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STATE OF THE ART OF THE METHODS FOR STATIC 3D SCANNING OF PARTIAL OR FULL HUMAN BODY

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ABSTRACT

This paper presents an overview of the different 3D surface digitization technologies commercially available for the measurement of the human body.
Complete systems for the digitization of the human body exist since more than ten years. One of the main users of this technology was the entertainment industry. The faces and bodies of actors were digitized and the virtual characters replaced the actor in the movie. Nowadays, the state of the human body digitization is so high that it is not possible any more to distinguish the real actor from the virtual one. Indeed, for the rush technical development has to be thanked the movie industry, which was one of the strong economic motors for this technology.
Today, with the possibility of a massive cost reduction given by new technologies, methods for digitization of the human body are used also in other fields of application, such as ergonomics, medical applications, computer games, biometry and anthropometrics. With the time, this technology becomes interesting also for sport, fitness, fashion and beauty. A large expansion of human body digitization is expected in the near future.
To date, different technologies are used commercially for the measurement of the human body. They can be divided into three 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. Practical examples of commercial exploitation of human body digitization are also presented for different application fields.

Key words: 3D surface scanning, laser scanning, laser profiler, white light projection, hand held scanner, human body

1. Introduction

Complete systems for the digitization of the human body exist since more than ten 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 thirteen 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. Therefore, it is important to know deeply their characteristics and differences, for the selection of the adequate solution for a specified application.

2. Actual state of technology

Technologies used commercially for the measurement of the human body can be divided into three different groups:

- Laser scanning,
- Projection of light patterns,
- Combination modeling and image processing.

The next sections will give a description of the different technologies.

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2.1 Laser scanning

Laser scanning technology consists of using laser light sources to project on the human body one or more thin and sharp stripes (Fig. 1 left). Simultaneously, light sensors acquire the scene and by applying simple geometrical rules (named "triangulation", Fig. 1 right) 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.

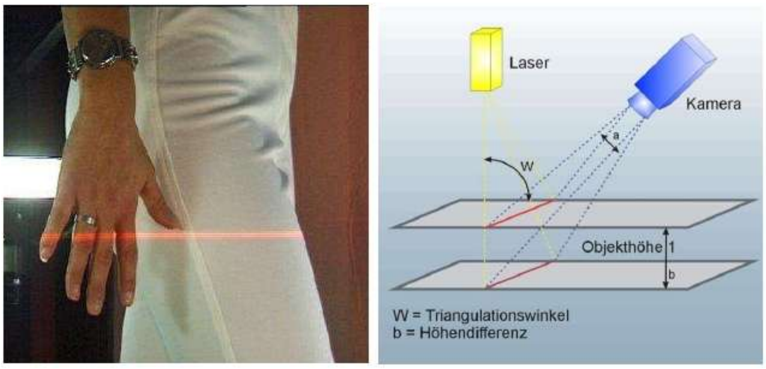

Fig. 1. Left: laser stripe on the human body. Right: triangulation method, different object heights result in different triangulation angles that can be measured by the light sensor (images of Vitronic).

A laser scanner unit is composed of the laser, the optical system and the light sensor. This unit is moved across the human body to digitize the surface. The type of movement and the number of employed units can vary depending on the human body parts to be measured. For example, the full body scanner of Hamamatsu Photonics (Japan) consists of four scanner units that move vertically synchronously along four pillars (Figure 2 left). A second example is the head scanner of Cyberware (USA). In this case, a unique scanner unit moves in circle around the head of a person (Figure 2 center). As last example is shown the foot scanner of Vitronic (Germnay): the scanner is composed of three units, which moves horizontally, two laterally and one from the bottom (Figure 2 right).
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 scanner 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, especially in the case of face measurement with its small scale and the required high resolution.

Figure 2: Laser scanning systems. Left: full body scanner *BodyLine* of Hamamatsu (Japan). Center: head scanner *Head & Face 3030 3D Color Scanner* of Cyberware (USA). Right: foot scanner *Pedus* of Vitronic (Germany).

2.2 Projection of 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 above. Instead of moving the scanner unit, a light pattern (usually in form of stripes) is projected onto the human body (Figure 3 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 3 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. The difference is that this happens in a single step and that the entire surface can be digitized by a single acquisition. For the increment of the resolution, the projected stripes are shifted and multiple scenes are acquired. 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 (Canada) (Figure 3 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. Figure 3 shows on the right an example of a full body scanning system composed of six scanning units. 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.

