The Use Of Statistical Methods In The Manufacture Of Clothing

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Abstract: - The aim of this study is to apply Elert's principles for the determination of body sizes based on the knowledge of height and body weight to the radius of a sphere of the same mass and density as a human. The problem is addressed through multidimensional data analysis which facilitates a specific method of predicting "the variables" based upon the inter-dependencies between them. Elert's System is the name of a general solution for the creation of sheer clothes designs which are created based on two body measurements of the customer. The independent variables in the experiment were further supplemented by a chest circumference and seat circumference. The experiment used a set of body dimensions from 1066 Czech women aged 18-60 years old measured in 1990. The output is a set of regression coefficients which can be used to calculate the so-called subordinate human body dimensions from which it is possible to generate the sheer documentation for the clothing product and verify the garment in 3D on a virtual figure. Elert´s principle is feasible useing two body dimensions and can be used in determining body size in the mass production of clothing.

Keywords: - Elert system, correlation, density of the human body, Body Mass Index, dimensional typology.

1 INTRODUCTION

It is known that the relationships and links between events and variables provide the possibility of using a known state of one variable (or some variables) to deduce the state of another (others). How to create a body utilizing this knowledge is also known, that is, how to realize this potential through instructions, formulas and computational algorithms. The number of applications is endless - and some of them may have a significant economic impact. A good example is anthropometric standardization during the preparation for mass production of items whose dimensions need to accommodate the physical dimensions of the potential users. Some years ago, there was an article published in a Polish journal, called "An Unusual System of Making Clothes". A tailor from Warsaw, Mr. A. Elert (supposedly a 'high-class' tailor), explained that any dimension of the human body can be expressed as a certain multiple of a radius of a hypothetical sphere of the same mass and density as the human body (the density is about 1.1g.cm-3). From this fact he then derived a system of clothing design; all he needed to know was the height and the weight of the individual. He published this idea in a Polish professional journal. A review of Elert's article is published in the Information Bulletin from 1993 under the name of "Dressing up with correlation" which was prepared by [1]. Regarding the Elert's principles (according to which, every physical dimension is a constant multiple of the radius of the sphere, which is derived from the body weight), according to Komenda, such a concept is idealized and naive, because it is non-statistical. From the anthropometric data, as he says, it is easy to find that in the sub-population of individuals of the same weight (of the same gender and age group) each physical dimension has its own variability. The circumferential dimensions vary only a little in such a sub-population, whilst the linear dimensions vary by a relatively large amount. The essence of such principles is practically applicable only to a limited central subset of the body size group - and even then only to a limited degree [1].

2 IMPLEMENTATION OF ELERT'S PRINCIPLES IN PRACTICE

This article aims to highlight the opportunity to determine the dimensions of the body size based on height and weight of the human body, which is the standard basis for editing production documentation in the clothing industry. Since Elert's publication was not available, the article of S. Komenda was used when making deductions and addressing this issue.

2.1 Typology of the human body

Body dimensions are specific features of each individual. It is possible to determine the average value for one category of people, but it cannot be assigned to any one person only. There is a very large variety of sizes. For example, for body height the average value has been found to be 169.5cm for men and 157.3cm for women. However, some individuals do not conform to these categories and they differ from the average [2]. Yet, body height is a relatively more constant dimension than body weight. While the body height differs only by 25-30%, weight differs significantly more – up to 50-100%. This number is influenced by many factors, for example, by diseases, obesity, anorexia or bulimia, but also by the metabolism of the individual (Palm Size Body Composition Analyzer BC-2). A common way of determining if someone is underweight or overweight is the BMI [3].

$$BMI = \frac{m}{h^2} \tag{1}$$

where:

m - bodyweight [kg], h – body height [m].

The results are evaluated according to the categories determined by the European standard, Figure 1. The BMI categories are just a simplified model.

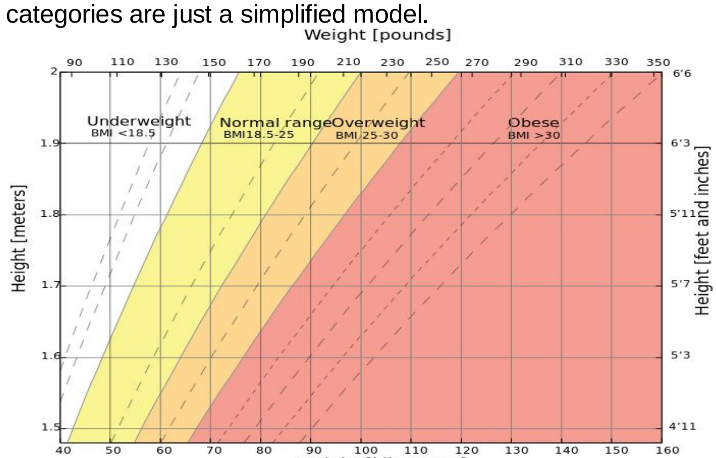

Figure1. The categories of BMI for the population [4]

The dashed lines represent subdivisions within a major class. For instance the "Underweight" classification is further divided into "severe", "moderate", and "mild" subclasses [4].

