DEVELOPMENT OF A LOW COST BODY SCANNER FOR GARMENT CONSTRUCTION

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ABSTRACT

During the last decade several body-scanner have been introduced in the market, to be used in anthropometrical and ergonomic studies as for garment construction. In this field, having a reliable body digitizer able to extract the dimensions needed for clothing production has become fundamental not just for made-to-measure garments, that still represent a 10% share in the European market [1], but also to create satisfactory products in terms of design and fitting, that is changing from mass-production to mass-customization. Such an ambitious objective requires overcoming the traditional size-based definition of garments: how can a single dimension represent the human variability? One of the authors, Mr. Quattrocolo, has patented a range of mannequins, FORMAX®, designed to take into account all possible body conformations extracted from anthropometrical statistics.

The main limit of the body-scanner available today is that they are too bulky and too expensive to be introduced in garment shops. In this paper a low-cost apparatus and its driving software are proposed, combining a simple hardware with the knowledge about body conformations and the statistics databases with huge amount of digitizations from which they have been extracted.

1. INTRODUCTION

Garment construction is one of the most important industrial sectors in Italy, due to very large proceeds of sales, second only respect to the automotive industry. The request for more competitive products leads the companies to increase the satisfaction of their customers: this is achieved with products distinguishing themselves for quality and fashion, but also for best fitting and comfort.

The main contradiction of garments industry is that companies must satisfy fitting requirements of a mass-product dedicated to a target (the human race) that is far away from the standardization!

A review of the specialized literature demonstrated that made-to-measure garments represent a growing trend, with a 10% share in the European market being worth 3 billions EURO [1]. That's why the European Community has sponsored several researches attempting to transfer the benefits of made-to-measure to the mass production; the problems connected to this task are due to the fact that most of made-to-measure producers are small or medium companies, so that their methods and techniques cannot be transferred to an industrial production easily.

The main goal is realizing a mass customization of the production, to transfer the requirements of customers for best fitting inside the companies.

Such an ambitious projects requires an update of usual instruments of tailor: first of all overcoming the traditional size-based definition of garments and measures and referring the new definition to the real statistic distribution of volumes among the population; second realizing and testing instruments by which it would be possible to take body measures quickly and carefully; third jointing this parts by e-commerce to obtain the direct relation between the company and the customers.

One of the authors, Mr. Quattrocolo, thanks to his big experience about garment construction, has patented a range of mannequins, FORMAX®, designed to take into account all possible body conformations extracted from anthropometrical statistics. A company provided with a complete set of such mannequins has a realistic model of the target population to which the garments is dedicated.

Such a point of view about garment fitting induces to reject the traditional idea of size and to accept the classification of customers by their conformation: the identification number, according to Quattrocolo's theory, should be an index of body volumes distribution, since the main trouble for fitting is the way to cover these volumes which cannot be summarized by linear dimensions. The statistical survey of volumes distribution summarized in some categories is the only true reference of human shape. Among these categories a set of different man heights is defined to accomplish the exact identification of a customer.

The other instrument that needs to be available in the market is a low-cost body scanner, to be placed in any shop interested to the made-to-measure production: identifying the conformation and the height of customers is the first step to send an order from the shops to the garment producers.

The purpose of this article is to explain the development of a body scanner designed for garment construction which can identify the conformation of subjects but also be used to renew the data of statistical survey so to update the conformation categories.

Overview of the scanner specifications.

