High Accuracy Passive Photogrammetry 3D Body Scanner

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Abstract

This paper presents a new and high accuracy passive photogrammetry device intended for the three-dimensional scanning of the full human body. This device, named *Bodygrammer*, does not need laser beams, structured light, strips or any projection on the human body. It just takes a series of pictures of the body inside a cabin, whilst wearing an elastic mesh. Thus, it comprises only cheap and simple commercial elements to build, in just a few seconds, the digital 3D model of the body, also known as an avatar.

Since it is based on synchronized pictures, its acquisition time is only hundredths of second, avoiding unwanted movements by the person. This dramatically reduces the acquisition time while providing high accuracy in the results. For end users, the *Bodygrammer* is completely harmless. By using an elastic mesh there is no need to get naked in order to allow the system to take the images, which are deleted automatically right after the generation of the avatar. As the mesh mildly constrains the body, the resulting avatar is highly suitable for apparel applications.

This device performs very intensive calculations by means of a newly developed software based on GPU (Graphic Processing Unit) computation, that quickly obtains the avatar from just the pictures. The system allows us to get both manual and automatic 3D measurements such as chest circumference, limb length, waist perimeter, etc.

The *Bodygrammer* has already been thoroughly tested with real people for anthropometric studies. The resulting measurements have been successfully validated using third-party 3D contact techniques. In addition, all the individuals measured with the device have reported a satisfactory user experience which is of vital importance in order to be widely accepted in the real world.

Keywords: bodygrammer, avatar, anthropometry, passive photogrammetry, measurement, body scanning, low-cost, fashion, online, garment, size, tailor, apparel, image.

1. Introduction

1.1. Technological background

Systems for whole digitalization of the human body have been well known for several years. Nevertheless, their high cost pushes them to be used in limited and exclusive fields, such as ergonomics, the military industry, film production, luxury cars, etc.

In recent years new techniques and methods have been developed. With lower costs, these methods have allowed more applications in fashion, medicine or sports industries, but always on high end products.

Current used commercial technologies for the body scanning can be sorted into three main groups [1]:

- Laser scanning
- Light pattern projection
- Image based processing and modeling

The image based processing and modelling technology obtains the three-dimensional geometry of the human body by image processing. There are two different techniques: silhouette extraction and photogrammetry.

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1.2. The new device

This paper introduces a new high accuracy 3D scanner for the human body, named *Bodygrammer*. The device uses the passive close-range photogrammetry technique in order to obtain the 3D model of the body, also known as the avatar. The hardware required is significantly cheaper than in other devices using other techniques, allowing us to achieve a low cost device for full body scanning. Since the synchronization of camera shots and lighting has been enhanced, the accuracy of the measurements obtained with the *Bodygrammer* device is similar or even better than that reached with other devices. The range of the body surface to be scanned has been also improved, with good results in the underarm and inner thigh areas.

The person to be scanned should wear a special two-piece elastic suit. Black dot marks as well as coded target marks are spread all over the white suit surface. From pictures, those marks are read by the software, which gives them an accurate 3D spatial position [2]. This point cloud is the base from which the avatar is built. Thus far, the avatar does not include the head, hands and feet of the scanned person.

2. Methods and instrumentation

2.1. The stall

Externally the device is a stall with a footprint of around two square meters and high enough to host a person inside. The structure can be disassembled into several sections to ease delivery.

A cylindrical booth is located inside the stall. Calibration marks are spread all around its white inner surface. 32 photographic digital cameras are attached to the booth structure and, consequently, placed between the cylindrical inner surface and the square outer surface of the stall. The cameras have a resolution of 8 MPx each. As part of the ceiling and part of the floor are made of a transparent material, lightning flashes can be placed above the ceiling and below the floor in order to illuminate the scene.

Photographic cameras and light shots are controlled by a specific hardware and a computer, which also collects pictures from each camera. Those pictures are managed by proprietary software in order to get the avatar of the scanned body. The commercial version of the *Bodygrammer* will immediately erase all those pictures just after obtaining the avatar, in order to preserve the privacy of the scanned person.

2.2. The suit

The subject enters into the stall with a two-piece white suit (from now on to be called the “mesh”) adjusted to his/her body. This mesh avoids the psychological problems detected in other devices requiring the subject to be practically naked in the moment of data capture. Additionally, the small compression that the mesh implies on the body will produce an avatar whose measurements are significantly better for fashion applications.

