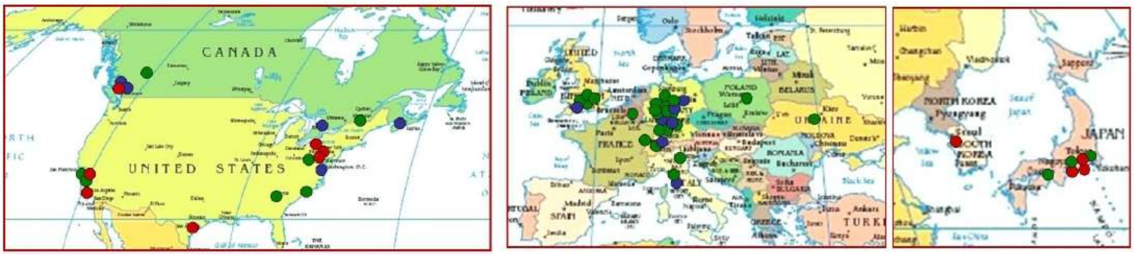

Fig. 3. Distribution of companies developing and producing systems for the 3D measurement of the human body. Red dots: laser scanning. Green dots: white light projection. Blue dots: other systems.

The next sections will give a short description and some examples of the different technologies.

2.1 Laser scanning

Laser scanning technology consists of using lasers to project onto the human body one or more thin and sharp stripes. Simultaneously, light sensors acquire the scene and by applying simple geometrical rules the surface of the human body is measured. To assure the inoffensiveness of the light beam, only eye-safe lasers are used. Special optical systems and mirrors are used for the generation of stripes from a single laser light beam. The laser scanner unit, which is composed of the laser, the optical system and the light sensor, is moved across the human body to digitize the surface.

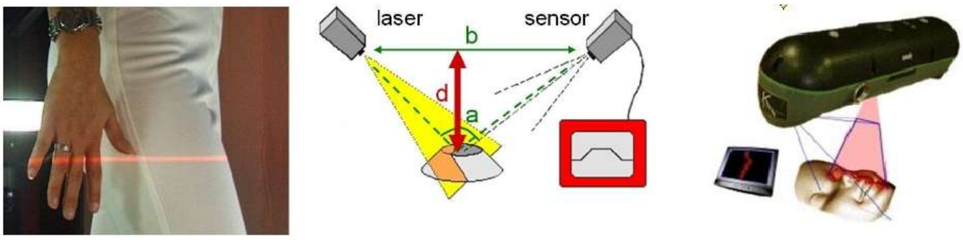

Fig. 4. Left: laser stripe on the human body. Center: triangulation method, different object heights *d* result in different triangulation angles *a* that can be measured by the light sensor. Right: the scanner unit is moved across the human body to scan its surface.

The type of movement and the number of employed units can vary depending on the human body part to be measured. For example, the full body scanner of Vitronic[1] (Figure 5 left) consists of three scanner units that move vertically synchronously along three pillars. A second example is the head scanner of Cyberware[2] (Figure 5 center). In this case, a unique scanner unit moves in circle around the head of a person. As last example is shown the foot scanner of Vorum Research Corp.[3]: the scanner is composed of three units, which moves horizontally, two laterally and one from the bottom (Figure 5 right).

Fig. 5. Laser scanning systems. Left: full body scanner *Vitus LC* of Vitronic GmbH (Germany). Center: head scanner *HS 3030RGB/PS* of Cyberware Inc. (USA). Right: foot scanner *Yeti* of Vorum Research Corp. (Canada).

The high costs for production of hardware components for the laser scanning technology have to be considered as disadvantage. Additionally to the laser, the light sensor and the optical system, also precise electric motors have to be used for the displacement of the scanner units. Moreover, the complete scanning system has to be calibrated so that the geometrical disposition of all the elements can be determined exactly. A second disadvantage of this method is the time required for the digitization of large surfaces. There is no problem for the measurement of extremities as feet and hands, since these body parts can be kept immobile for some seconds. But, in the case of the measurements of head or full body, it is practical impossible to stay immobile for several seconds. Uncontrolled movements as breathing or muscle contraction can generate errors.

2.2 Projection of white light patterns

The second technology used extensively for human body measurement is based on the projection of light patterns. It comes closer to the solution of the problems described in the previous section. Instead of moving the scanner unit, a light pattern (usually in form of stripes) is projected onto the human body (Figure 6 left). A light sensor (e.g. a digital camera) acquires the scene. The scanning device is composed usually of a pattern projector and a light sensor (Figure 6 center). More complex systems use two or three light sensors. The measurement process is similar to the method of laser scanning: stripes on the surface are measured singularly by using triangulation. Usually, binary coding systems (Figure 6 right) are used to determine the origin of the single stripes; for the increment of the resolution, the projected stripes are additionally shifted.

