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RECENT ADVANCES IN 3D FULL BODY SCANNING WITH APPLICATIONS TO FASHION AND APPAREL

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Abstract: This paper presents the recent advances in 3D full body scanning technologies with applications to the fashion and apparel industry. Indeed, 3D body scanning systems equipped with dedicated software solutions may serve the customers of for various purposes: automatic extraction of body measurements, recommendation of adequate garment sizes, virtual representation of garments on 3D human body model, production of customized garments. In the last couple of years, a large cost reduction of the 3D full body scanning equipment took place and new manufacturers appeared in the marked, thus increasing the interest of fashion and apparel industry in methods and technologies for digitization of the human body. This paper gives firstly an overview of the various methods used for the 3D measurement of the human body, depicting their differences and characteristics. The focus is then placed on the recent advancements of complete 3D full body scanning systems developed especially for fashion applications. Complete automatism is achieved both in the 3D scanning and 3D data processing in order to extract the relevant body measures and to generate avatars that represent accurately the scanned persons. Software packages for virtual-try-on applications have also been continuously ameliorated, allowing a true-like visual representation of garments virtually worn by the generated avatars.

1. Introduction

Complete systems for the digitization of the human body exist since more than twenty years. One of the main users of this technology was the movie industry. Its visual effects had to appear more and more realistic. A new idea stuck: replace the real actors with virtual ones. Two representative examples are the movies *The Abyss* of 1989 and *Terminator 2* of 1991. For the visual effects in *The Abyss,* produced by 20th Century Fox twenty years ago, one of the first 3D laser scanner (from Cyberware [1]) was used to digitize the face of two actors.

Beside visual effects, anthropometry and ergonomics were the other two main application fields of body scanning technologies. In fact, the first 3D whole body scanning system, the *Loughborough anthropometric shadow scanner (LASS)* [2], was developed by the University of Loughborough (UK) in 1989 with the aim of conducting anthropometric surveys.

The military industry was also using 3D scanning equipments, but its application was primarily ergonomics. Only lately, in the mid nineties, whole body scanning systems began to be used also for uniform fit. This marked the start of 3D body scanning for clothing industry, which was then finalized with the commercialization in 1998 by [TC]^2 (USA) [3] of the first 3D whole body scanner developed especially for the fashion industry.

The methods and techniques for the digitization of the human body were in the two last decades continuously ameliorated, more efficient and powerful scanning systems were developed and new software tools were introduced for a more efficient use of the resulting data. The number of available solutions increased and with the time, the different scanning systems profiled themselves more clearly for specific application fields. Moreover, with the possibility of a massive cost reduction given by new technologies, human body digitization became interesting to various fields of application, such as animation, computer games, art, sculpture, ergonomics, medicine, cosmetics, biometry and fashion.

This paper gives firstly an overview of the various methods for the 3D scanning of the human body; details are then given on the recent advances of 3D whole body scanning systems.

2. Actual State of Technology

Technologies used commercially for the digital measurement of the human body can be divided into four major groups (see Figure 1): (a) laser scanning, (b) white light scanning, (c) passive methods (as photogrammetry, silhouette, visual hull), (d) technologies based on other active sensors (as millimeter-wave radar, TOF 3D cameras) or touch sensors.

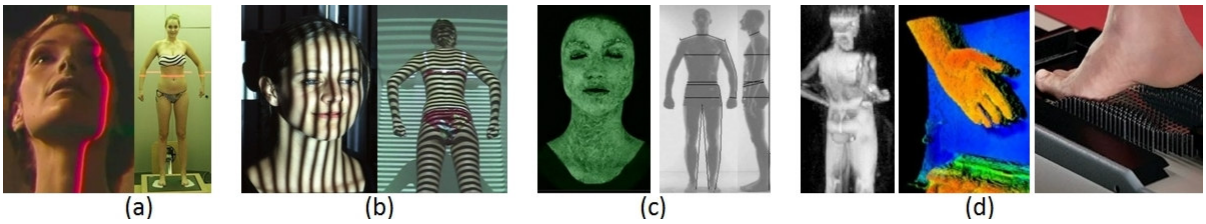

Figure 1: Technologies used commercially for the 3D measurement of the human body.