The upper part of the mesh covers the trunk, arms and neck, and the lower one covers the inferior limbs down to the ankles. The mesh fabric is white lycra, whose composition is 60-90 % polyester and 10-40 % elastane, which provides an optimum elasticity. The quality of this tissue increases its durability and resistance to washing, enabling reuse in various applications by different people, once washed. The commercial version of the *Bodygrammer* will also use disposable meshes made of a proper elastic fabric.

The mesh is stamped with two types of control targets:

- Dot marks in a regular pattern. The 3D grid is obtained by restitution of such simple marks. They are black circles of 4 mm in diameter, with a distance of 14 mm between centers.
- 14-bit coded targets, similar to calibration targets that are also located in the booth and serve to calibrate the cameras. They are uniformly distributed on the whole mesh.

Figure 1. Front view of the Bodygrammer device.

Figure 2. Oblique view of the Bodygrammer device.

2.3. GPU Computation

With the introduction of GPU computation, many computer vision algorithms are being adapted to exploit the performance gain experienced when a GPU is used. In image processing algorithms, hundreds of pixels are calculated the same way. A CPU is forced to process all of them one by one, except when a multicore CPU is used. In this case parallel processing can be performed, thus allowing us to compute at the same time a number of pixels between 2 and 8.

On the opposite side we find GPUs (Graphics Processing Unit), which have been extensively used since their introduction at the end of the previous century. Originally they were developed in order to be used as graphics coprocessors, i.e., to leverage the CPU from the complex calculations required in 3D games. These specialized processors have vastly improved their performance during the last decade and they have been inherently designed with parallel processing of vectorial data in mind.

This way, and considering the *Bodygrammer* ´s demanding image processing requirements, GPU has been used as a general purpose processor using GPGPU (General Purpose Computing on Graphic Processing Units) and OpenCL programming language, intended to perform image processing tasks much more quickly than on a conventional CPU. This is compatible with the most important GPUs available today, nVidia and ATI, and OpenCL code can also be compiled for modern CPUs from Intel and AMD, allowing us to keep a single version of the software with the subsequent saving of time and ease of code maintainability [3].

3. Test

3.1. Validation of the cabin functionality

For the validation of the cabin functionality and the convenience of lycra meshes, a study has been performed on a population sample of 20 individuals of different body types and gender. This meets a spectrum wide enough, and the classification matches the Heath-Carter somatotype, which is the most often used today in Anthropometry to understand and differentiate the body shape of a person [4]. Twelve meshes were fabricated with different sizings grouped by gender, so that there was 6 meshes for women and 6 for men.

The somatotype technique is used to estimate the body shape and its composition. The resulting somatotype provides a quantitative summary of the physique, as a unified whole. It is defined as the quantification of the shape and composition of the present human body. It is expressed in a rating of three numbers representing the endomorphic, mesomorphic, and ectomorphic components, respectively, always in the same order. The endomorphism represents the relative adiposity, the mesomorphism represents the strength or relative musculoskeletal magnitude, and the ectomorphism represents the relative linearity or slimness of a physique. The four main somatotype categories are:

1. CENTRAL: no component differs by more than one unit with respect to the other two.
2. ENDOMORPH: the endomorphism is dominant, the mesomorphism and the ectomorphism are more than ½ unit smaller.
3. MESOMORPH: the mesomorphism is dominant, the endomorphism and the ectomorphism are more than ½ unit smaller.
4. ECTOMORPH: the ectomorphism is dominant, the endomorphism and the mesomorphism are more than ½ unit smaller.

In these groups, (9 females and 11 males), an anthropometric study was performed, using anthropometric instruments approved by the ISAK (International Society for the Advancement of Kinanthropometry), measuring a total of 10 body dimensions for the purpose of determining their somatotype or body shape, listed below: weight, height, triceps subcutaneous, subscapularis, supraspinatus and calf skinfold, flexed arm and calf circumference, bicondylar diameter of the femur and humerus.

Table 1.Maximum and minimum values of the sample.

	Minimum value	**Maximum value**
Age (years)	22	48
Height (cms)	150,2	184
Weight (kg)	40	117
Humerus diameter (mm)	5,7	8,1
Femur diameter (mm)	7,8	11,8
Arm perimeter (mm)	22,2	40,5
Calf perimeter (mm)	32,3	48
Triceps skinfold (mm)	6,2	33
Subescapularis skinfold (mm)	8,6	30
Supraespinatus skinfold (mm)	4,6	33,4
Calf skinfold (mm)	8,4	30,4
ENDOMORPHY	2,4	8,1
MESOMORPHY	2,8	9,7
ECTOMORPHY	0,1	3,8

Table 2.Somatotype categories found in the sample.