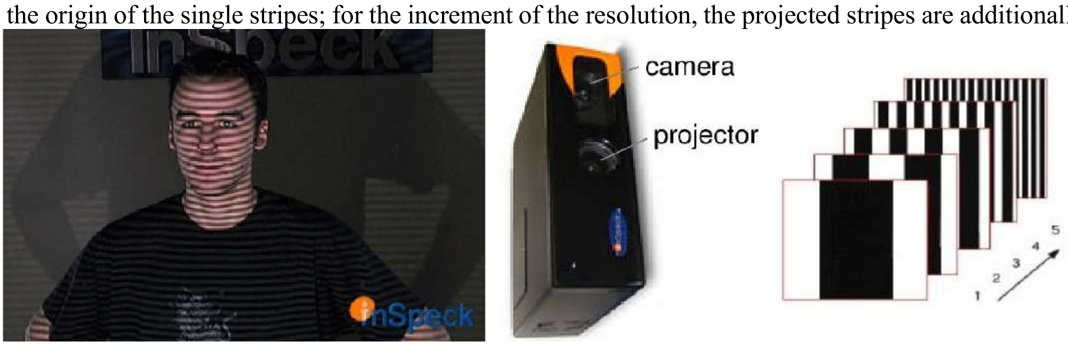

Fig. 6. Left: projection of light pattern as stripes. Center: scanning device *Capturor* of InSpeck Inc. (Canada). Right: projected sequence of binary coded stripes pattern.

Different patterns are employed by the different manufactures. Figure 7 give some examples of possible variations of the classic binary code.

Fig. 7. Examples of projected light pattern. From left to right: vertical stripes by 3D-Shape GmbH (Germany), horizontal lines by Wicks and Wilson Ltd. (UK), color coding by Sanyo Electric Co.Ltd. (Japan), squared pattern by Eyetronics NV (Belgium), dot pattern by VX Technologies Inc. (Canada).

The major difference to laser scanning is that the acquisition happens in a very short time and that it results in the digitization of entire surface parts. Everything happens in short time period (mostly under one second), so that human bodies can be digitized without problems: the uncontrolled movements of the person are not a problem. However, the field of measurement of such scanning devices is limited, e.g. *Capturor* of InSpeck[4] (Figure 6 center) can measure surfaces with maximal size of half part of the human body (e.g. upper torso). To measure large parts of the human body (e.g. entire head, full body) multiple scanning devices are required. This procedure has the disadvantage, that multiple units cannot be used simultaneously since they interfere with each other's light patterns projections. Practically, this means, that multiple equipments have to be used serially. This implies again an extension of the acquisition time.

The disposition and the number of employed sensors and projectors can vary depending on the human body part to be measured. For example, the face scanner of Breuckmann[5] (Figure 8 left) consists of one projector and two cameras that acquires both sides of the face of a person. A second example is the face scanner of IVB Jena[6] (Figure 8 center). In this case, a mirror systems is employed to project the light pattern from five directions by using a single projector; five cameras acquire the different scenes. As last example is shown the full body scanner of InSpeck[4] (Figure 8 right): the scanner is composed of three pillars, each having two units, each composed of a camera and a projector.

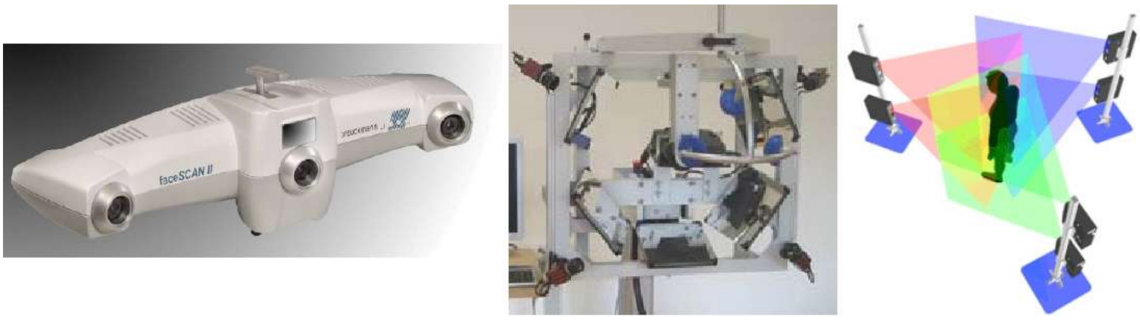

Fig. 8. White light projection systems. Left: face scanner *faceSCAN-II* of Breuckmann GmbH (Germany), with two cameras and one projector. Center: face scanner *Gscan* of IVB GmbH (Germany), with one projector, five cameras and mirrors system. Right: full body scanner *Mega 3P* of InSpeck Inc. (Canada) with six units, each with a camera and a projector.