Scanner	Cyberware WB4	Hamamatsu	Hamano Eng. Voxelan	TC²	TecMath	Telmat	Turing C3D	Vitronic Vitus 3-D 1600 (3400)
POC	Sue Addleman	Kenneth Kaufman	Mr. Hamano	Judd Early	Rainer Trieb	Jean-Loup Rennesson	Tim Nibblet	Klaus Bauer
City	Monterey, CA	Bridgewater	Sakado, Takatsu	Cary, NC	Kaiserslautern	Strasbourg	Glasgow	Wiesbaden
Address	2110 Del Monte Ave.	360 Foothill Road	KSP-D339, 3-2-1	211 Gregson drive	Postfach 2049	4 Rue Thomas Mann	University Ave., Boyd Orr Bldg.	Hasengartenstr. 14a
ZIP	CA 93940	08807-0910	Kawasaki 213	27511/7909	67653	67200	G12 8QQ	65189
Country	USA	USA	Japan	USA	Germany	France	UK	Germany
Tel.	18086571450	9082310960	81448192168	9193802156	496312053420	− 33388277120	1413376410	61171520
Fax	18086571494	9082319074	81448192171	9193802183	496312052803	− 33388277122	1413390795	611715203
Email	Sue@cyberware.com	kangro@pipeline.com		..@tc2.com	Trieb@tecmath.de	jlr@telmat.fr	tim@turing.gla.ac.uk	bm@vitronic.de
Website	Www.cyberware.com		www.ksp.or.jp/hc	www.tc2.com	www.tecmath.de	www.telmat-net.fr/symcad	turing.gla.ac.uk	www.vitronic.de
Price indication	US$410k	US$100k	US$200k	US$200k	US$100k	US$50k	US$200k	US$180k (US$250k)
Technique	Laser	LED	Slit-light laser	Light pattern proj.	Laser	B&W image	Light pattern proj.	Laser
# projectors	8	8	4	6	2	1	Variable	4 (8)
# CCD	4	8	2	6	2	1	Variable	16 (24)
Measurement angles	75,180,255,360	2,8,172,178,182,188,352,358	Irrelevant	60,150,150	0,180	0,90,180	0,75,180,255	30,150,210,330, (0,90,180,270)
Scanning volume	2 × 1.2 cm cylindrical	200 × 90 × 50	11 × 0.74	1.1 × 1.1 × 2	2.2 × 0.8 × 0.8	210 × 110		2.1 × 1.2 × 0.8 (2.0 × 1.0)
Scanner dimension (meters)	3.8(w) × 3. (D) × 2.9(H)	275 × 159 × 167			2.8 × 1.9 × 1.1	240 × 150 × 400		3.05 × 2.5 × 1.8 (3.8 × 3.8 × 4.8)
Scanning duration (s)	17	7	30	2–8	1.5	3 × 1/30	< .2	21 (20)
Color	Yes	No	No	No	Option	No	Option	option
Merging	Yes	Yes	Offline by body markers	Yes	No	In progress	Yes	Yes
Range resolution (mm)	0.5	1	?	1	1	0.8	3–5	2 (1)
Horizontal resolution (mm)	5	7.5	3.4	2	8	1.4	1-Jan	2 (1)
Vertical resolution (mm)	2	5	3.4	2	5	1.4	1.5	2
Eye safe	Yes, Class I	Yes	Yes	Yes	Yes	Yes	Yes	yes
Scan direction	Vertical	Top—bottom	Irrelevant	Irrelevant	Vertical	Instant 3D capture	Instant 3D capture	Vertical
Supplied Software	CyScan, CyPie	Visual basic/C + + application	Unknown	Dedicated (included)	Quick visualisation	Clothing specific	Quick visualisation	Vitronic C + +
Size of a scanned subject (Mb)	8	0.3		6		0.25	Variable	6
Hardware needed	SG Indigo 2	PC	PC	PC (included)	PC	Unix system, PC in progress	PC	PC
Application areas	Anthropometry, apparel design & computer graphics	Clothing fit	Anthropometry	Clothing fit	Human modelling	Custom-made and made-to-measure apparel	Anthropometry, movie industry	Arts, anthropometry

Fig. 1. Body scanner for garment construction available on market [4].

2. BODY SCANNERS FOR GARMENT CONSTRUCTION

During the last decade several body-scanner have been introduced in the market. At the beginning these instruments were dedicated to anthropometrical and ergonomic studies so they have been developed for careful acquisitions of the human shape [2-4]. Transferring these type of instrument into the garment industry is still difficult because of the following reasons:

the excessive cost and the excessive dimensions, that limit their distribution into the shops;

long time of acquisition (order of minute);

request of personnel well up on the functioning of the instrument;

since these systems have been "adapted" to garment industry, but they still lack tailoring know-how, the functionality of their driving software is not sufficient.

