3D MEASURING OF HUMAN BODY BY ROBOTS

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Abstract

The visual robot developed by the authors not only measures human sizes in garment trade and is a tool for quality control in manufacturing, but it is also useful for other special fields such as intelligent assembly, recycling and environment protection.

The article is about the integrated application of methods, equipments for 3D measuring of human body.

We have elaborated the optical equipments and robot controlling, and have created informatical connection between them. After a gentle tuning the device is applicable for measuring processes and quality control in garment trade.

The surface of the human body is modelled by 3D interpolation. A 3D optical scanner defines body base points. We have developed a measuring cabin. Laser beam lights fixed to the moving frame scan body surfaces. Cameras attached to the frame make photos of laser lit surfaces and send them to the server machine that processes the pictures and defines the surface points of Bezier patches on the human body. In order to build the system we have designed the number and positions of camera settings, control systems, data communication strategies and methods to calculate position points.

Due to complexity and concave cambers alternative methods are necessary too. There is a distance measurer 6D robot working with the cabin. Robot positions are programmed and the body coordinates are sent to the server machine in order to complete the surface data.

We have designed and developed adjustment of human body, trajectory of robot frame, robot control systems, a communication protocol, measuring parameters and calculation methods of 3D positions.

Key words: *visual robot system, 3D human body modelling, 3D measuring of human body, adaptive robot control, garment trade*

1. INTRODUCTION

For 3D dress design process the human body needs to be precisely modelled. . Sylvie system developed at Budapest University of Technology and Economics uses a feature based body model [1]. We have developed an integrated robot-scanner equipment for more accurate definition of geometry of garments. This presentation is about the background of the measuring process.

2. STRUCTURE OF THE EQUIPMENT

We use two cooperating computer controlled equipments (a cubicle and a robot) for measuring the surface geometry of the human body. There is a computer controlled moving frame in cubicle. Line lasers installed on the frame scan along the body while cameras rigged on the frame store pictures of the illuminated body surface. The stored pictures are sent to the controlling computer. The machine processes pictures and defines the points of the body surface. There is a 6D robot equipped by a camera and a laser distance-meter measuring the hidden places for the frame (fig.1).

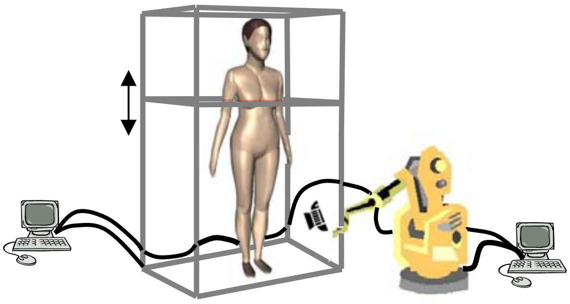

Fig. 1 The cubicle and the robot

Frame is programmed on serial port, the robot is controlled by KRL programming language by KUKA [2]. We have developed controlling programs by Borland Delphi [3], Alkenius' CamRemote components [4] are used to program the Canon firmware [5]. Stabila distance measurer [6] is connected to serial port. Serial communication serves for data and command communication, too. Robot and frame control computers of are connected to each other.

MEASURING BY CUBICLE

As we want to achieve necessary accuracy for garment trade, we had to calibrate photos of parallel cameras, in order to develop measuring methods as well as to analyze errors.

3.1 Iterative calibration

The task of the frame is the definition of the points on a two-dimensional curve based on photos. Points of the curve are defined by picture processing methods. The question is only how to define the 3D position of points upon the photo. In order to find the non-linear bijection between the photo and the 3D plane, we used an iterative calibration.

Take a photo of a square by defined dimensions. Corners of the square are *A*, *B*, *C* and *D* in order (Fig.2). Let the origin of *x*-*y* planar coordinate-system *O* be the centre of the square (intersection of diagonals)! The question is how to define ζ and η coordinates an optional *P* point.

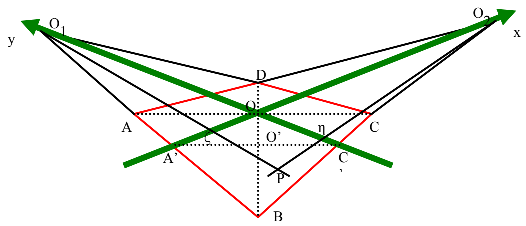

Fig. 2 Geometry of the iterative calibration

As the projective mapping *AB* and *CD* parallel lines are crossing at O_1 point, *AD* and *BC* lines are crossing in O_2 point. *X*-axis of the coordinate system with *O* origin goes through O_2 like the y axis goes through the O_1 point. Accordingly the image of x-axis is the OO_2 line and the image of y-axis is the OO_1 line.