Figure 2 show the geographical distribution of all the existing companies developing and producing systems for the measurement of the human body, divided into the three groups: systems based on laser scanning, white light scanning and the rest. The systems and products for human body scanning are developed and produced in the three regions North America, Europe and Asia. The majority of white light scanners (green dots in Figure 2) are developed in Europe: mainly in Germany and UK. Whereas, the distribution of OEMs of laser scanners (red dots in Figure 2) and systems based on other methods (blue dots in Figure 2) is more uniform.

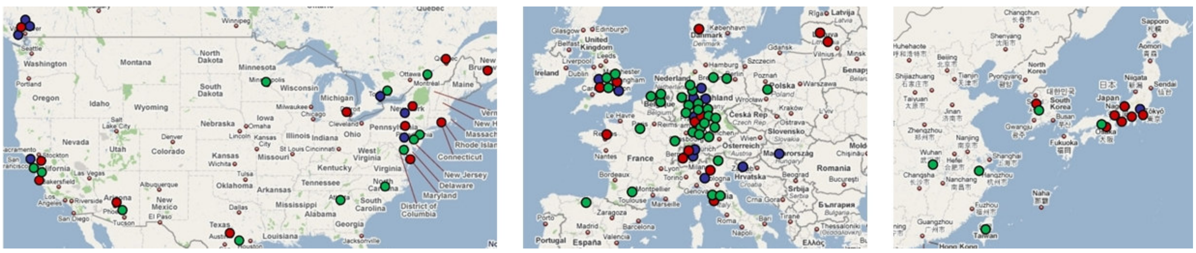

Figure 2: Geographic distribution of OEMs of systems for the 3D measurement of the human body. Red dots: laser scanning; green dots: white light scanning; blue dots: other systems.

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.

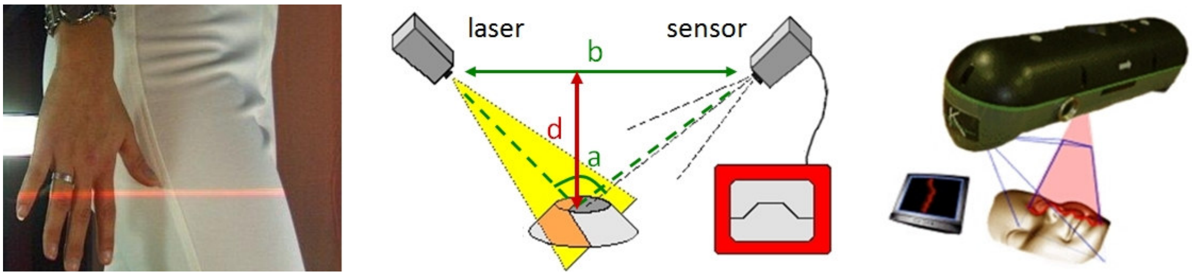

Figure 3: Left: laser stripe on the human body. Center: schema of the triangulation method. Right: the scanner unit is moved across the human body to scan its surface.

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 [4] (Figure 4 left) consists of three scanner units that move vertically synchronously along three pillars. A second example is the face and head scanner of Cyberware [1] (Figure 4 center); in this case, a unique scanner unit moves in circle around the head of a person. As last example, the foot scanner of Vorum Research Corp. [5] is composed of three units, which moves horizontally; two laterally and one from the bottom (Figure 4 right).

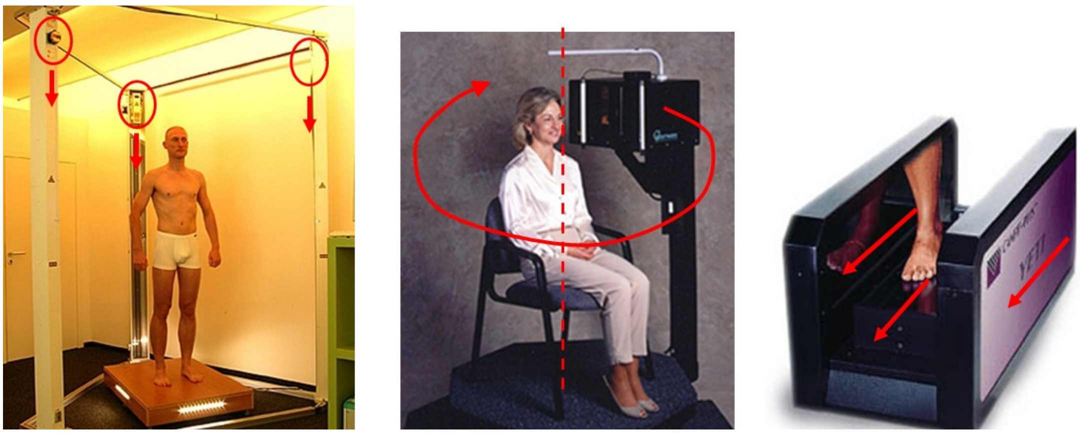

Figure 4: Left: full body scanner *Vitus LC* of Vitronic [4]. Center: head scanner *HS 3030RGB/PS* of Cyberware [1]. Right: foot scanner *Yeti* of Vorum Research Corp. [5].