	Number of individuals
CENTRAL	1
ENDOMORPH	7
MESOMORPH	4
ECTOMORPH	1

These results determine that the sample includes representatives of the four major somatotype categories.

3.2. Bodygrammer measurement validation methodology

The measurements obtained by means of the *Bodygrammer* device have been successfully validated using a third-party alternative measurement method. The last is based on a portable articulated arm coordinate measurement machine (CMM), according to ISO10360 standard.

The methodology used for the comparison of the results was performed by measuring common points on a mannequin, used as an invariant model. The CMM arm directly touches a series of points on the mannequin using a spherical probe. The same points were measured onto the calculated mesh obtained by the *Bodygrammer*. The distances between these points were calculated using both methods and their difference was computed.

Figure 3. Photographs of the 20 individuals in the population sample with different somatotypes.

4. Results

Once all individuals have been manually measured, they entered into the *Bodygrammer* cabin to test its functionality and to obtain the avatars. On leaving the cabin, a survey was performed on the individuals to check their satisfaction level and experience inside the cabin.

Table 3.Results of the survey on usability of the cabin and comfort of the mesh.

	YES	NO
1. Clothing size	Since S to XXL size	
2. Usually have trouble finding clothes with sizes that feel good	11	9
3. Has felt comfortable with the mesh	17	3
4. Prefer to be scanned in lingerie / swimsuit	5	15
5. Has felt comfortable inside the cabin	19	1
6.Would get into a simillar cabin on your own if found in a commercial store	16	4
7. You prefer to save the photographs taken, or prefer them to be deleted once the avatar has been generated	16 – save photos	4 - delete photos
8. Shop for clothes online	7	13
9. Have problems with sizing and need to return purchases	3	3

The sizes of the meshes were enough to clothe each and every one of the individuals properly, so that all body parts were covered fully and correctly. Lycra elasticity makes the material conform to the shape of the body and constricts it lightly, preventing the appearance of wrinkles or folds, thereby allowing us to obtain a very smooth avatar, perfect for subsequent anthropometric measurements. 85% of respondents expressed their satisfaction with the comfort of the mesh. Furthermore, the fact of being dressed in a mesh is also valued positively, compared with being dressed in lingerie or swimwear.

In all cases, regardless of the height and build of the individual, the cabin worked well regarding the placement of the cameras and its internal dimensions, with respect to the mobility of the individuals inside. All photographs were taken properly so that it was possible to obtain the avatar of each individual successfully.

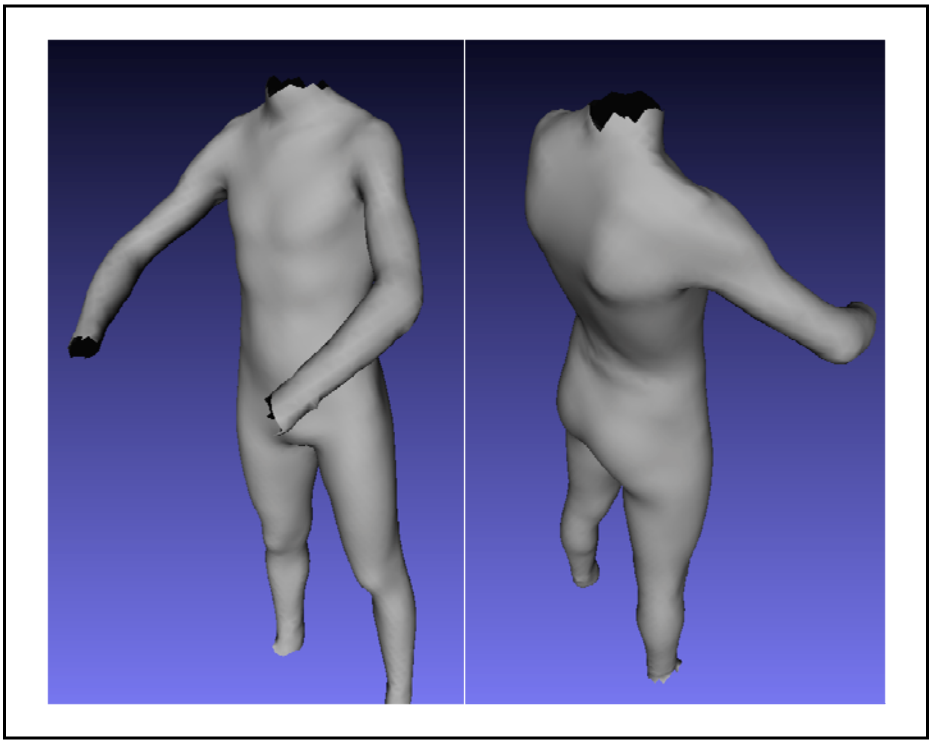

Figure 4. General view of an avatar generated by the Bodygrammer device.