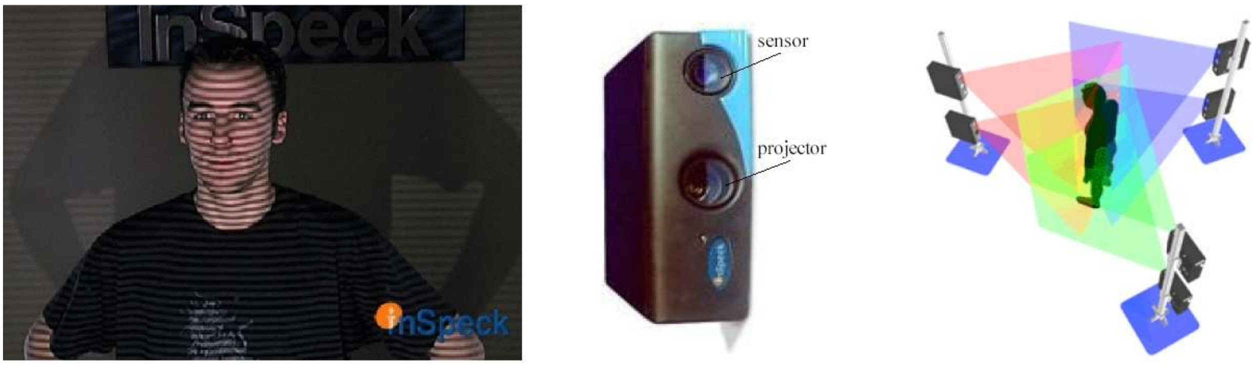

Figure 3: Left: projection of light pattern as stripes. Center: scanning device *Capturor* of InSpeck (Canada). Right: six Capturors compose a full body scanning system.

More advantageous, in comparison to laser scanning, are instead the today's costs of the technology. A very simple solution is for example shown in Fig. 4 left: a usual digital camera and a light projector. The special holding serves for a simplified calibration process (determination of the geometrical disposition of all the elements). In Fig. 4 right, is displayed, as second example, the full body scanner *TriForm* of Wicks and Wilson; to note are the holdings for the hands for a simplified immobilization of the person during the measurement process.

Fig. 4. Left: scanning systems with projection of light: *Shapesnatcher* of Eyetronics (camera and projector). Right: full body scanner *TriForm* of Wicks and Wilson.

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. Two examples are described to explain this technique: the 2D full body scanner *Contour* of Human-Solutions (Germany) (Figure 5 left) and the face modeler *FaceGen* of Singular Inversions (USA) (Figure 5 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 preparation of mass customized dresses.

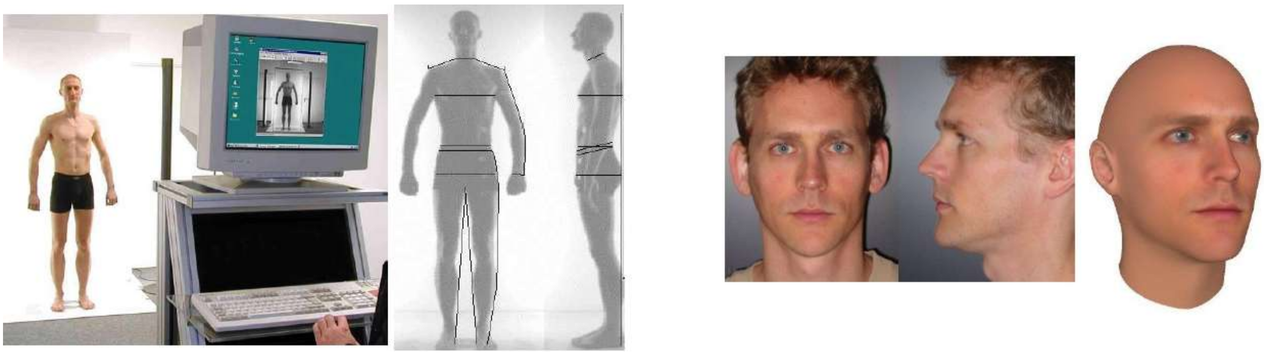

Figure 5: Left: 2D Full body scanner *Contour* of Human-Solutions (Germany), scanning equipment and silhouettes images used for the measurement. Right: face modeler *Facegen* of Singular Inversions (USA), used images for the generation of the virtual head and generated 3D face model with texture.

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. The big advantage of this combined technique (image processing and modeling) is its extremely lower price compared to real 3D measurement.

2.4 Required and useful 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 scanners are therefore provided with standard software for the visualization, for the treatment, for the exporting and eventually for the editing of the data. Figure 6, on the left, shows for example the result achieved by *TriForm* full body scanner of Wicks and Wilson (UK) and at the center the result of a head scanning system of InSpeck (Canada). 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 as a colored 3D model of a female head has already been processed.