2.2. White Light Scanning

The second technology used extensively for human body measurement is based on the projection of light patterns and is called for simplicity *white light scanning*. In contrast to laser scanning, instead of moving a single (or multiple) laser line over the human body, a light pattern (usually in form of stripes) is projected onto the human body (Figure 5 center). The scanning device is composed usually of a single white light projector and a single camera (Figure 5 left). More complex systems use multiple cameras and projectors. 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 5 right) are used to determine the origin of the single stripes; for the increment of the resolution, the projected stripes are additionally shifted.

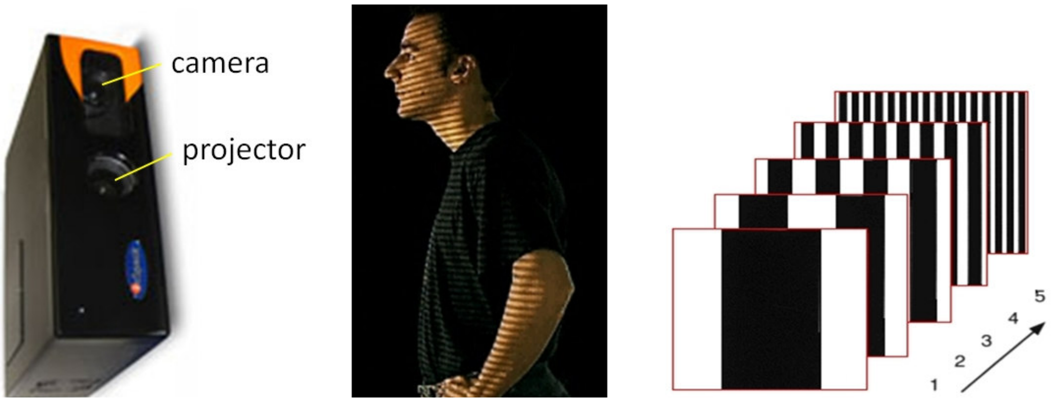

Figure 5: Left: scanning device *Capturor* of InSpeck [6]. Center: projection of light pattern as stripes. Right: projected sequence of binary coded stripes pattern.

The major difference to laser scanning is that the digitization of entire surface parts may happen in a very short time. However, the area of measurement of such scanning devices is limited, e.g. *Capturor* of InSpeck [6] (Figure 5 left) can digitize 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.

The disposition and the number of employed sensors and projectors can vary depending on the human body part to be measured. For example, the full body scanner of InSpeck [6] (Figure 6 left) is composed of three pillars, each having two units, each composed of a camera and a projector; whereas the face scanner (an old version) of Breuckmann [7] (Figure 6 center) consists of one projector and two cameras that acquires both sides of the face of a person. As last example, is shown the intra-oral scanner of Cadent [8] (Figure 6 right): in this case, the system is miniaturized in order to be inserted in the mouth of a patient to digitize his teeth.

Figure 6: Left: full body scanner *Mega 3P* of InSpeck [6]. Center: face scanner *faceSCAN-II* of Breuckmann [7]. Right: intra-oral scanner *iTERO* of Cadent [8].

2.3. Passive Systems: Photogrammetry, Visual Hull, Silhouettes

The third group comprehends all the passive measurement methods, i.e. with the only use of image data acquired by one or multiple cameras and without the need of external light sources. Photogrammetric, computer vision and image processing techniques are employed to gain 3D data from the images. The mostly applied passive methods for the measurement of the human body are: multi-image photogrammetry, visual hull and silhouette analysis.

Multi-image photogrammetry employs multiple images acquired from different directions by calibrated cameras. Sophisticated matching algorithms determines corresponding points in the different images; by forward rays intersection it is then possible to compute their 3D coordinates, resulting in a dense 3D points cloud. Figure 7 shows an example of multi-image photogrammetry used for the 3D measurement of a human face [9].