Two different approaches can be followed to achieve the result of a body scanner good for garment world:

implementing a software easy to use also by non technicians and dedicated to cloth makers;

designing and developing new types of body scanner.

The first way was followed by the constructors of traditional body measurement systems: for these body scanner all old problems remained (they are complex, expensive and bulky) and the cost of an extra software was added. However thanks to the cost lowering of electronic equipment, some of these devices have gained a relevant role, even if limited to big companies.

In Fig. 1 there is a summary of the body scanners available. A rapid view of the data of Fig. 1 confirms the aforementioned statements. The request for a quick body scanner (order of seconds), although less accurate (these systems are capable of 0.5-1 mm as standard accuracy, while for garment construction it is sufficient an accuracy of about 5-10 mm) is in contrast with the characteristic of the body scanners showed; this is mainly due to the structure of these scanners: the mean for scanning the surface is a laser or a structured light device, that must be translated along the entire surface of the body to avoid shadows. The receiver (one or more digital cameras or other similar devices) captures and records the images produced by an horizontal line projected on the body and can be either fixed or in motion with this. The reconstruction of the human shape is made by the elaboration through triangulation techniques of the data acquired by the receiver [4]. The time of acquisition is so constrained to the time necessary at the motion devices to cover the entire distance and to the time necessary at the receiver to records data.

Another important aspect is that some means used by these scanners, such as laser light, could be harmful for the consumer. These systems available on the market are hence not useful for garments shops due to their cost, technical and structural complexity.

Some other scanners are effectively cheaper, thanks to a deep simplification of the structure and of the acquisition devices. These body scanner show static acquisition device, taking advantage from the number of cameras to obtain satisfactory views of the body, or from bounding the scanning area to the region of real interest [5-7].

In spite of the growing simplicity of the system, there are more shadows on which the system cannot acquire and limits on body regions.

Otherwise there are cases in which the scanner has been built for the purpose to acquire only bond region of the body as in the case of the body scanner developed by Levi's [8] in which only the inferior region of the body is considered.

