BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

FACULTY OF MECHANICAL ENGINEERING

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INDUSTRIAL PRODUCT DESIGN ENGINEER

IN THE FIELD OF

IMAGE BASED MEASURING TECHNIQUES FOR APPAREL INDUSTRY

WITH THE PURPOSE OF BEING AWARDED THE PHD DEGREE

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The evaluation of the thesis and the minutes of the defense are available in the Dean's Office of the Mechanical Engineering Faculty of the Budapest University of Technology and Economics

1. Introduction, research background

Technical textile, intelligent clothing, virtual garment fitting and several similar phrases characterize the textile industrial developments of the 21st century. More and more textile industrial companies are obliged to give up their former product range and to start to develop new products and services based on new, latent demands so that it can survive even in the strong price decreasing competition against the continuously increasing volume of cheap clothes coming from the East in an improving quality. The EU has already recognized the bad market position of the European textile factories, and established a new defense strategy that slows down the inflow of eastern goods, however it cannot stop it. On the other hand, it provides significant research funds for the development of new products and new services that help the survival of companies. One of the most significant research directions is the ‘virtual fashion store’ topic that is supported in the framework of the E-TAILOR and the LEAPFROG programs by the EU.

An important element of the virtual fashion store is the static and dynamic illustration of garment behavior. The user can ‘fit on’ the garments found in the catalogue with the help of the computer body model, or can check the correctness of the dress pattern without really sewing the planar parts of the clothes together. Of course, the body dimensions of the user and the textile properties are needed for the virtual representation. Accordantly, all over the world intensive research is carried out into the development of body scanners and modeling of textile behavior and determination of properties necessary for that. More and more scanning image formation methods appear on the market with the help of which the sizes of 3 dimensional bodies can be measured with high accuracy.

However, the determination of properties necessary for modeling the human body is not a simple task. It is difficult due to the complexity of the human body and owing to the fact that the measurement should be carried out on a living subject whose body surface continuously changes with time and space – as opposed to conventional technical materials. The several founded but soon ceased companies and their developed products all prove that the direction of development is already known, while the final aim is not reached by research and development yet. For example the utilization of the points generated by the scanning machine, the 3D scanner is still a problem due to the large amount of data.

Modeling the textile behavior and determination of material properties necessary for that are made difficult by the properties of the textile itself. The rheological behavior of textiles significantly differs from that of other sheet-like structural materials. However, exactly this characteristic textile behavior is the reason for the pleasant wearability of textiles, its nice draping and capability to take the curve of spatial shapes. Several modeling programs have already been issued but none of them fulfills completely all the requirements posed on the simulation.

Computer aided apparel industrial design systems have been being developed at the Polymer Engineering Department and at the Department of Mechatronics, Optics and Information Engineering at the Budapest University of Technology and Economics since 1983. Related to this field, my research work involved the development of measurement techniques necessary for the 3D garment design system.

2. Aims

Literature deals extensively with body scanners, which are measurement devices used for the 3D reading of the human body mainly for the apparel industrial purposes. More literature sources compared the products available in the market, and based on that the conclusion that the most widespread technical solution in case of body scanners is the use of light and within that reading with a laser line can be drawn.

Although the available body scanners enter the market after several years of development work, they still can be unsuccessful if they do not provide a solution for the processing of the huge amount of data read by the scanner. The rapid development of computers, and the rocketing increase in the capacity and speed of processors and backing storage are still not enough for the processing of the huge amount of bulk data read by the scanner. Data processing is still a complicated field under development.

In order to be able to stay in competition the developers should utilize the special opportunities of the application field. The amount of data read can be reduced due to the lower accuracy requirements of apparel industrial scanners. The accuracy of scanning in the apparel industry is acceptable with ±5 mm measurement error based on literature and empirical data.

A good method to reduce the amount data is weighing, meaning that sampling is done less frequently on less complicated areas, while more densely on more complicated, more important places. Another advantageous solution is parametric modeling, in case of which characteristic body shape categories are formed based on the accurately digitalized shape, then after the measurement of a few data in the series measurements the adequate body type is selected, and the spatial model that describes the figure of the measured person well is created through modifying the parameters.