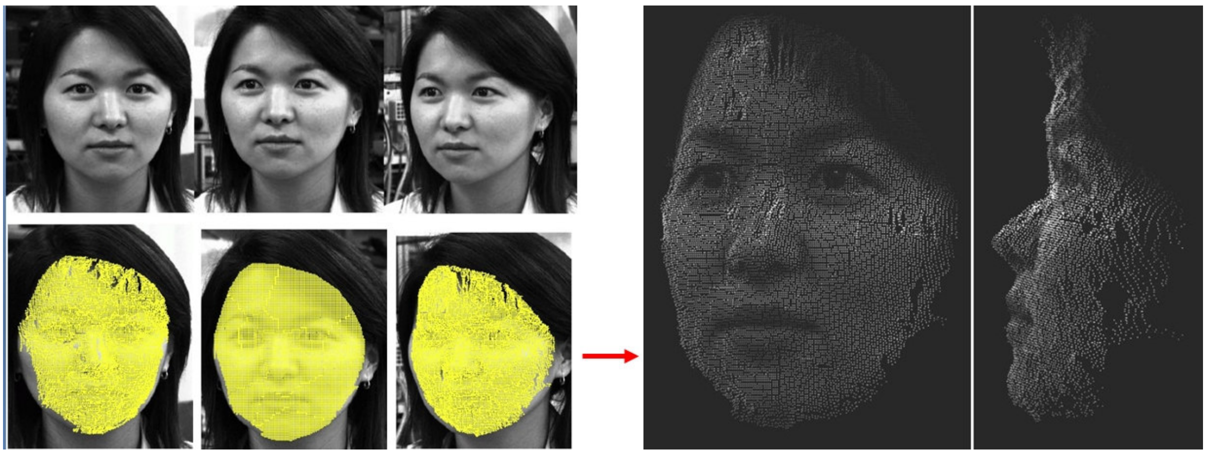

Figure 7: Face scanning system based on multi-image photogrammetry. Left: three images (top) and matched corresponding points (bottom). Right: resulting (colored) 3D points cloud.

The method of visual hull [10] also employs a set of images acquired from different directions. In this case the 3D reconstruction is performed by the volume intersection approach. Figure 8 (left) shows its principle: the bounding geometry of an object imaged by multiple cameras can be obtained by intersecting the cones formed by its projection onto the image planes and the focal points of the cameras. The resulting 3D volume is called *visual hull*. The more cameras are employed, the more precise is the obtained visual hull. In the practical situation, the object in the images has to be separated from the background in order to obtain a binary image representing its *silhouette*. Figure 8 (on the right) shows an example of a full body 4D scanning system of the company 4D View Solutions [11] based on visual hull. The used eight images, the extracted silhouettes and the obtained 3D reconstruction are shown.

Figure 8: Left: principle of the visual hull method. Right: example of 4D capture system based on visual hull, *4DV Classic* of 4D View Solutions [11].

The third passive method also utilizes silhouettes images but in a simpler way. In this case, body measures are extracted from a limited number of images. An example is described to explain this technique: the 2D full body scanner *Contour* (unfortunately not produced anymore) of Human-Solutions [12] (Figure 9). Two images of a person are acquired: from the front and from the side. By using the symmetry of the human body, the relevant measures of the human body are determined with sufficient accuracy from the silhouettes.

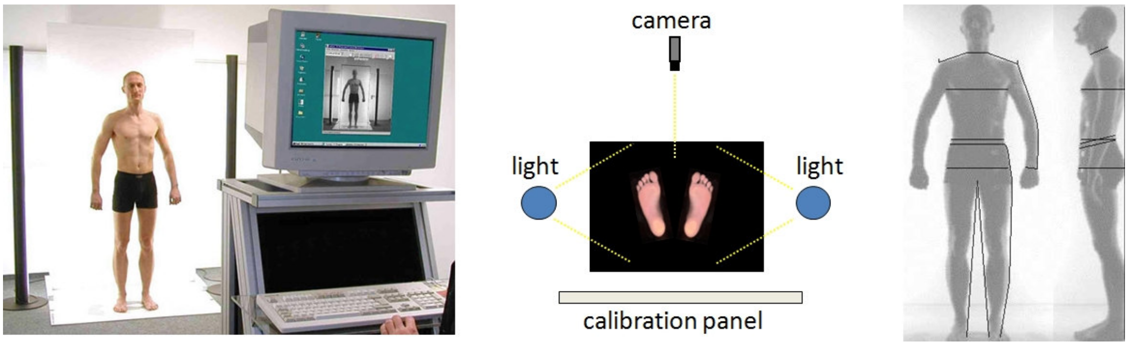

Figure 9: 2D full body scanner *Contou*r of Human-Solutions [12]. Left to right: scanning equipment, setup, silhouettes images with extracted measurements.