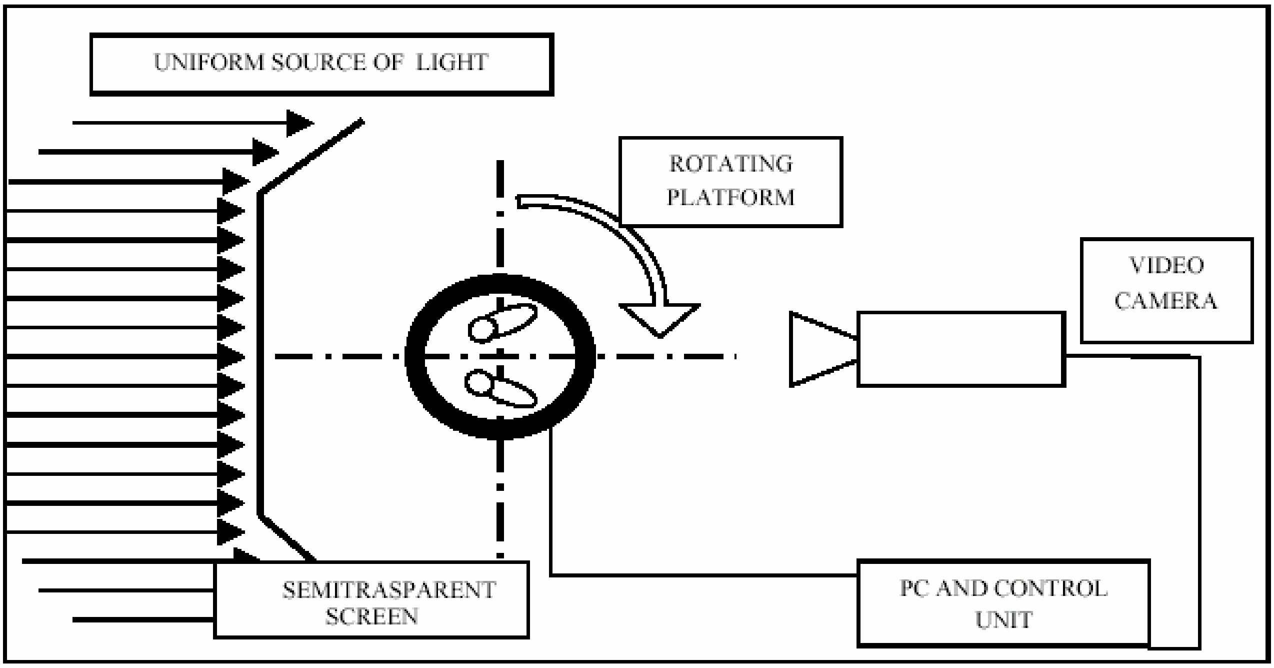

Fig. 2. Scanfit.hardware set up, top view.

3. SCANFIT®, A LOW-COST APPARATUS TAILORED FOR GARMENT INDUSTRY

In order to minimize cost and complexity of a body scanner a promising technique is making use of common photographic equipment; this is surely less invasive and harmful of the other techniques and the hardware costs are negligible.
Here a brief description of a body scanner design for garment construction is presented. This device tries to overcome the disadvantages described before. The main lines followed for its development are obviously simple structure and low cost technique for acquiring, dedicated and easy to use driving software, portability end ease of installation.

SEMITRASPARENT
SCREEN
VIDEO
CAMERA
ROTATING
PLATFORM
UNIFORM SOURCE OF LIGHT
PC AND CONTROL
UNIT

3.1 Hardware description

The acquiring technique selected is photographic analysis, which is the cheapest and not harmful available; a simple traditional or digital camera can be used collecting a wide range

of images of the subject. No peculiar lamps or other specific devices are needed, and a set of commonly used lamps is used to light up the figure, from the back of the subject, through a semitransparent screen in order to have a uniform distribution of the luminosity.
The system is integrated with an easy to disassemble and transport cabinet so it can get ready everywhere.
Fig. 2 shows a scheme of the components of this innovative scanning system.
The position of acquiring device is fix and the movement is transferred to the subject.
The acquisition device is a single camera interfaced with a PC for its high velocity of acquisition and for the convenience of analysis. The area of scanning covers nearly the entire body leaving out only the lower part corresponding from half of tibia to the feet: using a wider angle lens would introduce an excessive distortion of the image, while raising the distance between the camera and the subject would compromise the quite small size of the overall system (actually it is contained in a 1.2×2.5 m^2 area).
The subject is positioned on a rotating platform: this platform turns along what would be the axis of the subject. Behind the subject and the rotating platform a diffuser screen of light is disposed so the contrast of the shadow of the body on these screen reveals the shape of the profile of the body to the camera. During the revolution the images of the figure profiles are captured by the camera so to have in a short time (a revolution lasts about 15s) a wide range of profiles (about 120).
The subject wearing only underwear is positioned on the platform: the feet position is defined by a reference relief, while a couple of bars helps maintaining the correct posture of arms; the posture (Fig. 4, left) has been defined so to guarantee maximum visibility of the chest, sufficiently undeformed shoulders, repeatability of subject positioning and a mean to contrast the inertia during the platform revolution. Furthermore, the assistant to the acquisition can see the actual shape of figure and correct the position of the subject inviting him to correct the posture.
The rotating platform is interfaced with a PC that provides to synchronize its angular position with the acquired image. All the images are recorded on the PC and can be visualized and analysed in post processing.