Although more line laser based body scanners are available in the market, literature deals with research into the application fields and not the structure of the scanners. The design process and operation principle of these devices are held strictly as a secret due to the great competition. I have drawn the conclusion from the dimensions and constructional arrangement of commercially available devices that if the structure of the scanners is designed based on scientific examinations, their applicability and accuracy can be improved significantly.

The applied image processing methods and calibration techniques are also secret as the above mentioned design process. Literature in this field can mostly be found only in professional books, and there these topics are only detailed theoretically. The task of image processing is to gain the most information from the images taken during digitalization necessary for us with special methods (brightness, contrast adjustment, application of color and other filters etc.). A further task in case of laser line based scanners is to determine the geometrical transformation that gives back the adequate contour of the given surface based on the light line recorded in the image with the help of the digital image and calibration. In case of nowadays available body scanners the literature does not deal with the method of image processing and transformation, and do not detail the calibration methods important for the accuracy of the scanner.

Other usual application areas of scanners capable of the digital measurement of human body dimensions are anthropometry, ergonomics and medical technology besides apparel industry. Draping is an important fabric characteristic, hence its examination and research is crucial for virtual apparel design and modeling, dimensioning light constructed roofs, composite vehicle production and in several other fields. According to the literature, draping is measured with the measurement devices prepared for this purpose, with fixed table and fabric size. If only apparel industry is taken into consideration, much larger size fabrics are used than the size than can be measured with a conventional measurement device. Hence mainly in other fields, such as technical textiles (canopies or the reinforcing fabric in composites) body scanner still has some unexploited potentials.

I have set the following points as the aims of my PhD dissertation after a detailed overview and processing of literature:

1. Development of the experimental model of an open apparel industrial measuring system based on image formation and digital image processing.
2. Development of image processing and calibration methods for the measurement system.
3. Determination of operation parameters that fulfill the requirement system of the measuring device based on scientific research
4. Proving the applicability of the measuring system for studying the size dependency of fabric draping.

3. Applied measurement principle and the etalons used

Fig. 1 illustrates the relative spatial position of the measuring device and the measured surface. During the measurement, the line laser diode in plane Y-Z projects a horizontal (parallel with plane X-Y) red light line on the examined surface in front of the vertical base plane (plane X-Z), while the CCD camera also in plane Y-Z makes a picture of the enlightened area from a position higher than the diode. The light line provides a distorted – to an extent depending on the geometrical arrangement – image of the planar section of the surface viewed from the camera position. If the relative position of the base plane, the camera, the diode and the examined surface is known, the spatial geometrical data of the planar section appointed with the laser line of the surface can be determined (Fig. 1).

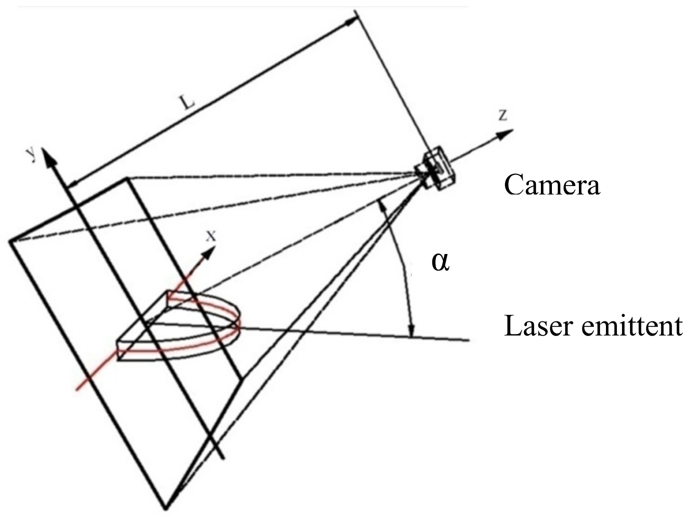
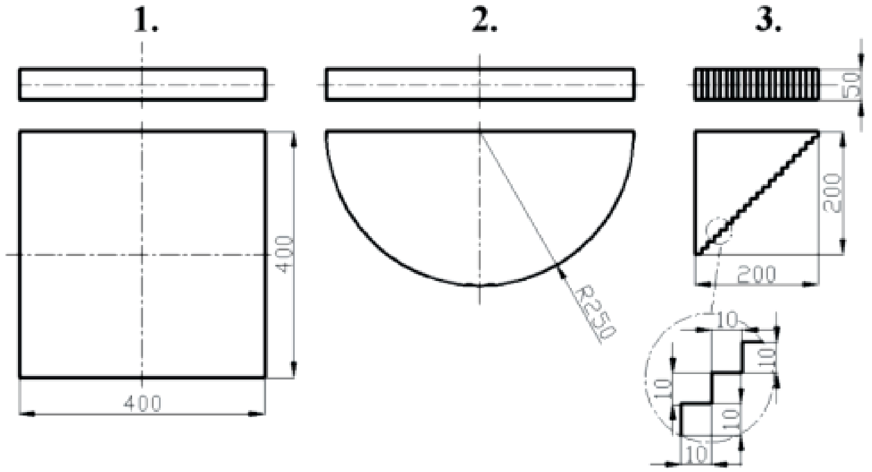