2.4. Other Active Sensors

In the recent years, new technologies based on other active sensors have been applied also for the measurement of the surface of the human body. A very interesting product resulted by applying a new technology onto the human body, allowing to perform a whole body scan while the person remain fully clothed. In this case the active sensor uses ultra-high frequency radio waves: a transceiver illuminates the human body with extremely low-powered millimeter waves; the radiation penetrates clothing and reflects off the body; the reflected signals are then collected by the array/transceiver and processed for measurement. Intellifit Corporation [13] translated this technology into a complete solution for 3D full body scanning. The Intellifit System is shown in Figure 10 (left). The scanning process works in the following way: a person steps inside the cabin without undressing, the "L" shaped millimeter-waves transceiver (red box in the image) swings around 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 a list of body sizes of the human body (with an accuracy of 6mm).

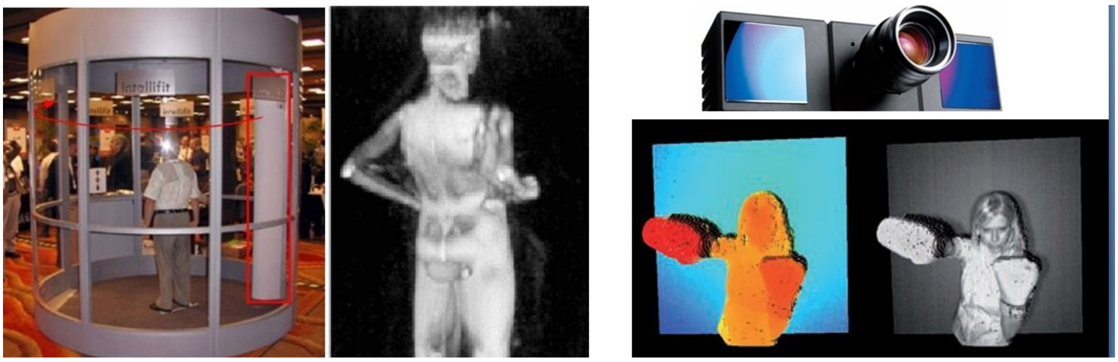

Figure 10: Systems based on other active sensors. Left: full body scanner *FotoScan* of Intellifit [13] and a millimeter-wave image. Right: 3D camera *PMD[vision] CamCube* [14] and example of acquired 3D data; colored 3D depth map(left) and gray scale image (right).

A second technology based on other active sensors is also exploited for human body scanning. In this case, 3D cameras employ special CMOS sensors where every pixel delivers in real-time the distance to the imaged object. Various manufactures are present in the market. Figure 10 (right) shows the example of the 204x204 pixels 3D-camera of PMD Technologies [14]. These cameras are based on the phase-measuring time-of-flight (TOF) principle. An array of diodes emits a near-infrared wave front that is intensity-modulated. The light is reflected by the object and imaged by an optical lens onto the dedicated 3D-sensor. By measuring the phase delay between the emitted and received light, the distances of the object can be determined. The core of 3D-cameras is the CMOS sensor: the 3D measurement method based on TOF is integrated in every pixels of the sensor; the results are 3D images at video rates. The current CMOS technology, limits for the moment, the sensor size to about 40 KPixels.

2.5. Contact Measurement

As last technology available for the digital measurement of the human body, has to be mentioned the simple but effective method of contact measurement. Two examples are shown in Figure 11, an electronic tape measurement and a foot plantar touch matrix scanner. In the first case, the method combines classical body measurement and digital technology. The measurement process is similar to classical tape measurement, where lengths are measured by a tape at different key-location of the human body (chest, waist, sleeve, etc.), but the digital device records electronically the measured distances. Some devices, as for example the *e-tape* of E-Measurement Solutions [15] (Figure 11 left), delivers the measured data to PC via wire-less; in this way, the measurement process results faster.

The second example of Figure 11 is a foot plantar digitizer of the company Amfit [16]. The scanner is based on a touch probe matrix of 500 elements. The person places his foot over the touch probe matrix; the displacements of the single elements deliver the 3D measurement of the plantar of the foot.