2.3 Image processing and modeling

The third technology utilizes image processing and modeling techniques for the digitization of the human body. In this case, 3D measurements are not performed, but 3D information is generated and extracted from 2D images. Two examples are described to explain this technique: the 2D full body scanner *Contour* of Human-Solutions[7] (Figure 9 left) and the face modeler *FaceGen* of Singular Inversions[8] (Figure 9 right). By the first example, three images of a person are acquired (two from the front and one from the side). By using the symmetry of the human body, the most important sizes of body are computed with sufficient accuracy from the silhouettes of the body. The extracted body sizes are used, in this specific example, for the production of made-to-measure dresses.

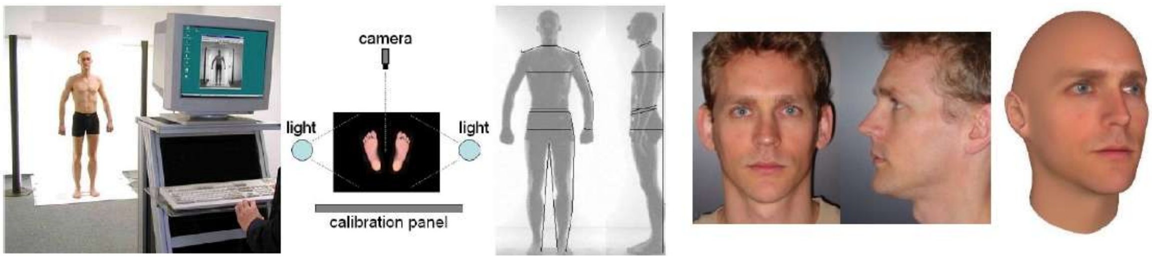

Fig. 9. Systems based on image processing or modeling. Left: 2D full body scanner *Contour* of Human-Solutions GmbH (Germany); scanning equipment, setup and silhouettes images with extracted measurements. Right: face modeler *Facegen* of Singular Inversions (USA); used images and generated 3D face model with texture.

The second example shows the possibility to generate extremely realistic face models by using only two images of the person (from the front and from the side). The 3D computer model is generated manually with the help of user-friendly software tools. In this case, a real measurement of the human face is not performed. However, the produced 3D computer models are extremely photorealistic and completely adequate for applications as, for example, animation and computer games. Figure 9 (right) shows the two used images and the resulted 3D face model. The big advantage of combining image processing and modeling techniques is the extremely lower price compared to real 3D measurement.

2.4 Other active sensors

In the recent years, new technologies based on active sensors have been applied also for the measurement of the surface of the human body.

A very interesting product resulted by applying cylindrical holographic imaging technology onto the human body, allowing to perform a whole body scan while the person remain fully clothed[9]. In this case the active sensor uses non-harmful, ultra-high frequency radio waves to obtain accurate body measurements. A millimeter-wave array/transceiver illuminates the human body with extremely low-powered millimeter waves. The radiation penetrates clothing and reflects off the body. The reflected signals are collected by the array/transceiver and analyzed by a image processing computer.

The company Intellifit Corporation translated this technology into a complete solution to extract 3D human body measurements for custom fit applications. Intellifit System (Fig. 10 left) is composed of the 3D scanner based on the millimeter-waves technology and the accompanying software.

The scanning process works in the following way: a person steps inside the Intellifit cabin without undressing, the “L” shaped millimeter-waves transceiver swings around and over the person to acquire the required data. The entire scanning process lasts about 10 seconds and the collected data consists of about 200'000 points on the surface of the human body. Out of the measurements, automatic algorithms determine about 200 characteristic body sizes of the human body with an accuracy of about 6mm.