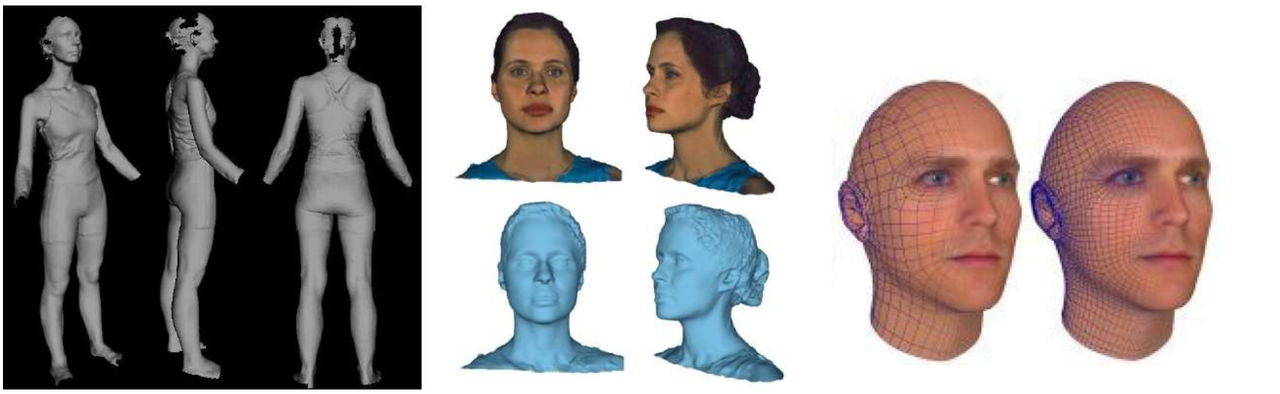

Figure 6: Left: result of *TriForm* full body scanner of Wicks and Wilson (UK). Center: head model (with and without texture) resulted by using InSpeck (Canada) head scanner system. Right: two different levels of detail of a 3D face model resulted by *Facegen* of Singular Inversions (USA).

Data compression plays an important role by the digitization of the human body. 3D scanning processes generate very large amount of data, e.g. the female head model in Figure 6 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 6 on the right shows an example of a 3D face model at two different compression factors: the details of the eyes, nose, and mouth must be conserved, whereas the data resolution in areas with fewer details can be reduced.

3. Applications and exploitation of human body digitization

3.1 Introduction

Various application fields exploit the digitization of the human body since many years. The different applications can be classified into two big groups, distinguishing them by their requirements:

- The first is more interested in the visual aspect of the results and regards mainly movie industry, animation, computer games, and virtual reality.
- The second, more interested in the quantitative aspect of the result, namely the measurement, includes ergonomics, anthropometrics, medical applications, and biometry.

The next paragraph will give some examples of the exploitation of human body 3D surface measurement techniques for various fields.

3.2 Appeal / fashion / beauty

Experts dealing with styling of persons are increasingly interested in commercial applications of human body digitization in their field. They wish to show their clients how they will look before they buy trendy dresses or before they choose for a beauty treatment. They also wish they could provide them with customized dresses at affordable costs. Figure 7 shows examples of existing applications in this field. On the left is shown a snapshot of a virtual fashion show with digitized human models. On the center is displayed a digital customer card with stored body sizes, that were determined by full body scanning process. On the right is shown a so called *virtual-try-on* solution, where different cloth items can be tried virtually on a 3D model of a person.

Figure 7: Examples of exploitation of human body digitization for styling applications. Left: virtual fashion show, from *Digital Fashion* (Japan). Center: digital customer card with stored body sizes, from *e-Tailor* project (EU). Right: 3D virtual-try-on solution, from *Optitex* (Israel).

Figure 8 and Figure 9 show other possible applications in beauty branches, namely hairdressing and accessories (e.g. glasses). In both examples, the appeal of the human face is changed virtually by adding digitally haircuts or glasses to the digitized 3D human face.

Figure 8: Example of applications in beauty: virtual added haircuts, from *Stellure* (USA).

Figure 9: 3*D iView* (Israel) acquisition system (left); virtual 3D frame and lenses (center); 3D eyewear virtual-try-on (right).

In the case of virtual-try-on of eyewear, the benefits are manifolds for both customers and optical stores [1]. From the point of view of the client, the benefits are: 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 possible benefits are: 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.

3.3 Size surveying [2]

Recently, human body size surveys have become a complete necessity. All institution and companies working on ergonomics are expecting information for practical immediate exploitation. 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. Establishing a national anthropometry data base for the nation's citizen is now undoubtfully a necessity.
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. 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.
The automatic recognition of anatomic landmarks as defined by ISO7250 works well for the standard posture, however some problems still remain for very fat people. On the other hand, research group are working for the development of algorithm for the automatic landmark recognition also for the sitting posture.