Fig.1 Measurement principle

The measuring device designed and built using the principle mentioned above is an experimental model that has one optical unit. The person to be examined can be measured only from one side at a time, but this was already enough for carrying out my planned experiments. The Sylvie 3D Body Scanner and the Sylvie 3D Drape Tester equipped with four optical units was built based on the experience gained with this experimental measuring device, and I have participated in this project actively in the research group of BME.

3 special etalon prisms were used for the measurements (Fig. 2). In case of designing and dimensioning the prisms, the average peripheral dimensions of the human body were considered. The three prisms were produced on a CNC milling machine. The return error of the machine is max. ± 0.05 mm, hence the accuracy of the etalons produced with this machine is at least one order of magnitude higher than that of the examined measuring device. (The error of the measuring device can be max. ± 5 mm.) The material of the prisms is Sika Block M450 type artificial wood, especially applied in CNC operations.



Square etalon Semi-circular etalon Step etalon

Fig.2 Square and step-shaped calibration prism (1., 3.), and semi-circular control prism (2.)

The semi-circular etalon was used as the object of known shape and geometry in the comparative measurements since the main application field of the scanner is reading the surface of the human body and although the human body is not a perfect cylinder at any place but can be approximated with this shape the best. The square and step etalons were used as the calibration for my measurements.

4. New scientific results – theses [1-6]

THESIS 1: I have designed and built an experimental surface reading measuring device (Fig. 3) for apparel industrial purpose, with the help of which the main parameters, namely position determining coordinates, camera settings, distance and tilt angle as well as the image processing method could be studied independently. The prototype of the Sylvie 3D Body Scanner was prepared based on these results.