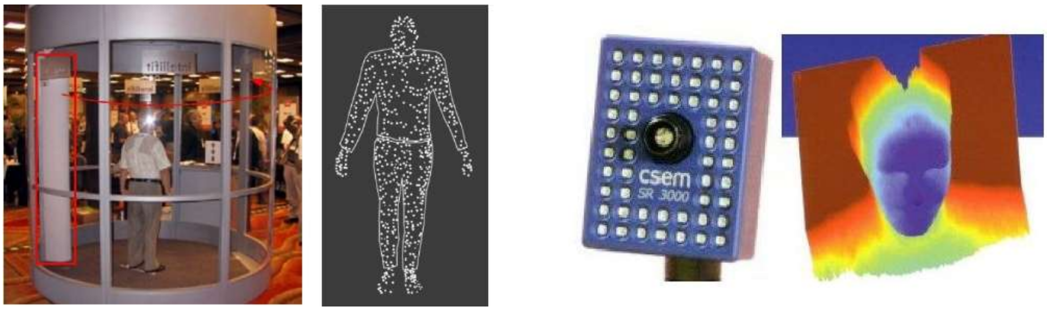

Fig. 10. Systems based on active sensors. Left: full body scanner *FotoScan* of Intellifit Corp. (USA) and collected points on the human body; the right box shows the L-shaped millimeter-waves transceiver that swings around the person. Right: 3D camera *SwissRanger SR 3000* of CSEM (Switzerland) and example of real-time acquired 3D data.

A second technology based on other active sensors is also exploited for the measurement of the external surface of the human body. In this case, 3D cameras employ special CMOS sensors where each pixel measures the distance to the imaged surface part.

Different manufactures are present in the market. Figure 10 (right) shows the example of 3D camera of CSEM[10]. These cameras are based on the phase-measuring time-of-flight (TOF) principle. A light source (in this case, an array of emitting diodes) emits a near-infrared wave front that is intensity-modulated. The light is reflected by the scene and imaged by an optical lens onto the dedicated 3D-sensor. Depending on the distance of the target, the captured imaged is delayed in phase compared to the originally emitted light wave. Measuring the phase delay, the distances of the complete scene can be determined. The result of the acquisition is a depth map of the scene.

The core of such cameras is the CMOS sensor. In fact, the 3D measurement method based on TOF is integrated in the CMOS sensor. Each pixels of the sensor is constructed to measure the phase difference between the emitted light source and the captured returning light. The result are real-time 3D images of the recorded scene.

The actual CMOS technology limits the sensor size to about 25 KPixels. For this reason, to time, these sensors can be exploited only for few applications regarding the human body, as for example in security (surveillance) or automotive (recognition of pedestrians).

2.5 Digital tape measurements

As last technology available for the digital measurement of the human body, has to be mentioned a simple but effective method: the electronic tape measurement.

The method combines classical human body measurement and digital technology. The measurement process is completely similar to classical tape measurement, where lengths are measured by a tape at different key-location of the human body (chest, waist, sleeve, etc.). The tape device records electronically the measured distances. Some devices, as for example the e-tape of E-Measurement Solutions[11] showed in Figure 11, delivers the measured data to PC via wire-less. In this way, the tape measurement process results faster and simpler.

Fig. 11. Electronic tape measurement. Left: *e-tape* device of E-Measurement Solutions Ltd. (UK). Center: measuring the chest of a person. Left: measured data is transferred via wire-less to the PC.

3. CONSIDERATIONS

3.1 Differences of systems and results

In the previous section were discussed the various technologies available for the 3D measurement of the human body. Different companies are employing these technologies for the development and production of systems for the digitization of the human body. These systems differentiate themselves strongly and for the normal user it could be a problem to determine which system best suits to his specific application.
We take as example the case of full body scanning systems. Twenty one companies, world wide, are producing and selling more than thirty different full body scanners. Figure 12 shows some results obtained by the 3D scanning process from different products. As can be seen, the results differ a lot: there are point clouds, surface models, textured models, unprocessed data, etc.. In fact, the used equipment is different, the employed processing is different and the targeted applications are also different. This variability results also in a very large price range of the products: full body scanning systems are available from 20'000 Euro up to 400'000 Euro.

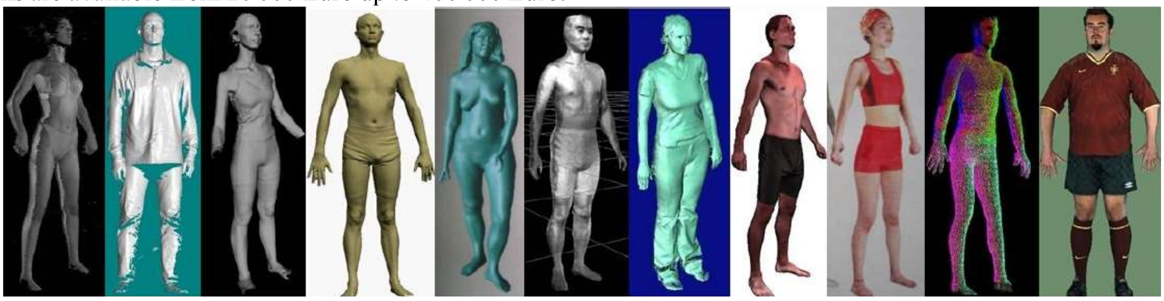

Fig. 12. Examples of results obtained by different 3D full body scanning systems.