3.2 Body measures estimation
The real core of the system is the software which analyses the images, estimates the body measures and identifies the subject conformation according to CAD Modelling TM knowhow (the flow chart is shown in Fig. 3).
The first step consists in pre-processing the acquired images, converting them in a monochromatic format; in order to limit the noise introduced by reflections on the body skin or "light" areas due to white underwear, the threshold to set an image pixel to white has been raised up to 80% (the back light is more than sufficiently clear to be set white as well).

ACQUISITION
IDENTIFICATION OF THE
SUBJECT CONFORMATION
IMAGE PREPROCESSING
FRONTAL AND LATERAL
FRAMES
FRAMES
COMBINATION
GIRTHS AND DIMENSION
ESTIMATION

CHARACTERISTIC
HEIGHTS IDENTIFICATION
IMAGE

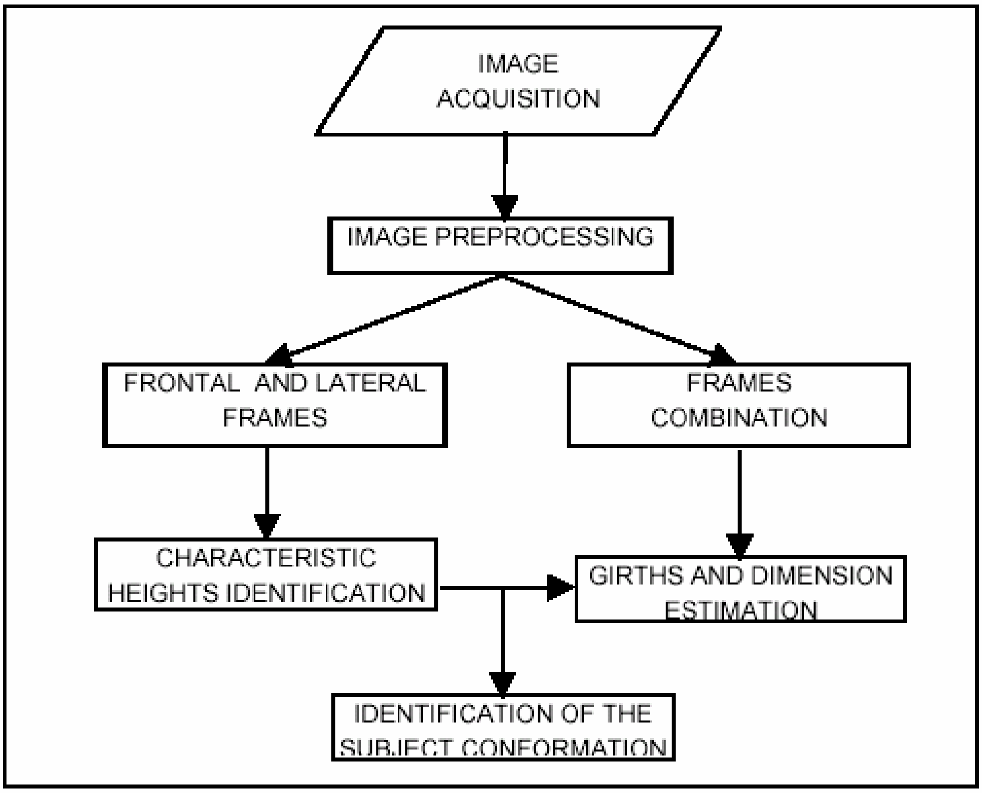

Fig. 3.Flow chart of logic processing to achieve characteristic measures of body.