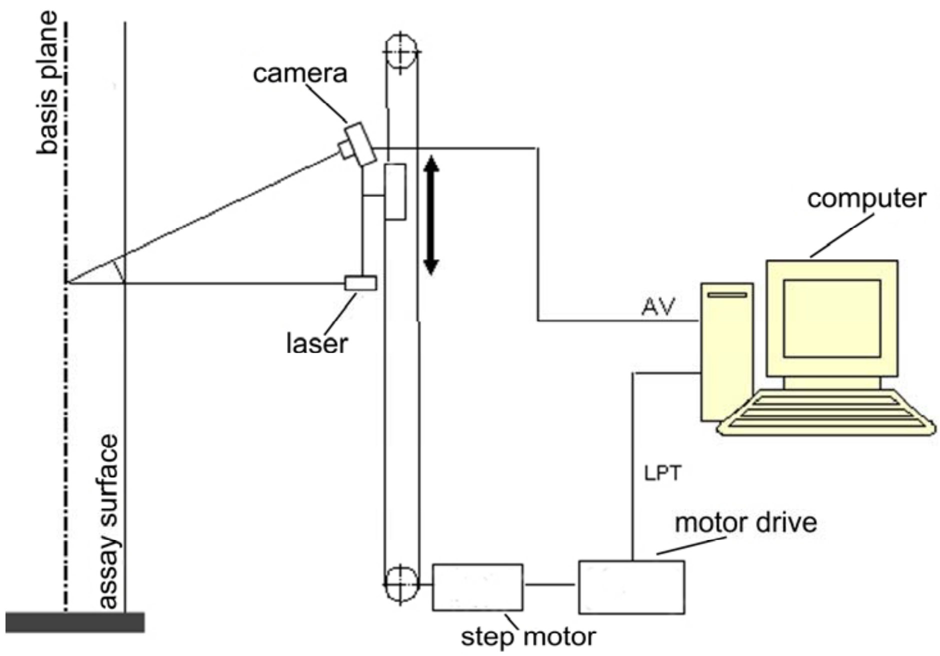


Fig. 3 Main units of the experimental device

Publications related to this thesis: [1], [2], [7], [8], [9]

THESIS 2: I have developed a central line searching method for the most accurate reading of the laser line considering the features of the images prepared with measuring device (Fig. 4). This way a faster image processing is made possible compared to the already known methods, and corresponds to the requirements of the apparel industry more. I have applied center line search in one point column from two directions with three different intersection point determining methods (Fig. 5) instead of the widespread matrix method. I have found that the best method for determining the center line of the laser band is the linear intersection point determining method, and I have proven this fact with measurements.

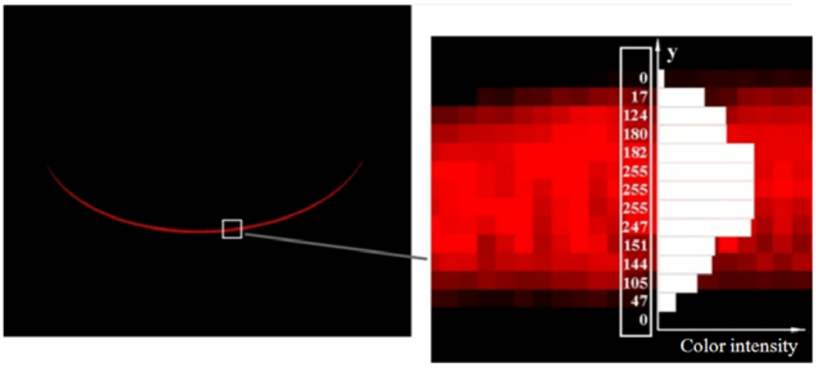


Fig. 4 Image taken with a camera and the base of processing

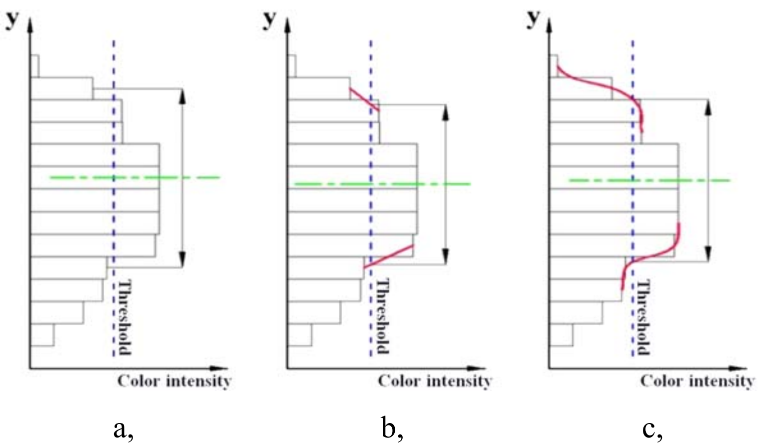


Fig. 5 The three different center line determining methods
(a, pixel based; b, linear interpolation based;
c, curve interpolation based)

Publications related to this thesis: [2], [3], [4]

THESIS 3: I have proven that in case of line laser scanners prepared for the apparel industry the most favorable value of the camera angle, i.e. the angle of the projection plane of the laser emittent and the optical axis of the camera is 30°. This is the camera angle at which the radius of the circle determined with regression from the points gained from the measurement of the semi-circular etalon is the nearest to the nominal radius of the semi-circular etalon, and also the relative deviation of the measurement points and the deviation calculated related to the radius of the circle determined with regression remains below the ±0.5 mm theoretical measurement error (Fig. 6). Furthermore, this is the setting at which vertical projection lapping is minimal, while the most data that can be evaluated are obtained from the measurement.