Figure 11: Left: electronic tape measurement *e-tape* [15]. Right: plantar foot scanner *Amfit Digitizer* [16] based on a touch probe matrix.

3. Recent Advances in 3D Full Body Scanning

In the last years, the interest of the fashion sector in technology for 3D full body scanning has increased considerably. This fact reflected in the increase of the available solutions and tools tailored specifically to applications in fashion and in the amelioration of existing systems.

3.1. Full Automatic Data Processing for Body Size Extraction

Complete full body scanning systems are usually accompanied by software solutions for the determination of body sizes from the 3D scan data. Such solutions are available since many years. The new advancements in this case are in the automation of the processing. Nowadays, typical software solutions measure completely automatically anatomical landmarks (about 90 points) and body measures (about 120). Moreover, the extracted measurements are often compatible with anthropometric and ergonomics norms (e.g. ISO7250, EN13402). Two examples are shown in Figure 12, from Human-Solutions [12] and Cyberware [1].

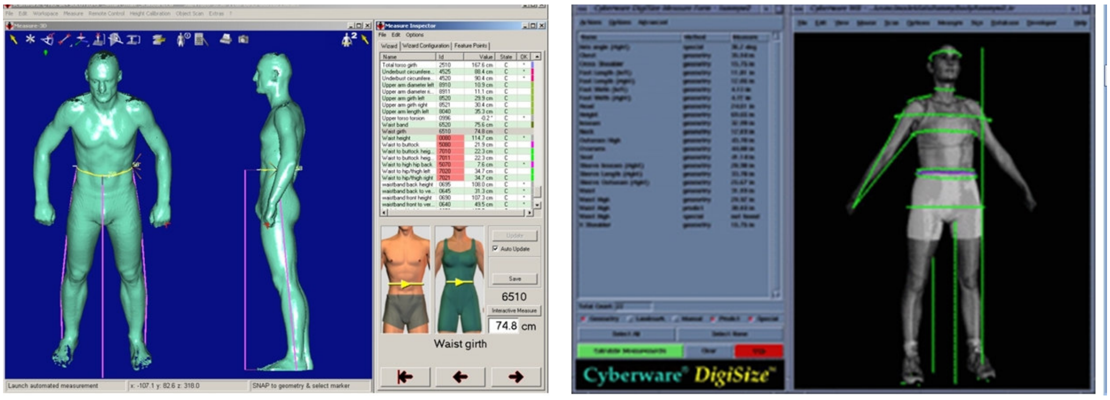

Figure 12: Left: *Anthroscan* of Human-Solutions [12]. Right: *DigiSize* of Cyberware [1].

3.2. Full Automatic and Autonomous Scanning Process

Automation in the data processing is also accompanied by the advancements in the scanning process. In fact, recently have been developed fully autonomous body scanners, such as for example the *NX-16* of [TC]^2 [3] (Figure 13). The entire scanning procedure and data processing are fully automatic and autonomous, so that there is no need of personnel to operate the scanner: the person operates alone the scanner and trig the scanning process by pressing a button located on holding levers inside the scanning cabin. Recorded messages and video presentations inside the cabin give additional information and instructions. The obtained 3D data is then processed fully automatically to extract body measures (as in 3.1).

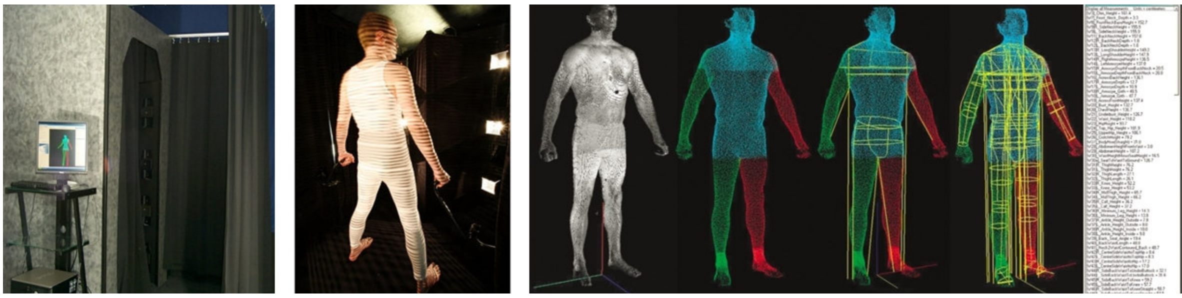

Figure 13: Autonomous full body scanning solution *NX-16* of [TC]^2 [3]. From left to right: the scanning cabin; inside the scanner; automatic data processing.