2.2 Determination of body density and the radius of the sphere

The human body is composed of water, fat, minerals and proteins. The optimum ratio of body composition is shown in Figure 2. The density of water is 1.0g.cm^{-3}. The densities of water and of the human body are very close. The average density of the body changes with age. It is lowest among infants. Women have a lower average body density than men, caused by their higher proportion of fat and smaller proportion of muscle. The density of the human body varies: during inspiration (breathing in), it has a value around 0.945g.cm^{-3}, after exhalation, 1.025g.cm^{-3}. Normally, for the density of the body, a value of 1.1g.cm^{-3} is used and also Elert used this figure for his calculations.

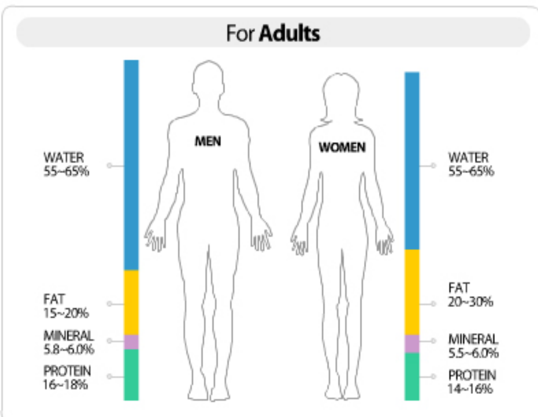

Figure 2. Optimal ratio of a body composition [5]

One of the most reliable ways to determine the density of the body is the method of hydrostatic weighing. Another possible solution is to use a general formula for the calculation of the density and that is to calculate the proportion of the total body density and the total volume of the object. In our case, the human body.

$$\rho = \frac{w}{V} \qquad (2)$$

where: ρ – average body density [g.cm^{-3}], w – total body weight [g], V – total body volume [cm^3].

Elert used a principle where the mass of the human body is transformed into a sphere with the same mass and density as the human body. Then he could determine the individual dimensions of the body as specific multiples of the radius of the said sphere. To calculate the radius of the sphere the following formula was used:

$$r = \sqrt[3]{3V/4\pi} \qquad (3)$$

where: r – sphere radius [cm], V – total body volume [cm^3].

As the basis for the calculation of the radius of a hypothetical sphere of the same weight, the formulas (2) and (3) were used, while the body weight and the density of 1.1g.cm^{-3} were known.

3 THE EXPERIMENTS

For this experiment, a set of body dimensions of 1066 women in the age range of 18-60 years measured in 1990 by the Research Institute of Clothing in Prostejov was used. The measurements were performed according to CSN 80 0090 standard [6]. From these body measurements, seven were used for the construction of upper and lower body - back length, upper limb length, lower limb side length, back width, chest circumference, waist circumference and seat circumference were chosen.

3.1 Processing of measurements using multidimensional data analysis

Correlation, regression and statistical analysis provide a forecasting method for certain "variables" based on the inter-dependencies between them. One value is estimated based on the knowledge of a second variable using linear regression, the output of which are the regression coefficients, which in turn can be used to calculate the so-called subordinate body measurements. When calculating the regression coefficients, the following independent variables are used:

- Body height and weight (T_1_w)
- Body height and the radius of a hypothetical sphere (T_1_r)
- Body height, chest circumference and seat circumference (T_1_T_{88}_T_{93})

The dependent variables are the observed subordinate physical dimensions, in our case: back length, back width, length of the upper limb, side length of the lower limb, chest circumference, waist circumference and seat circumference. The regression coefficients were calculated using the QC Expert program and are shown in Tables 1 to 3 [7].