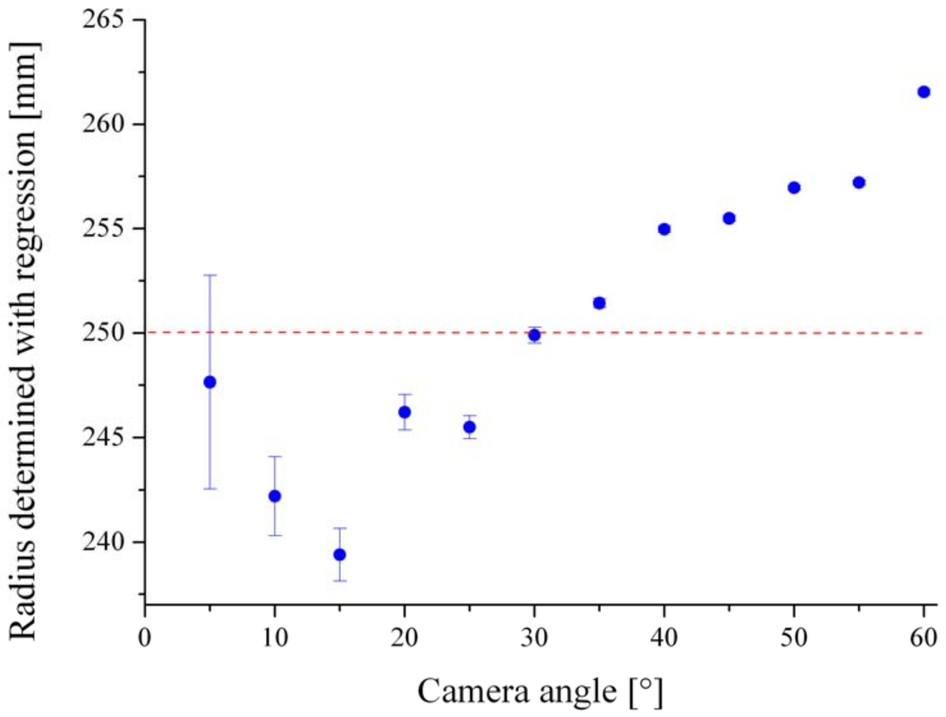


Fig. 6 Radius determined with regression and deviation as a function of camera angle (α)

Publication related to this thesis: [5]

THESIS 4: I have determined the theoretical relation between the distance of the camera of the measuring device from the base line (Fig. 1) and the projection lapping (T.1):

$$\varepsilon_{vt} = \frac{\Delta x}{a} * 100 = \left(\frac{1}{\sqrt{1-\frac{b^2}{L^2}}} - 1\right) * 100 \qquad \text{(T.1)}$$

where ε_{vt} is the projection lapping [%], Δx is the difference between the actual and projected maximal horizontal size [mm], a is the size of the longer semiaxis of the approaching ellipse while b is the size of the shorter semiaxis [mm], and L is the distance of the camera from the base line [mm]. I have compared the measurement results with the theoretical curve (Fig. 7) and have concluded that the average variance is δ_t=1.12% in the 600-1800 mm range of distance L. It can also be concluded that the camera should not be placed farther from the base line than the 1000 mm chosen by me since above this distance the decrease in projection lapping is not significant any more.