Image of the coordinate line of P point parallel by the y-axis goes through P and O_1 like image of x-coordinate line goes through P and O_2. They cross the axes at ζ and η. Due to the nonlinear mapping with unknown parameters there is no direct formula.

The real 3D and the photo positions of *A*, *B*, *C*, *D* points and *O* origin are known. Coordinate axes divide the square up to four quadrants.

One of them contains the P point. Corners of the quadrants are known, for example x-coordinate of C' is 0 and y-coordinate is the same as the y coordinate of known B point, analogous y coordinate of A' is 0, and x-coordinate is the same as the x-coordinate of known A point.

At first sight we are not closer to the solution, but the size of the side of the $A'BC'O$ square is the half of what it was in case of $ABCD$ square. We can estimate coordinates of P point better (ζ coordinate is between A' and O and η coordinate is between O and C').

O' origin of the new $A'BC'O$ square can be defined by the intersection of $A'C'$ and OB diagonals. By the O' origin we can divide $A'BC'O$ square up four quadrant again. One of them contains the P point giving a better estimation.

We can go on dividing squares. It is all the same which quadrant contains the P point. The special situation above is used only because of the figure.

By refining the subdivison better and better estimation can be taken about the original ζ and η coordinates. The photo resolution is the only limit.

Position of every P point can be defined by help of A, B, C and D calibrating points. The iteration is easy to program. It is a quick coordinate defining algorithm.

3.2 Common calibration of more views

There are four cameras installed on the frame. Four cameras take pictures of a calibrating square from different directions. (Fig. 3) Definition of coordinate directions on four pictures is needed for common handling of the pictures.

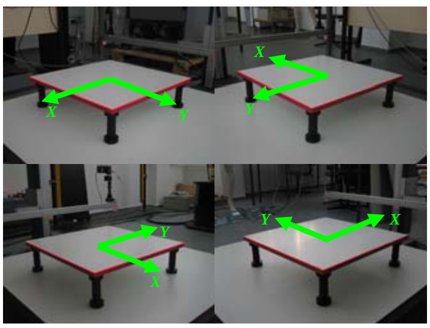

Fig. 3 Calibrating pictures of four cameras

We have to find corners of the calibrating square in the pictures. Edges close to the camera are defined by filtration of red color (on right side of the fig. 4). Farther edges are defined by edge detection based on the gradient of brightness (on left side of the fig. 4). [7]

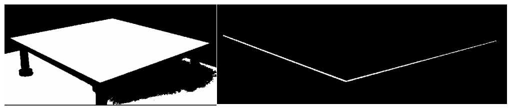

Fig. 4 Calibrating edges by picture processing

Our aim is not only to define the points of the edges, but also to define the corner points. If corners are known, they are useable in the the iterative calibration in coordinate systems of the fig. 3.

Determination of corner coordinates starts at the corner closest to the camera. If we define the point of the edge image in the coordinate system connected to the left-bottom corner of the photo then regression lines can be defined for every x_s on section $x<x_s$ and $x>x_s$. Let the error of the regression H is a function of x_s! In other words $H(x_s)$ is the sum of the differences of y_i point coordinates and the $a*x_i+b$ lines [8] with unknown parameters (x_i are point coordinates) in front of the corner and behind the corner (1).

$$H(x_s) = \sum_{x_i<x_s} (y_i - (a_{x<x_s} * x_i + b_{x<x_s}))^2 + \sum_{x_i>x_s} (y_i - (a_{x>x_s} * x_i + b_{x>x_s}))^2 \qquad (1)$$

Minimum of $H(x)$ will be at the real position of the corner at x^*. Substituted back on $x<x_s$, or $x>x_s$ section y^* will will be identifiable (fig 5.).