Table1. Regression coefficients – independent variable T_1_w

Body part dimension	ČSN classific.	k_{T1}	k_w	A
Back length	T_{48}	0.16273777	0.06267904	10.6114212
Upper limb length	T_{60}	0.33832271	0.06652172	8.29237912
Lower limb side length	T_{63}	0.7178869	-0.0170131	-12.5755323
Back width	T_{77}	0.00129702	0.21511377	21.6998948
Chest circumference	T_{88}	-0.1522973	0.79263668	68.0563805
Waist circumference	T_{90}	-0.3130699	0.9418094	65.8764954
Seat circumference	T_{93}	0.00683374	0.72192244	51.4353585

Table 2. Regression coefficients – independent variable T_1_r

Body part dimension	ČSN classific.	k_{T1}	k_r	A
Back length	T_{48}	0.16210827	0.522132	2.20336957
Upper limb length	T_{60}	0.30585633	0.569658	4.1822287
Lower limb side length	T_{63}	0.71710347	-0.12171	-10.6220328
Back width	T_{77}	-0.0828146	1.806124	5.87346661
Chest circumference	T_{88}	-0.4189569	6.682531	2.01520242
Waist circumference	T_{90}	-0.5723219	7.909633	-21.2524044
Seat circumference	T_{93}	-0.1950589	6.05563	-14.6570751

Table 3. Regression coefficients – independent variable T_1_T_{88}_T_{93}

Body part dimension	ČSN classific.	k_{T1}	k_{T88}	k_{T93}	A
Back length	T_{48}	0.186262	0.031324	0.041464	3.761568
Upper limb length	T_{60}	0.339524	0.073258	0.009007	4.586496
Lower limb side length	T_{63}	0.707267	-0.026076	0.015127	-10.989163
Back width	T_{77}	0.028574	0.254004	0.002268	6.954989
Chest circumference	T_{88}	-1.42E-13	1.000000	1.82E-12	9.09E-12
Waist circumference	T_{90}	-0.168231	0.709160	0.471768	-10.613344
Seat circumference	T_{93}	-3.13E-13	-5.12E-13	1.000000	-1.32E-11

3.2 Verification of the results

Using the calculated regression coefficients, it is possible to find the subordinated physical dimensions necessary to design the clothing based on the known basic body measurements (body height, chest circumference, weight and radius). Each subordinate body dimension can be calculated from the following relationships:

$$T_i = k_{T1} * T_1 + k_w * w + A \quad (4)$$

$$T_i = k_{T1} * T_1 + k_r * r + A \quad (5)$$

$$T_i = k_{T1} * T_1 + k_{T88} * T_{88} + k_{T93} * T_{93} + A \quad (6)$$

where: Ti – body dimension value, KT1– body height coefficient, T1 – body height, kw – weight coefficient, w – weight, kr - coefficient for the hypothetic sphere, r - radius of hypothetic sphere, kT88- coefficient of chest circumference, T88 - chest circumference, kT93- coefficient of seat circumference, T93 - seat circumference, A – absolute value. The best way to verify the results calculated by the regression coefficients is to substitutetthem with the basic dimensions of the proband listed in Table 4 in the above equations. The differences which occurred are seen in Figure 3.

Table 4. Basic Body dimensions of the proband

Body part dimension	ČSN classific.	Proband dimension [cm]
Body height	T_1	167.30
Weight	w	55.00
Hypothetical sphere	r	22.86
Back length	T_{48}	40.20
Upper limb length	T_{60}	62.50
Lower limb side length	T_{63}	107.50
Back width	T_{77}	32.60
Chest circumference	T_{88}	83.50
Waist circumference	T_{90}	67.20
Seat circumference	T_{93}	95.00

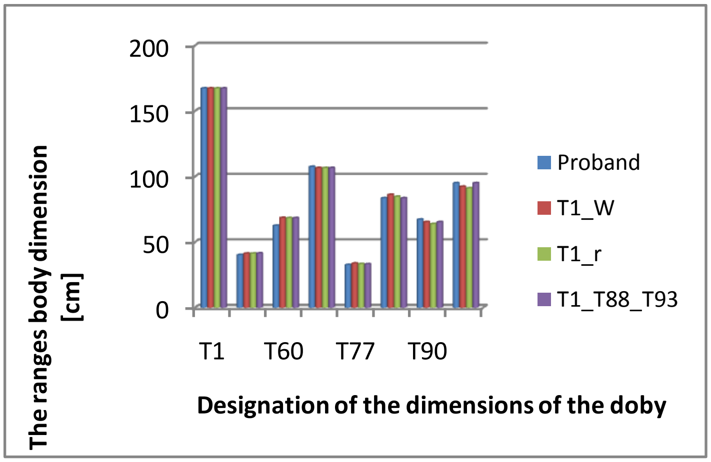

Figure 3. Graphic display of calculated body dimensions for upper and lower body

From the calculations and from the graph, it is evident that the dimensions calculated on the basis of weight or radius of the hypothetical sphere are comparable to the measured values of body measurements as follows: back length is about 1cm long, upper limb length is longer by up to 5cm, lower limb side length is same, back width is about 0.7cm narrower, chest circumference is about 1cm larger, waist circumference is about 1.9cm smaller, seat circumference seat is up to 2.5cm smaller.