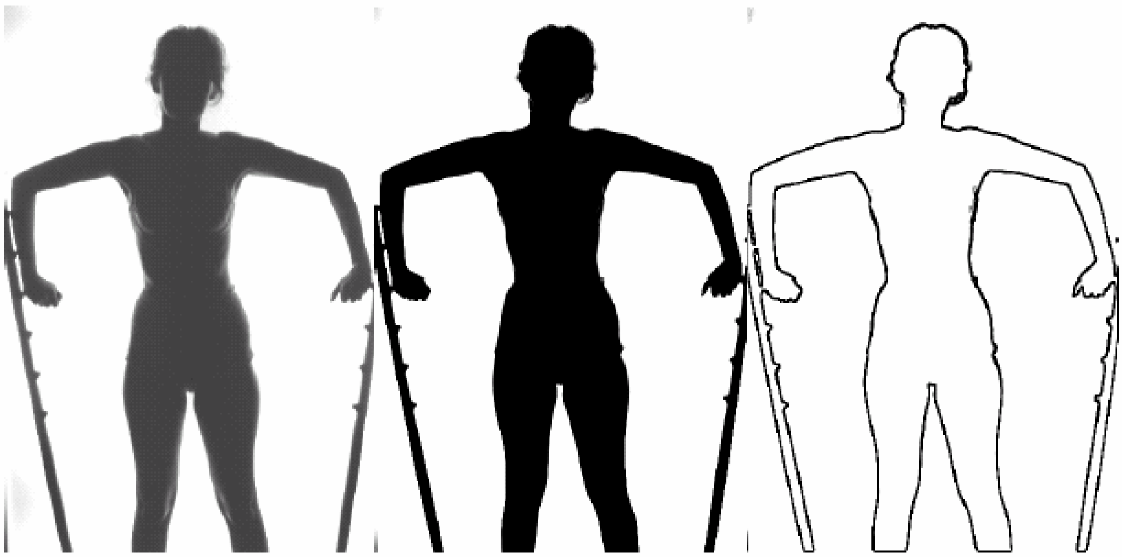

Fig. 4. An example of image captured by the system (left), its conversion in a monochromatic image (center) and contour extraction (right).

The black and white images are then processed to obtain the contour of the profile; in Fig. 4, the whole process is shown for the frontal image.
Among all the images recorded, the frames corresponding to frontal and lateral views are selected; by the analysis of these frames the software identifies the heights corresponding to the neck, shoulders, armpits, chest, waist, hip and all the relevant points for garment definition (*marks* in the following). To locate these points the software is leaded by mathematical considerations about the curves that describe the profiles. For example, the height of hip is determined where the tangent to the curve that describes the back profile of a lateral view is vertical; again in the lateral view, the waist is located at mid way between the upper vertical tangent and the inflexion point of the back profile (Fig. 5). The last rule is resulted as the best compromise to identify the waist for any kind of human conformation (from extremely slim to extremely fat). Since the contour extraction algorithm introduces a sort of "roughness" on the profiles, before performing each *mark* identification the best fitting polynomial (usually a third order) is evaluated in the range where such a point is expected to be, as a function of the subject height that is the first parameter estimated.