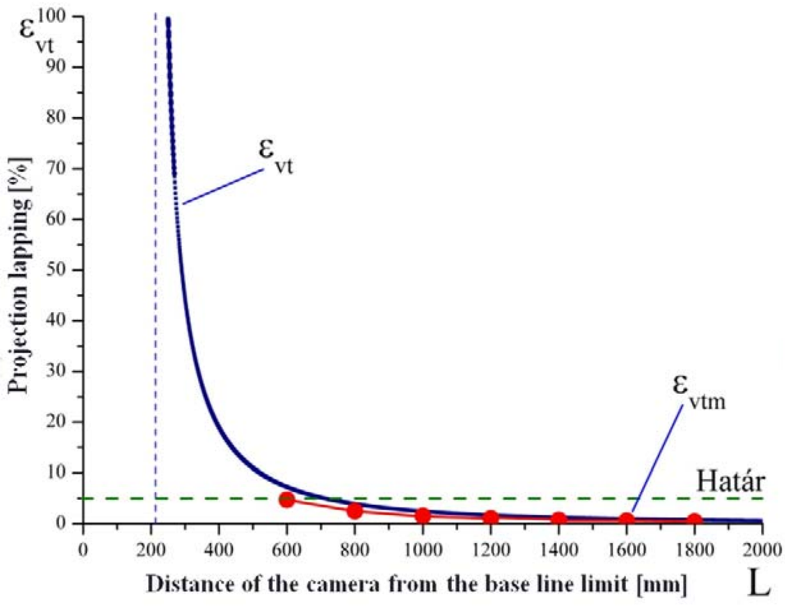


Fig. 7 Connection of the values obtained theoretically and with measurement

Publication related to this thesis: [5]

THESIS 5: I have examined four different calibration-transformation methods (Fig. 8) that describe the geometrical relation between the examined object and the image taken during scanning. I have worked out the analytical geometrical (method 1) and the identification method (method 4), while numerical geometrical (method 2) and iteration processes (method 3) were taken from the literature. I have shown that the iteration method is the best for the solution of this task, however the analytical and numerical geometrical methods also fulfill the requirements of the apparel industry.

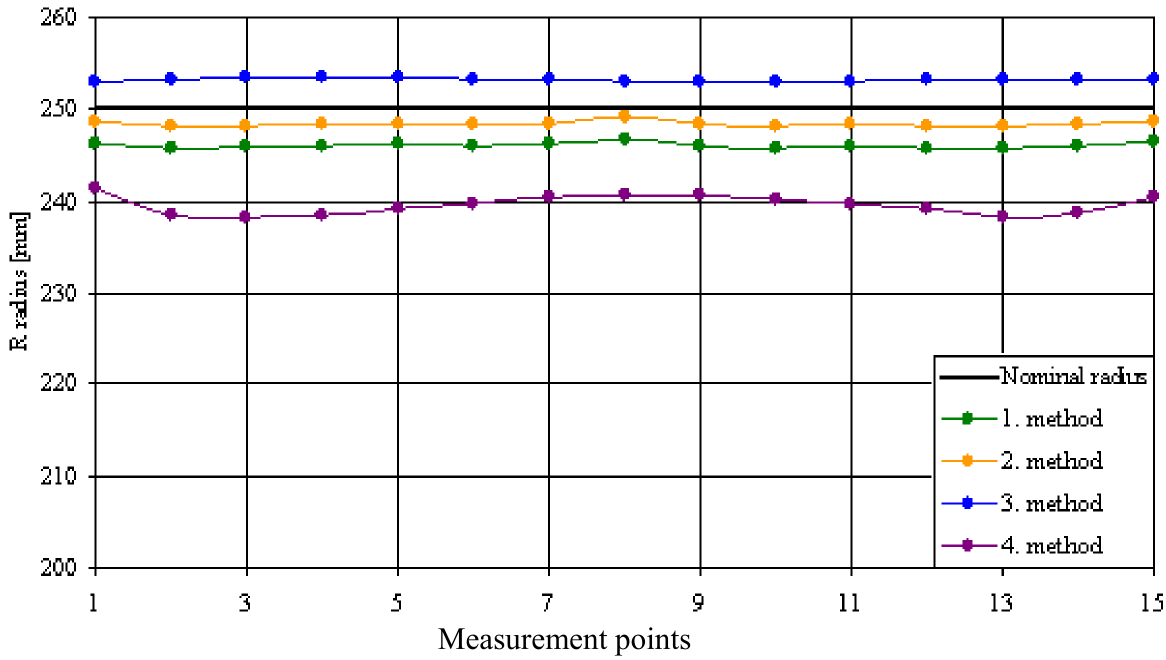


Fig.8. Comparison of values obtained with the 4 methods

Publication related to this thesis: [6]