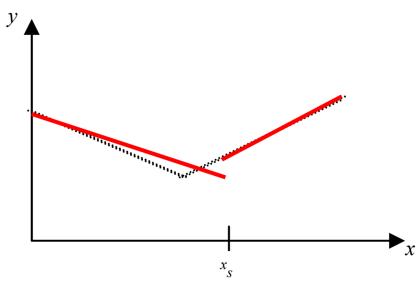

Fig. 5 Corner point definition

Coordinates farthest away from the camera can be counted similarly. The only difference is that regression lines should be searched on the edges of the square.
Corner points on the left and right sides are derived as the intersections of the defined regression lines.
Fig 6. shows the defined regression lines and corners on calibrating square.

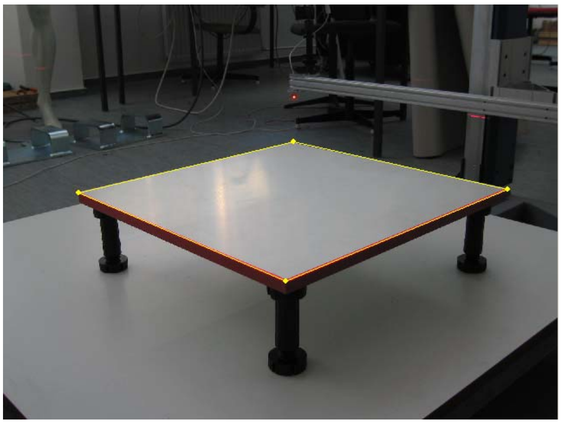

Fig. 6 Quadrangle of the calibration

3.3 Determination of laser lighted cross section point positions

Points of body surface lit by laser beams are stored on camera shots. Coordinates of lit points are derived from the calibrating points and the altitude of the frame (fig. 7).

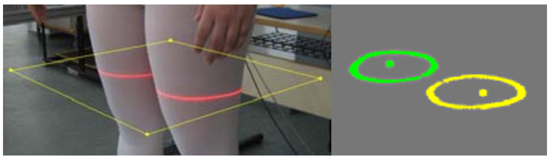

Fig. 7 One shot and the reconstructed point set from four side shot

Width of the lit surface curves is 6-8 pixels by applied (1600x1200) resolution as it is shown in the strongly enlarged picture of fig 8.

Fig. 8 Enlarged lit curve

Points should be defined by picture processing methods, but the result will be better, if regressed curves are searched. Surface curves on body parts are approached by Fourier series [8]. The angles as the independent variable of the curves are determined from the centre of gravity of point set and the position of points on actual level.
Approximating function (R) is the distance from centre of gravity as the function of the angle from x-axis (φ). Only the first $2*n+1$ members of Fourier series are considered where the n is defined differently on different body parts.

$$R(\varphi)=\frac{1}{2}a_0+\sum_{i=1}^{n}a_i\cos(i\varphi)+\sum_{i=1}^{n}b_i\sin(i\varphi) \qquad (2)$$

Unknown Fourier coefficients are determined by least square method. If there are N points on the actual level where the distance and the angle of k-the point is (R_k,φ_k), then a_i, b_i coefficients are defined by the minimum of (3).

$$\sum_{k=1}^{N}\left\{R_k-\left[\frac{1}{2}a_0+\sum_{i=1}^{n}a_i\cos(i\varphi_k)+\sum_{i=1}^{n}b_i\sin(i\varphi_k)\right]\right\}^2=\min \qquad (3)$$

In order to find the minimum, a system of linear equations should be solved.

3.4 Precision analysis

In order to analyse precision, a cylinder with of 102 mm diameter is taken to different positions of the equipment (fig. 9).

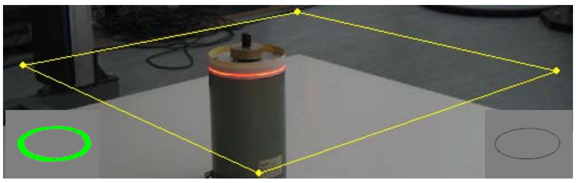

Fig. 9 Calibrating cylinder, points and approximation

Fig. 10 shows the difference between the nominal and measured diameters as the function of the central angle at a single position of the equipment.
Fig 11 shows the diameter error of measuring as a function distance from the centre of the equipment.