In order to verify the performance gain experienced with the OpenCL implementation, we have measured the execution times of different processes involved in the avatar generation. As OpenCL allows the execution of the code in heterogenous devices, it is very simple to determine if the kernel will be executed on a conventional CPU or on a GPU [5].

In order to define the conditions of the experiment, we have set up the following input parameters for the algorithm:

- Image size: 4096 x4096 pixels
- Template window size: 7 x 7 pixels
- Search window size: 31 x 31 pixels

On the CPU / GPU side we have chosen, respectively, an Intel Xeon E3-1225 CPU and an nVidia GTX560 GPU.

Table 4. GPU versus CPU results

Process executed	GPU time	CPU time
Grayscale conversion	0.1585 sec	0.1534 sec
Image downsizing to 1024 x 1024	0.0405 sec	0.0154 sec
Disparity map calculation	7.5941 sec	845.9301 sec
Scaling and interpolation of the disparity map	0.3641 sec	1.1935 sec
Image downsizing to 2048 x 2048	0.0133 sec	0.0851 sec
Disparity map calculation	31.5741 sec	3,185.1351 sec
Scaling and interpolation of the disparity map	1.2241 sec	1.2060 sec
Image downsizing to 4096 x 4096	0.0381 sec	0.3051 sec
Disparity map calculation	127.7390 sec	12,333.5460 sec
Final polynomial interpolation step	3.707 sec	118.7907 sec

In order for the *Bodygrammer* to calculate the 3D coordinates of the points, aspects like evaluating the quality of the camera calibration and the photogrammetric project quality have been considered [6].

Table 5. Field Camera Calibration results.

Focal length (mm) / deviation	5.8999 / 0.002
Principal Point H (mm) / deviation	2.7911 / 5.8E-004
Principal Point V (mm) / deviation	2.2222 / 0.001
CCD H size (mm)	5.76
CCD V size (mm)	4.29
K1 / deviation	0.00391 / 6.0E-007
K2 / deviation	-5.639E-06/ 3.5E-009
K3 / deviation	-1.117E-06 / 2.7E-011
P1 / deviation	0.000108 / 4.0E-006
P2 / deviation	4.17E-05 / 4.9E-006

Table 6. Camera calibration quality for the avatar generation.

Number of images	32
Points per image	4,976
Image coverage	93.318 %
Marked points RMS (pix)	0.002386
Marked points maximum RMS (pix)	0.7431
Marked points minimum RMS (pix)	0.0015

Table 7. Photogrammetric project quality for the avatar generation.

Project Overall Quality	
Number of images	32
Adjustment RMS (pix)	0.0001067
Points Quality	
Marked points RMS (pix)	0.225
Max RMS (pix)	0.893
Min RMS (pix)	0.027
Coordinate Calculation Accuracy	
Ray intersection accuracy RMS (mm)	0.69
Ray intersection accuracy Max RMS (mm)	0.95
Ray intersection accuracy Min RMS (mm)	0.19

The following table shows the distances calculated between the common points measured using both the BG and the CMM arm, and the differences noted.

Table 8. Difference between each distance.

Distance	BG (mm)	Arm CMM (mm)	Difference (mm)
1	422.878	423.518	0.64
2	362.214	362.764	0.55
3	295.473	295.153	-0.32
4	359.073	539.543	0.47
5	228.084	227.714	-0.37
6	206.795	207.025	0.23
7	136.845	136.735	-0.11
8	92.015	92.075	0.06
9	907.726	908.596	0.87
10	105.905	105.775	-0.13

Table 9. Comparison of the resulting remaindings.

(μ) Average	0.232
Maximum	1.113
Minimum	0.001
(σ) Typical Deviation	0.265

Taking into account the absolute dimensions of the mannequin model, around 180 cm high, and the working volume, around 70 cm width by 70 cm depth by 200 cm height, and considering the results shown above, the RMS accuracy on the avatar calculation is lower than 1mm.

5. Conclusions

The new and high accuracy passive photogrammetry device intended for the three-dimensional scanning of the full human body named *Bodygrammer* has met the validation tests, both from a functional point of view with respect to its usability: internal dimensions, speed, performance components (cameras, flashes, etc.) and also in turn its technique regarding its software synchronization and the avatar generation based solely on the photographs obtained.

The use of standard hardware components and its low cost make the *Bodygrammer* a device suitable for use in mass anthropometric studies and markets such as fashion, sports and online apparel shopping.

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