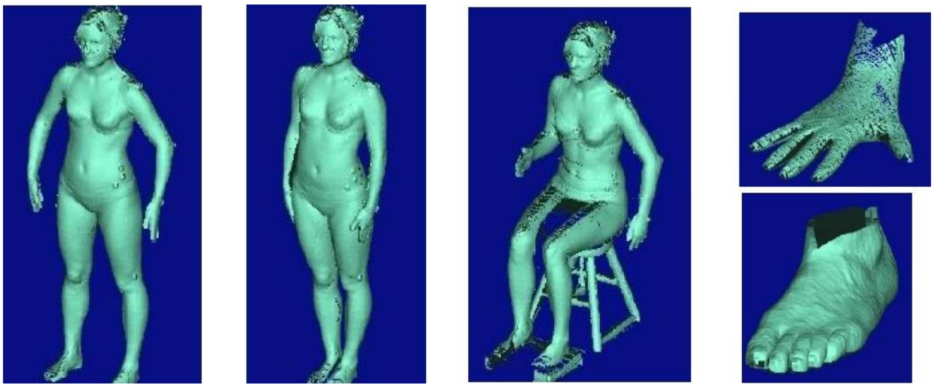

Fig. 10: 3D data required by size surveying [2]: standard (legs, arms apart), standing and sitting postures, foot and hand.

3.4 Medicine

The medical field represent an established group of users of human body 3D digitization techniques. Various applications exist already in orthodontics, prosthetics, orthopedics, plastic surgery, reconstructive medicine, forensic medicine, dentistry, ORL.
As commercial example for the medical field, Figure 11 shows the 3D measurement system for spine and posture analysis [3] developed by a German company. The system is based on structured light projection. The very short scanning time of about 40 msec allows the dynamic 3D measurement (4D) of the spine. The gained information is of great use for analysis and diagnosis.

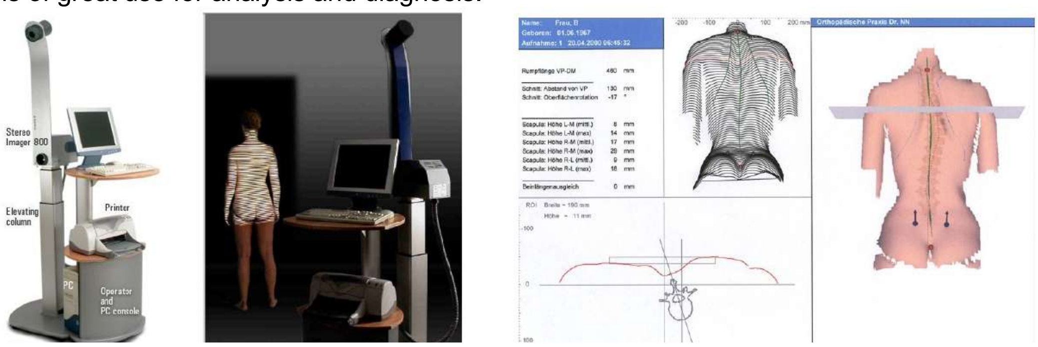

Figure 11: Human back measurement system *Formetric 3D/4D* [3] (Germany). Complete system (left), system in use (center), application software (right).

3.5 Cosmetics / dermatology

Cosmetics and dermatology are also exploiting 3D surface digitization techniques to study and analyze very precisely the skin topography in various regions of the human body. An interesting example is given by Total Contact Inc. (USA) in collaboration with the Skin Science Institute of Children's Hospital Medical Center of Cincinnati (USA) and the University of Cincinnati's College of Pharmacy (USA). They have implemented the use of Cyberware (USA) non-contact surface scanning system and TrueGage (USA) analysis software to quantify cellulite [4].
A Cyberware scanner (figure 12 left) was used to capture surface data of cellulite-affected thigh sites in females with varying degrees of cellulite, as well as subjects exhibiting non cellulite. The surface data were then analyzed to quantify the skin surface morphology and determine specific roughness values (figure 12 right).
A comparison of the roughness parameters extracted from the 3D scan data, with the grades established by expert by visual analysis, proved the correctness of the method for a quantitative measures of cellulite severity. This demonstrated ability to quantify cellulite will aid in development of remedies for reducing it.