3.3. Full Automatic Generation of Avatars

The data resulting from a full body scanner is usually in form of a 3D surface model representing the scanned person. The main disadvantages of this representation form are the large amount of data required (several MB) and the impossibility to change the pose/posture of the body model; thus there is a limited possibility to use 3D scan data for on-line applications and in application where the 3D model is animated. For these reasons, the use of parameterized 3D Avatars as description of the scanned person has increased. In fact, Avatars can assume various poses and can be easily animated. Moreover, the size of data required to define a parameterized Avatar is very small (in the order of kB). However, a good approximation of the overall shape of the human body is important for applications as best-fit or virtual-try-on (section 3.4). A recently developed solution (from [TC]^2 [3].) allows indeed the generation of a personalized and parameterized Avatar starting from the 3D data obtained from a full body scanner. Figure 14 shows the different steps of the fully automatic process: a parameterized Avatar is modified so that its shape represents as closely as possible the real shape of the scanned person. The result is a representation of the person with sufficient accuracy for typical applications in fashion, but with a very small file size that will allow its use for on-line applications. Moreover, it can to assume various poses and can be animated.

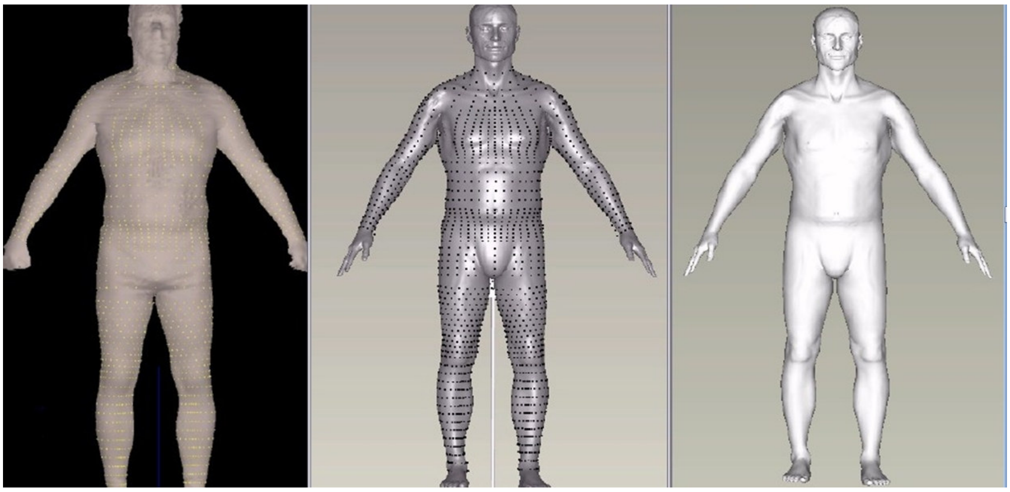

Figure 14: From left to right: 3D scan data with identification of points (in yellow); modification of the Avatar according to the scan data; resulting personalized Avatar [3].

3.4. 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 behaviour 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 [17]. Figure 15 shows an example of such solutions from Assyst-Bullmer [18]. The different parts of textile defining a piece of cloth are described as 2D patterns. 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 behaviour of the so formed cloth item over the human body model. Additional analysis tools are also available, e.g. tension analysis.

Figure 15: Example of virtual-try-on solution *Vidya* of Assyst-Bullmer [18]. From left to right: 2D patterns of the different cloth parts; parts placed and stitched around the body model; final result of the cloth simulation; analysis of the tensions in the cloth.

Various virtual-try-on solutions are available. Sophisticated modern solutions, as for example from OptiTex [19] (Figure 16), allow to import 3D body scan data and simulate different poses of the human body model. Additionally, motion information can be also imported; in this case, the behaviour of the textile is simulated dynamically on the moving body model.

Figure 16: Virtual-try-on by *3D Runway* of OptiTex Ltd. (Israel). From left to right: 2D patterns; 3D visualization of the final garment; comparison real-virtual; dynamic simulation.

4. Conclusions

This paper presented an overview of the different 3D digitization technologies used to measure the surface of the human body. The focus was then placed on the recent advancements of 3D full body scanning systems developed especially for fashion applications.

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