With such large offer of different products with different results and with a very large price range, the process of selecting the adequate system plays a key role. To perform a correct analysis and selection, it is important to clearly list all the requirements and to consider as many criteria as possible. The following table give some examples of important information that has to be determined in advance, before selecting the scanning system. This regards, for example, the desired measurement part, the expected type of result, the limitations regarding processing and location.

Table 2. Examples of criteria for the selection of the adequate scanning system.

Measurement of?	Full body, head, face, foot, hands, skin, back, chest, general parts, ...
Quality and type of result?	Accuracy, resolution, surface or point cloud, texture or color or b/w, ...
Processing?	Processing time, acquisition time, technical know-how, automatism, ...
Environment?	Space limitation, transportability, installation, light condition, sterilization, ...
Dedicated solutions for?	Crystal engraving, mass customization, plastic surgery, computer games, ...

3.2 Additional required software

For the completion of the overview on the actual state of the technology for the digitization of the human body, the required and helpful software has also to be described.
The raw data resulting by the scanning process can usually not be used in its original form. Mostly scanning systems are therefore provided with standard software for the visualization, for the treatment, for the exporting and eventually for the editing of the data. Figure 13, on the left, shows for example the result achieved by the full body scanner of Wicks and Wilson[12] and at the center the result of a head scanning system of InSpeck[4]. It can be clearly noticed that raw data of the full body scanner has to be processed. In the case of the head scanner, the result shown has already been processed.
Data compression plays an important role by the digitization of the human body. In fact, 3D scanning processes generate very large amount of data, e.g. the head model of Figure 13 (center) corresponds to about 27 Mbytes of data. Therefore, for an efficient and unproblematic storage, treatment and visualization of the data, adequate compression processes are required. These can be defined specifically to the different parts of the human body by considering the typical topology of their surface. We take the human face as example: every human face is round shaped, has a nose, a mouth, two eyes, etc. This basic information is used to reach strong compression factors without loosing the important features of the human face. Figure 13 (right) shows an example of a 3D face model at two different compression factors: the details of the eyes, nose, and mouth are conserved, whereas the data resolution in areas with fewer details is reduced.

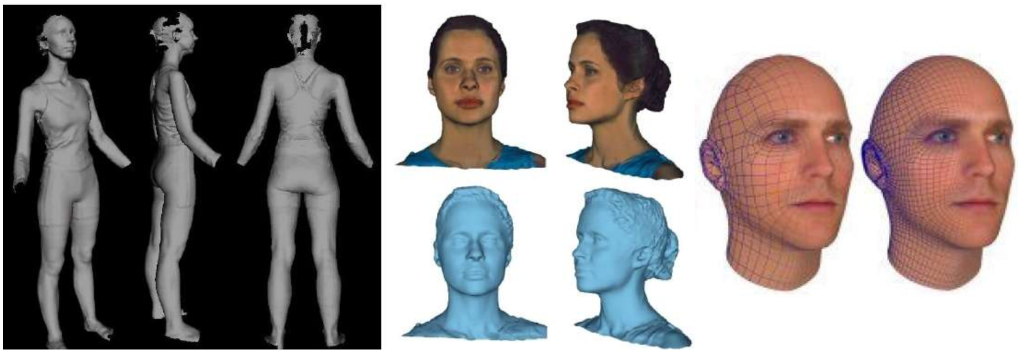

Fig. 13. Left: result of *TriForm* full body scanner of Wicks and Wilson Ltd. (UK). Center: head model (with and without texture) resulted by using InSpeck Inc. (Canada) head scanner system. Right: two different levels of detail of a 3D face model (images of Singular Inversions).

In the special case of full body scanners, the systems are usually accompanied by software solutions for the determination of body sizes. Figure 14 shows some examples of such solutions, some of them works completely automatically extracting body sizes useful for tailoring or anthropometric applications, others permit the measurement of specific areas of the human body. The solutions are tailored specifically to the type of data resulting from the scanning process and therefore it is recommended to use software solutions only with scanning systems from the same manufacturer.