3.3 Verification of the results in the design of women's pants

To verify the results of the experiment women's pants were selected with one waist selection on front and back piece. Additional dimensions, namely, step length, seat depth and pant bottom width were calculated using formulas based on proportional relationships, namely, body height and chest circumference. Construction of women's trousers is treated in the methodology Unikon as a macro, and is created in 2D CAD system AccuMark and verified in a virtual character in a 3D program, V-Stitcher. The outputs from both interconnected programs are shown in Figure 4, 5 and 6A to 6D.

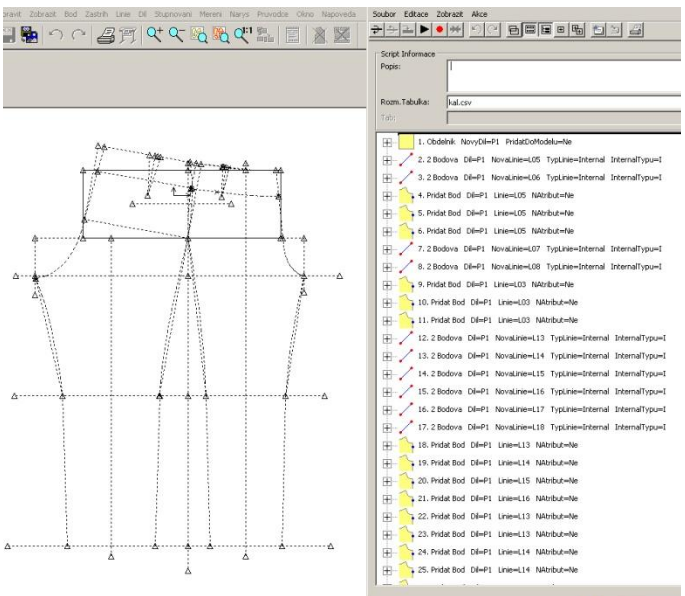

Figure 4. Design network of women's trousers

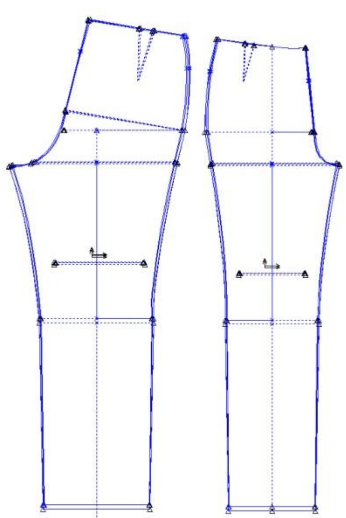

Figure 5. Back and front parts of women's trousers - output macros

Figure 6. A. B. C. D. Showing trouser created in a 3D program V-Stitcher to a virtual figure in different poses

The resulting differences in the calculated body dimensions, especially waist and seat circumferences, according to "T_1_w"; "T_1_r"; "T_1_T_{88}_T_{93}" can be resolved by increasing the allowances for freedom in the design formulas. Clearly, the correlations of clothing design dimensions with the body height T_1 and body weight w or with the hypothetical sphere radius r are mutually complementary - each dimension is "information-saturated", either mostly by the height, the weight or the radius - and only exceptionally both or in some case third circumferential dimensions, i e. chest circumference T_{88} or seat circumference T_{93}.

4 Conclusion

The benefit of this work is the finding that, as Elert stated, it is possible to use the radius of the hypothetical sphere with the same weight and density as the human body and the body height, to determine the subordinate body measurements. Based on the regression coefficients, the body measurements necessary for construction of clothing can be relatively accurately determined. This is evidenced by outputs in 2D CAD program and 3D virtual images of clothing on the figure. Applications are plentiful and some of them may have a significant economic impact especially in the mass production of clothing and footwear. Clothing is manufactured for an anonymous customer. It is not known who will wear the clothes. Therefore, part of the preparation of production must be the rational reflection on what sizes to produce. At this point correlation enters the scene. Without its existence, the production of ready-to-wear clothing would be unsolvable. Equally important is custom production which must respect certain relationships and regularities between the physical dimensions, as hundreds of years of experience has recognized and registered.

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