THESIS 6: I have created a new examination method for the determination of the size dependency of the fabric draping coefficient by using the apparel industrial measurement devices manufactured based on my research results. I have proven that the drape coefficient decreases if the radius of the table and fabric sample increases (Fig. 9). I have concluded based on my measurements that this decrease can be approached with a function of third order, and above table radius 500 mm underhang occurs in all examined cases. The third order polynomial characteristic of the approximating function is valid for all examined apparel industrial (sample 1-3) and technical textiles (sample 4-6).

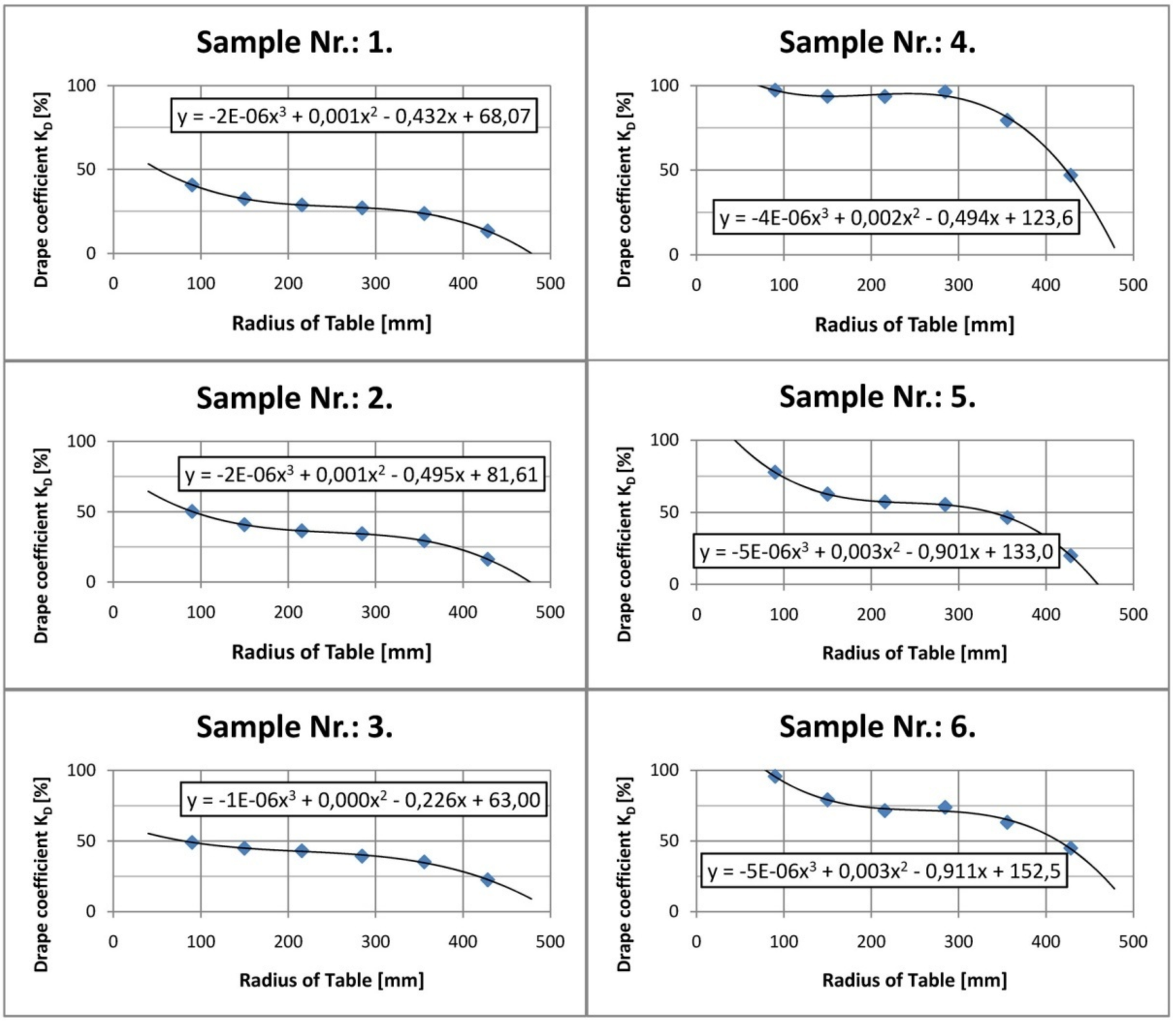


Fig. 9 Drape coefficients as a function of table radius for different fabrics

Publication related to this thesis: [9]

5. Summary, utilization of results

My dissertation deals with the development of apparel industrial measurement techniques based on computer aided image formation.

As a part of my work I have developed and built a surface reading measurement device and a test environment where the settings of all the units of the measurement device can be studied independently, and I have dealt with the adjustment of the objective and the examination of the properties of the image, camera angle and camera distance.

I have developed a new image processing method for processing the images taken during the measurements with the help of which the center line of the laser band can be determined at a sufficient speed with adequate accuracy.

I have applied four calibration transformation methods for the evaluation of measurement results out of which two were worked out by me. I have applied regression size and shape trueness evaluating methods with the help of which I have chosen the process that fulfills the requirements of the measuring device the best.

As a member of the research group at BME I have taken part in the construction of the measurement devices (Sylvie 3D Drape Tester and Sylvie 3D Body Scanner) with the help of which I studied the size dependency of fabric drape coefficients. The two devices operate on the same principle; hence I could provide the same environment for the