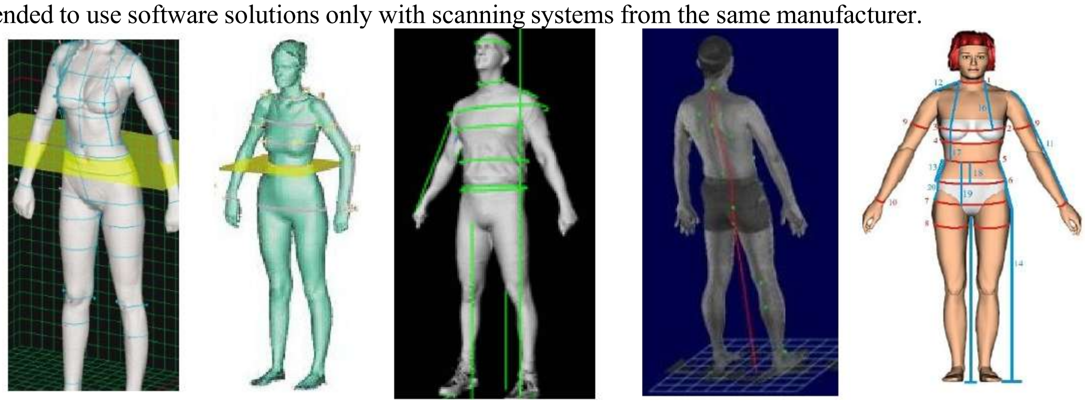

Fig. 14. Examples of automatic body sizes extraction. From left to right: automatic landmark recognition and measurement by *BL Manager* of Hamamatsu Photonics K.K. (Japan); body measurements by *Vitus* of Vitronic GmbH (Germany); automatic extraction of body sizes by *DigiSize* of Cyberware Inc. (USA); digital measurements by *Voxelan 3D Measure Workshop* of Hamano Engineering Co.Ltd. (Japan); extracted body sizes by *BodyFit 3D* of GFaI e.V. (Germany).

Complete full body scanning solutions, coupling 3D scanners with software measurement solution, increased in the last couple of years the attractiveness of this technology for the fashion industry. As consequence, as it will be described in the next section, the number of applications in this specific domain increased.

4. APPLICATIONS FOR FASHION AND APPAREL INDUSTRY

4.1 Virtual-try-on

The so called virtual-try-on solutions have gained importance in the last few years in different areas of the fashion industry. Virtual-try-on solutions simulate digitally the behavior of textiles onto the human body. In this way, they allow a virtual probe of cloth items onto digital human body models. 3D cloth simulation engines are employed to determine precisely how the cloth item will behave on the digital body model. Figure 15 shows an example of such solutions from Assyst-Bullmer[13]. The different parts of textile defining a piece of cloth are described as 2D patterns (as it is the case for usual CAD solutions employed in cloth manufacturing processes). For each part are specified all the required characteristics of textile, such as for example thickness or elasticity. The different parts are then placed in a 3D environment around a digital human body model and stitched together. The 3D cloth simulation engine will then determine the behavior of the so formed cloth item over the human body model.

Fig. 15. Example of virtual-try-on solution *Vidya* of Assyst-Bullmer GmbH (Germany). Left: 2D patterns of the different parts composing a cloth item. Center: the different parts are placed in a 3D environment around the digital human body model and are stitched together. Right: the final result of the simulation.

Virtual-try-on solutions are becoming interesting to different areas of fashion industry. For example, fashion designers can employ such systems to obtain first visual results of their creations without the need of the production of real prototypes. Cloth buyer can see remotely new cloth items without the need to have the real pieces shipped from distant locations. Experts dealing with styling of persons can show their clients how they will look before they buy new dresses. Some web-shopping solutions are also exploiting this technology to present their cloth items in 3D on virtual mannequins.
Various virtual-try-on solutions are available on the market. Modern and sophisticated solutions, as for example from OptiTex[14] (Figure 16), allow to import data from 3D scanning systems and simulate different poses of the human body model. Some of them allow additionally to import motion information from previously recorded data. In this case, the behavior of the textile is simulated dynamically.

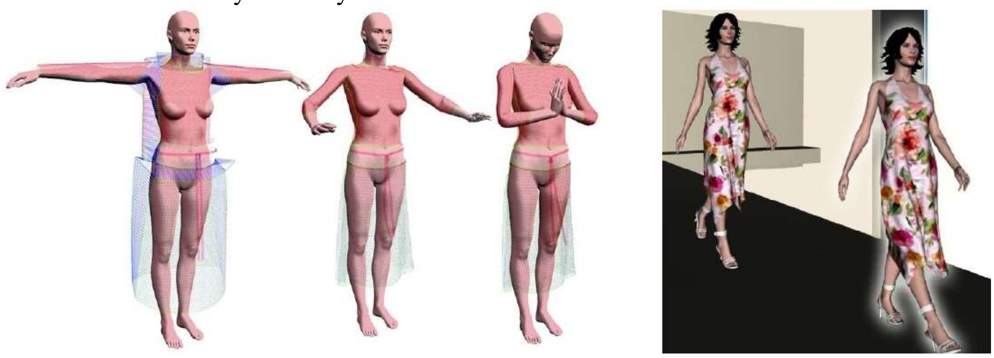

Fig. 16. Virtual-try-on by *3D Runway* of OptiTex Ltd. (Israel), with different poses of the body model (left) and with added movement (right).