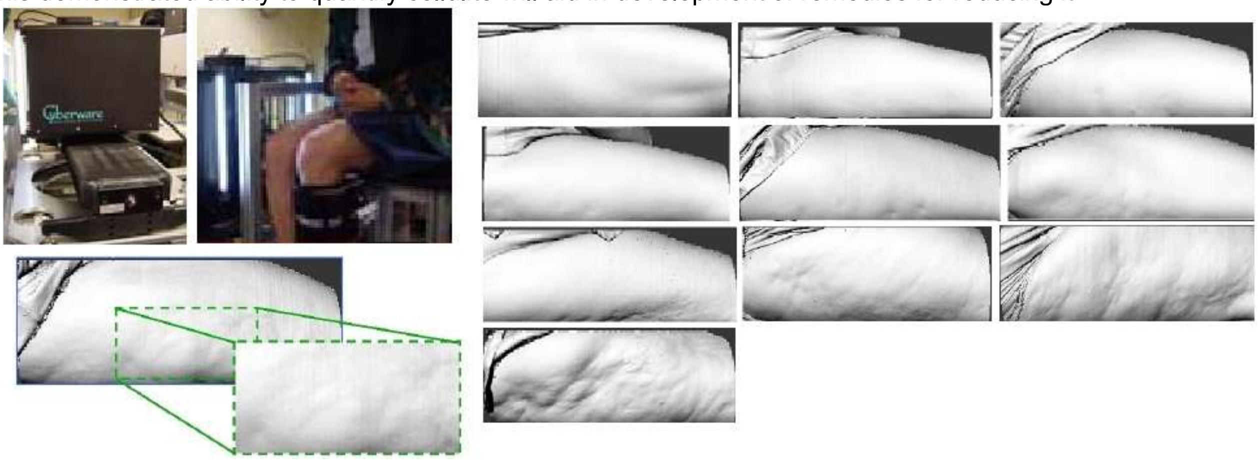

Figure 12: 3D laser scanning system, scanning the thighs and results (left); 3D scan images arranged with increasing cellulite severity grades (right).

3.6 Art

Artists are becoming more interested in 3D human body digitization since the costs of this technology has decreased in the last years and became more accessible to a larger group of users.
3D replica of human faces or full body are offered in various media, as for example, point cloud burned in crystal cubes, or small plastic figurines printed in 3D. However, such replicas do not represent real artistic exploitation of 3D measurement techniques. A very interesting example of how artists can exploit the technology for their work is given by Helmick and Schechter's sculpture of year 2000, called *Jurisprudent* [5] and installed at the Melvin Price Federal Courthouse in East St. Louis (IL, USA). Using traditional methods, the artists sculpted twelve life-size portraits of ordinary American citizens-representing twelve members of a jury. The heads were then laser-scanned, rapid-prototyped at small scale, cast in pewter in large quantities, finished with a hand-rubbed patina, and precisely affixed to hundreds of suspended cables. Collectively, the over 3,000 small sculptures coalesce into two monumental heads facing each other across a skylit courthouse atrium. Figure 13 shows the sculptures.

Figure 13: Artistic installation *Jurisprudents,* at the Melvin Prince Federal Courthouse (USA). Large view (left), the male face (center) and detail of the suspended small sculptures (right).

3.7 Animation

The last example of application of 3D human body measurements come from the technological innovation exposition 2005 in Aichi, Japan. A world-first in entertainment was shown at the Mitsui-Toshiba Pavillon: *Grand Odyssey*, a unique computer animated film [6]. Spectators queuing outside what appeared to be an ordinary cinema, were invited to place their faces into a hole in the wall for a few seconds. High-resolution digital cameras performed a quick scan from several angles, after that everyone could take their seats. The animated film was beginning as normal, but the cast was made up of walking, talking digital replicas of people in the audience. Each spectator were getting a role (there were soldiers, doctors, scientists and politicians involved in the story) as a Toshiba supercomputer was processing the one-time-only film.
The system named *Futurecast* was initially developed by Waseda University Professor Shigeo Morishima, and completed by Mistui-Toshiba engineers. The entire process can be described as follows: (a) a simple face scanner capture images from the person from different directions; (b) a 3D computer model of the person's face is automatically generated from the scanning data; (c) out of the 3D face model a parametrized face mask is automatically extracted, the parametrization allows to index face features as eyes, eyebrows, nose, mouth, etc.; (d) the face mask can then be directly inserted and animated in the computer animated movie.

Figure 14: *Futurecast* system (Japan). Left: Spectator original face, face scanner, 3D face model and parametrized face mask. Right: person's face inserted and animated in real-time in the movie.

4. Conclusion

In this paper was presented an overview of the different 3D digitization technologies used to measure the surface of the human body. Various examples of their use were shown for different application fields.

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