measurements with different size tables. I have created a special table-fabric size series so that the examinations can be compared. I have used apparel industrial and technical fabrics for the experiment. The drape coefficient decreases with a function determined with measurements and is of the same characteristic in case of all examined fabrics.

The Sylvie 3D Drape Tester and Sylvie 3D Body Scanner built based on my results prove the practical applicability of my work.

6. Scientific publications related to the theses

[1] **Szabó L.**, Halász M.: Line-laser 3D surface scanning machine planning for the apparel industry. In 'Proceeding of GÉPÉSZET 2004, 4th conference on mechanical engineering, Budapest, Hungary, 490-494 (2004).

[2] **Szabó L.**, Halász M.: Automatic determination of body surface data. In 'Proceeding of AUTEX 2005, 5th World Textile Conference, Portorož, Slovenia', 715-720 (2005).

[3] **Szabó L.**, Halász M.: Sylvie® 3D Body Scanner képfeldolgozó eljárásának fejlesztése. (Development of the image processing method for the Sylvie® 3D Body Scanner.) Magyar Textiltechnika, 100-103 (2006).

[4] **Szabó L**., Halász M.: Development of the image post processing of a 3D human body scanner. In 'Proceeding of GÉPÉSZET 2006 conference, Budapest', P 6, CD (2006).

[5] Al-Gaadi B., **Szabó L.,** Halász M.: A Sylvie 3D Body Scanner beállítási paramétereinek vizsgálata. (Examination of the setting parameters of the Sylvie 3D Body Scanner.) Magyar Textiltechnika, *Publication in progress.*

[6] Al-Gaadi B., Halász M., **Szabó L**.: Comparison of calibration processes of a surface determining measurement system. In 'Proceeding of GÉPÉSZET 2008 conference, Budapest', P 12, CD (2008).

[7] Halász M., Tamás P., Gräff J., **Szabó L.**: Computer aided measuring of textile-mechanical parameters. Materials Science Forum, *Publication in progress.*

[8] Halász M., **Szabó L.**, Tamás P.: Determination of textile-mechanical properties using image processing and simulation. In 'Proceeding of 3rd International Technical Textile Congress, Istanbul, Turkey', 464-471 (2007).

[9] **Szabó L.**; Halász M.: Examination of the size dependence of drape coefficient in the Sylvie 3D System. Tekstil, Zagreb. *Publication in progress.*