4.2 Virtual-make-over

Virtual-make-over solutions deal with the virtual styling persons in the area of the face, by changing or adding virtually make-up, haircuts or accessories. Figures 17 and 18 show examples in hairdressing (by Stellure[15]) and accessoring (by Visionix[16]). In both examples, the appeal of the human face is changed virtually by adding digitally to a digitized 3D human face, haircuts or glasses.

Fig. 17. Examples of a 3D virtual-make-over solution. Virtual added haircuts from *Stellure* (New Zealand).

In the case of virtual-try-on of eyewear, the benefits are manifolds for both customers and optical stores. From the point of view of the client: the unique high tech buying experience, the quick and easy way to select frames, the time saved on frame pre-selection, the possibility to share the frame selection with family and friends, the ability to see himself with new frames without lenses, the fast virtual try-on of new collections, and the private selection by Internet without obligation or embarrassment. From the point of view of the optical store: the augmented attractiveness of the store due to a unique purchasing experience, the reduced number of rejected frames due to accurate measurement, the saving on stock by holding less frame inventory, the extended availability of large collection of frames due to the virtual inventory, and the optician time saved by obtaining pre-selection of frames by the client.

Fig. 18. Example of 3D virtual-make-over. Left: 3D acquisition system *3D iView* of Visionix Ltd. (Israel). Center: 3D model of frame and lenses. Right: virtually placed eyewear onto a 3D face model.

4.3 Size surveying

Recently, human body size surveys have become a complete necessity. All institution and companies working on ergonomics are expecting information for practical immediate exploitation. In fact, it had been realized that anthropometric data could improve the quality of product design and usability, workstation and work place planning, and even laborer safety in certain environment. In the fashion industry, this information is used to tailor the size and shape of cloth items to stature and body form of the actual population.
National surveys have been initiated in the past in UK (SizeUK, 11'000 subjects scanned, 130 body measurement for each subject), in USA (SizeUSA), but recently also in Sweden and in France[17]. The standard posture used in all surveys features the legs and arms slightly apart of the human body, elbows and hand joints slightly bent. This to allow an automatic determination of the important anthropometric measures of the human body (ISO7250). The most recent size surveys (Sweden and France) have added additional sitting and standing postures. New surveys lunched in China also added the 3D measurement of hands and feet.

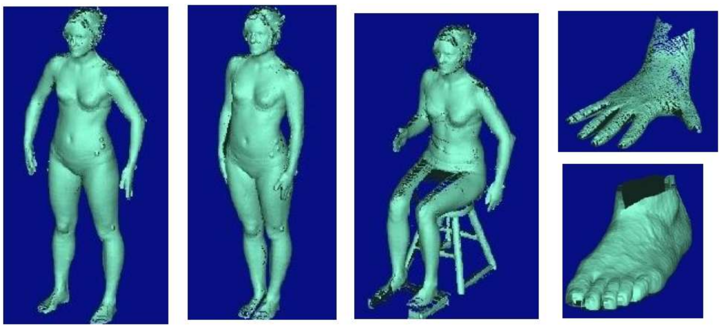

Fig. 19. 3D data required by size surveying: standard (legs, arms apart), standing and sitting postures, foot and hand.

4.4 Anthropometric mannequins

The shape of anthropometric dummies are based on statistical studies and recently on the results of size surveys. These special dummies are available commercially for babies, kids, teenagers at any growth stage, as well as men and women in many morphological conformations, from slim to extra heavy, with dimensions based on worldwide morphology market research. The anthropometric dummies represent exactly the conformations present in the population and assure that apparel collections are tailored to today's customer stature and form.
Figure 20 shows some examples of anthropometric mannequins. Different variations exist in the market regarding the form (fix mannequins, fully articulated), as well as regarding the employed materials. In some cases, special materials simulate the behavior of soft tissue.
3D scanning technology can also be applied for the production of personalized mannequins. In this case the anthropometric mannequin is built with regard of the measured sizes of a real person.

1. 2. 3. 4. 5.