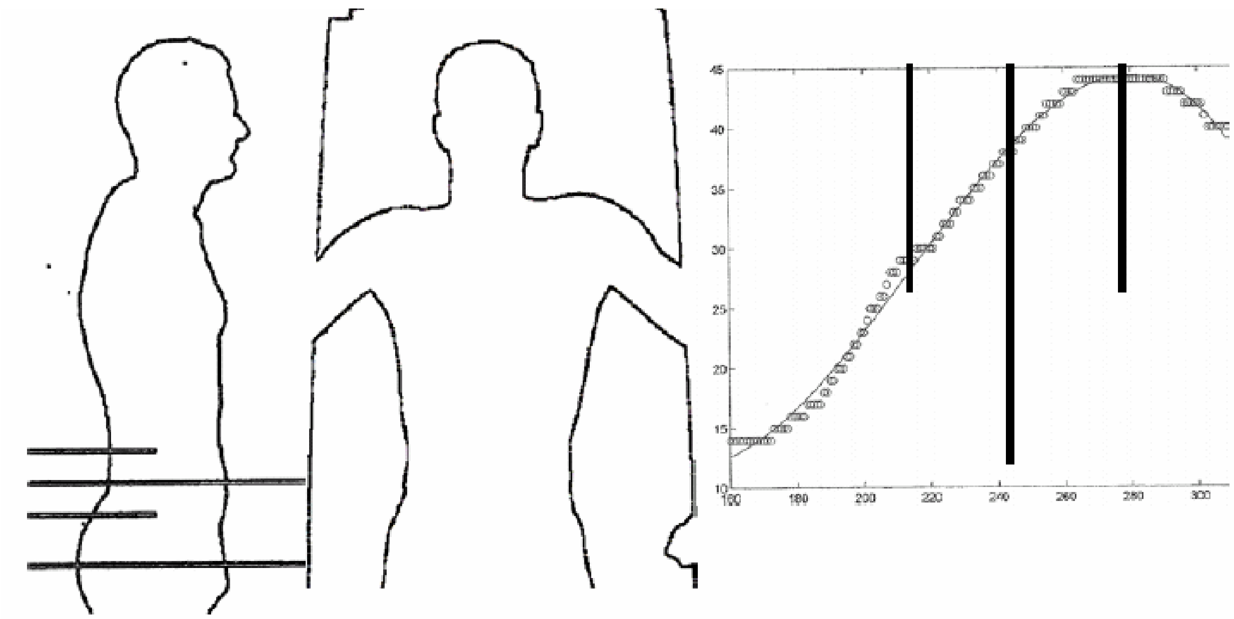

Fig. 5. The relevant points (*marks*) from a garment construction point of view, are located by the analysis of the lateral and frontal profiles of the subject (left and center). The contour of the raster image is converted in third order polynomials to identify the marks.

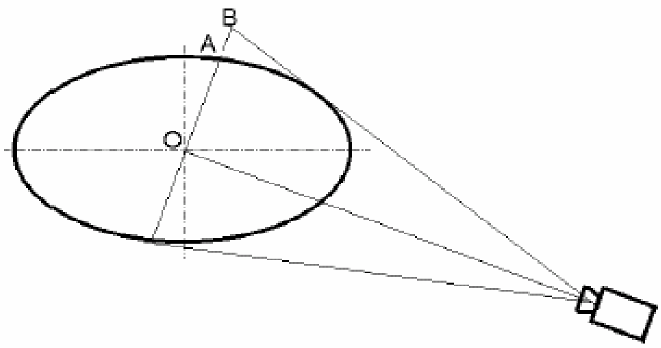

Fig. 6. Horizontal section view of the acquisition of an elliptical cylinder: the point A, intersection between the cylinder section and the plane normal to the camera axis, is hidden; the "apparent" contour B would lead to an unacceptable overestimation of the girth length.

Further details about this algorithm will be illustrated in a next publication since some improvements respect to the existing system have been defined and an updated Scanfit® is patent pending.

Once those *marks* are identified a comprehensive set of body dimensions are evaluated, according to the ISO standard [9]: neck girth, shoulder length, shoulder width, chest/breast girths, waist girth, hip girth, arm length, outside leg length, waist, hip, crotch heights. All the measures like the crotch height, shoulder width etc. are estimated by following the relative profile on the frontal frame between the corresponding *marks*.

Some further considerations are necessary for girths evaluation. These are obtained by combining the information contained in all the acquired frames. As shown in Fig. 6, it is wrong reconstructing a horizontal section of the body by attributing to the plane normal to the camera the width defined by the image contour, for any angular position; this would be true only for a circular cylinder, since also for an elliptical one the intersection between the plane normal to the view straight line, passing through the revolution axis, can be hidden by the rest of the profile.

Hence a more suitable technique has been adopted: for any body profile, the width of the contour at a given height is evaluated and two parallel straight lines are drafted on a horizontal plane, so that the distance between them is given by the evaluated width and the angle is given by the image angular position. The envelope obtained by combining all these segments defines a closed polygon that is an accurate reconstruction of the girth. This technique obviously should be valid only for convex sections of the body, but from a garment construction point of view this is not a problem, since clothes envelope the body (in fact, also the aforementioned standard [9] prescribes to take the body measures by using a tape measure with which the body is enveloped).