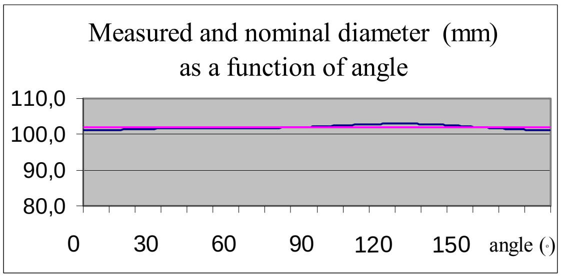

Fig. 10 Measured and nominal diameters

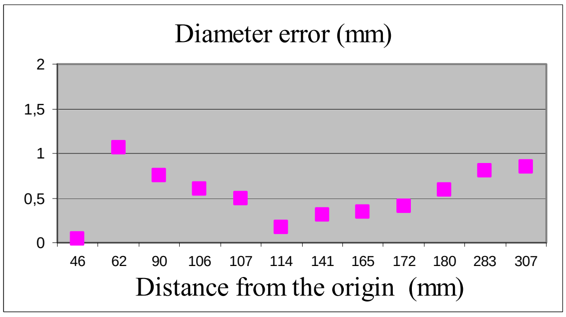

Fig. 11 Diameter error

Controls show that the absolute error is under 1 mm. It satisfies every demand of apparel industry.

3. MEASURING BY ROBOT

There are hidden parts of the body from cubicle for example armpits, groin. Kuka robot is equipped by a Stabila (TOF – Time Of Flight) equipment [6] and controlled to measure coordinates of points shown in fig 12.

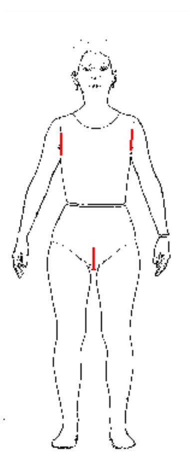

Fig. 12 Robot measured body points

Precision of Stabila is 1 mm satisfies every demand of apparel industry too.

4. APPLICATION

Measured 3D points are used to define the body model. Similarly to the parameterised model [1] body surface sectioned measuring features (Leg, trunk arm, shoulder, neck, head fig. 13). Surface of features interpolated NURBS. Vertexes of surfaces are defined by the measured points.

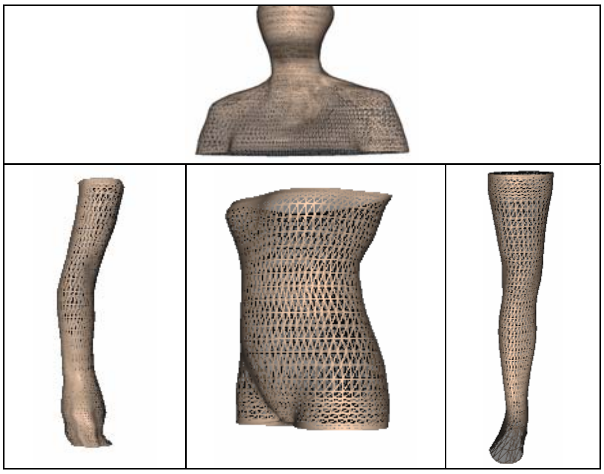

Fig. 13 Body part features

Positions of vertexes of features and surfaces (fig 14. b.) are determined from curves approximating point cloud (fig 14. a.).

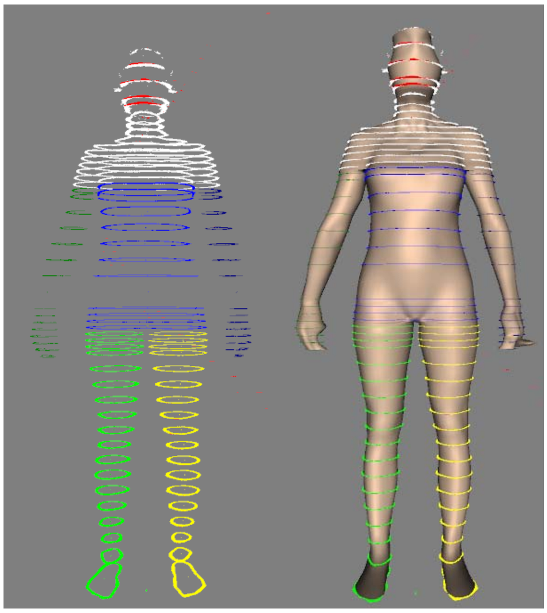

Fig. 14 Measured body model

The presented measuring equipment is useful not only in garment trade but in medical fields, too.

5. ACKNOWLEDGEMENTS

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