Fig. 20. Examples of anthropometric dummies. 1. Anthropometric mannequin *Alvaform* of Avalon Inc. (USA), covered with pinnable canvas and with soft belly. 2. Anthropometric parametrization of the dummies. 3. Anthropometric dummies *Lineforms* of Shapely Shadow Inc. (USA) and 4. *Realforms* made of a special material simulating the soft tissue. 5. Fully articulated anthropometric dummies *Formax* of CAD Modelling Ergonomics s.r.l. (Italy).

The most recent application of anthropometric mannequins resulted from the combination with virtual-try-on solutions. Virtual-try-on solutions are usually proposing fully parametrized general human body models, as for example from OptiTex[14] (Figure 21 left). In this case the user can modify the digital body model by changing different parameters. By introducing real anthropometric data, these models can be transformed into virtual anthropometric mannequins (Figure 21 right, from IFTH[18]), offering the same advantages of the real anthropometric mannequins but in a virtual environment.

Fig. 21. Left: fully parametrized virtual human body model used in virtual-try-on application, *Runway 3D* of OptiTex Ltd. (Israel). Right: virtual anthropometric mannequins based on anthropometric data, from IFTH (France).

4.5 Made-to-measure

The last example of application of 3D human body digitization techniques for the fashion and apparel industry regards made-to-measure. In the classical approach of made-to-measure, a dress or a cloth item is produced specifically for a person, that has been previously manually measured.

By using the technologies presented in section 2, together with measurement solutions presented in section 3, the process of manual measurement can be substituted by a digital process. Additionally, with the use of virtual-try-on solutions, the results can also be visualized and details can be chosen before the real production of the dress or cloth item. Figure 22 shows the example of made-to-measure jeans from 3D body scanning (from Bodymetrics[19]) and Figure 23 shows a made-to-measure application for footwear. In this case a 3D foot scanner *Shoemaster*[20] is used to acquire in 3D the shape of the feet of a person. The software solution allows then a precise definition of made-to-measure shoes based on the measured 3D model of the feet.

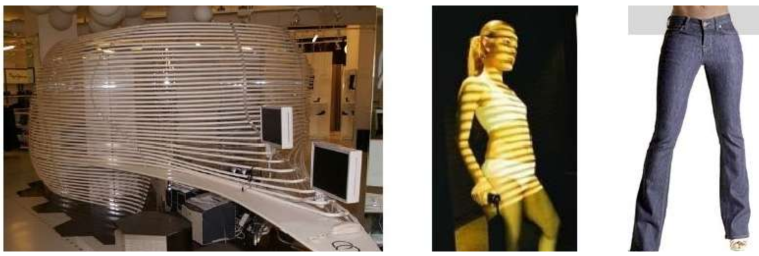

Fig. 22. Example of made-to-measure application. Left: full body scanning system *Pod* of Bodymetrics Ltd. (UK), situated in a shopping center. Right: made-to-measure jeans *Bodymetrics Bespoke* tailored to fit the customer's body.

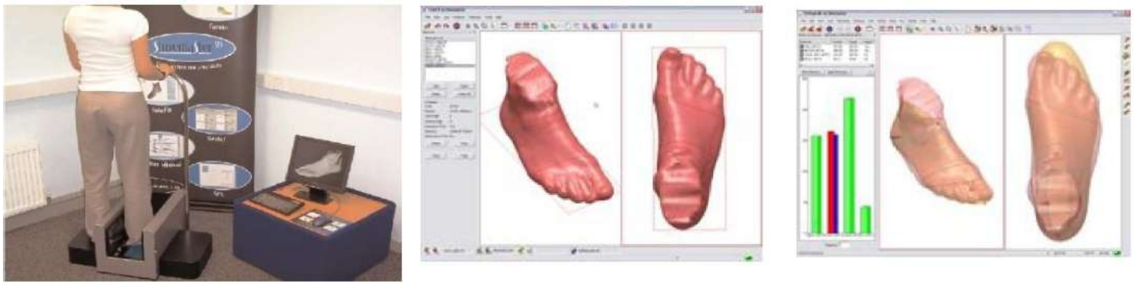

Fig. 23. Example of made-to-measure for footwear. Left: 3D foot scanner *Shoemaster* of CSM3D International Ltd. (UK). Center: 3D model of the scanned foot. Right: software solution for the design of made-to-measure shoes.

The technology is very promising, however the costs related to such complete solutions is still limiting its exploitation for made-to-measure applications.

5. CONCLUSION

In this paper was presented an overview of the different 3D digitization technologies used to measure the surface of the human body. A special interest was given to practical examples of the commercial exploitation of human body digitization with applications to the fashion and apparel industry.

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