Eventually, the identification of the subject conformation is performed, comparing the set of extracted body measures with the proprietary CAD Modelling TM database. The conformation identification number (*base x*), combined with the height of the subject is sufficient to define quite accurately how to build a made-to-measure cloth; inversely, a garment producer equipped with the corresponding FORMAX® mannequin, can guarantee an accurate fitting of its products for all his *base x* customers, since any prototype sample can be tested on a realistic model of that population type.

3.3 Test results

The proposed system has been tested with subjects belonging to any conformation, obtaining satisfactory results: the maximum error found is minor than ±10 mm for any body measure, but for the very main percentage of people, i.e. those belonging to the more common conformation shapes, the measurement errors are contained in a much smaller range ±5 mm.

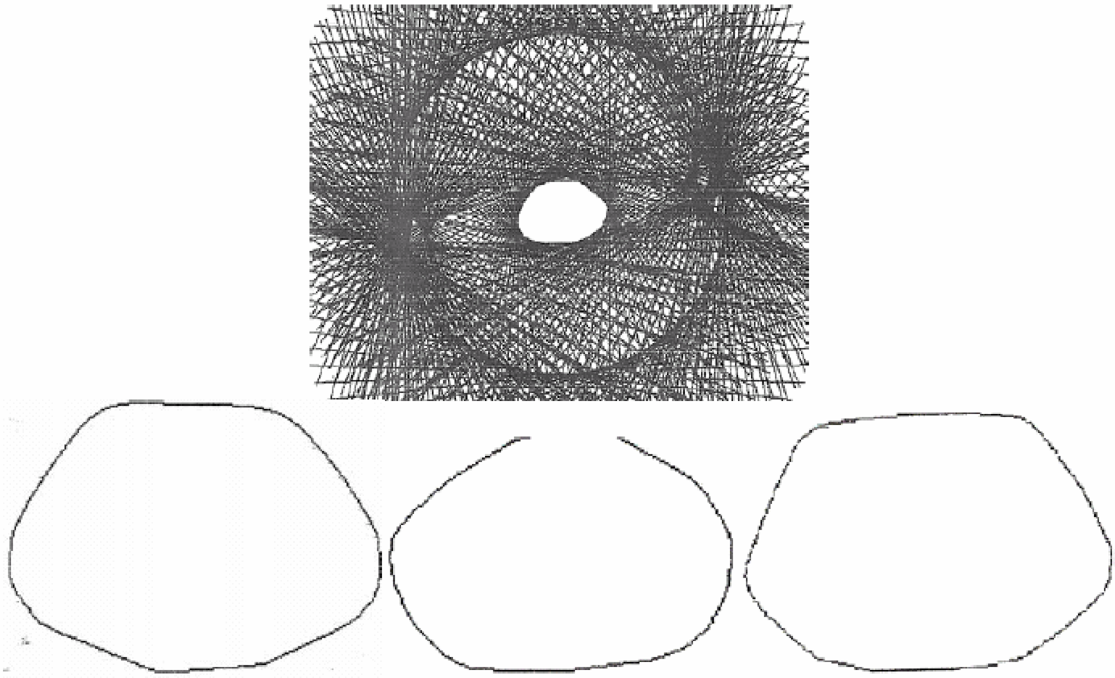

Fig. 7. Girths estimation as the envelope of the body contours widths calculated from each angular position (up). Some example of the reconstructed girths of chest (left), waist (center) and hip (right) of the same subject shown in Fig. 5.

4 CONCLUSIONS

Several sophisticated body scanners have been proposed in the last five years for the garment producers, but their success on the market is limited to the biggest companies due to their high cost and complexity. A low-cost apparatus and its driving software have been developed and presented in this paper. The main idea of the proposed approach is to combine a simple and low-cost hardware with the knowledge about body conformations contained in the proprietary databases of CAD Modelling TM.

The expenditure requests by such device are very limited, hence also small and medium companies can be encouraged to introduce this system in their activity. Also the engagement of the customer to be scanned is limited, so that its diffusion in garment shops can be promoted.

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