Predictive geometric models for some hygienic properties of multi-component fabrics

M A Chizhik¹, V Yu Yurkov¹,², E Yu Dolgova¹
¹Omsk State Technical University, 11, Mira Ave., Omsk, 644090, Russia
²Omsk State Pedagogical University, 14 Tuhachevsky Embankment, Omsk, 644099, Russia

Abstract. This paper is devoted to the geometric and computer simulation of hygienic properties of fabrics which are considered as multi-parameter and multi-component systems. We consider predictive models of fabric hygroscopicity and air permeability. There is a problem of building co-ordinate geometric models on condition that the set of experimental data is limited. We solve the problem for static multi-component systems. All models are considered as monoidal surfaces in the space of input and output parameters. The paper proposes an algorithm of building linear and quadratic models of fabric properties. Results of the investigations allow us to substantiate producer’s choice of fabric construction and composition for manufacturing the clothes of special purpose. The method suggested in the paper is one of geometric modulus of the software HYPER-DESCENT which has been developed formerly. Our geometric models together with software HYPER-DESCENT may be applied for simulation and prediction the properties of multi-parametrical systems or technological processes of light industry.

1. Introduction
At present there are the systems of technical control securing the safety of light industry products. As for the products of textile industry the main safety indicators are textile hygroscopicity and air permeability of fabrics. Values of textile hygroscopicity and air permeability of fabrics depend on the number of layers, the type of textile material, fabric construction, functional purpose and specific consumer features. Correspondence between product properties and safety standards is confirmed by certification or declaration. In order to determine the values of textile hygroscopicity and air permeability it is necessary to appeal to experimental laboratories but that leads to financial losses and waste of time. Therefore, design of predictive geometric models for textile hygroscopicity and air permeability of fabrics is actual problem at present.

Designing of special-purpose clothes is impossible without consideration of hygienic properties of fabrics [1, 2]. Investigation the hygienic properties of fabrics as functions of fabric structure and fabric composition has a great practical and theoretical significance [3, 4]. We consider the problem of prediction some hygienic properties on condition that the number of experimental fabric specimens is limited. If we will have that kind of functions we will be able to solve the following problems. The first problem is a problem of prediction or a problem of preliminary computation some properties which are essential for specific aim or concrete region. The second problem is a problem of searching some optimal correlation between structure properties of fabric and hygienic properties of clothes. It is important to take into account that optimization problem may be solved by means of proper mathematical model. The third problem is a problem of forming general data base including all properties of fabrics and corresponding properties of products. And the fourth problem is a very important problem of multi-component fabrics design having beforehand given properties.

Geometric aspect of predictive model design is characterized some special features connected with hygienic properties of light industry products. Firstly, consideration and description of input parameter mutual connections of the system are one of the important problems referring to data processing. Non-observance of this principle leads to breach of model adequacy and all output parameter evaluations

Published under licence by IOP Publishing Ltd
may be erroneous [5, 6]. Also it leads to incorrect models. Secondly, input system parameters may be of various types: discrete or continuous or fuzzy. All these types of parameters may be occurred on investigation the same system. Thirdly, it is necessary to take into account the monoidal character of the model in the space of input and output parameters [7]. From this point of view all special models may be considered as sections of monoidal hyper-surface. Fourthly, there are virtual modeling resources for the systems of that kind and these resources are unlimited theoretically. But we have no means to create some general visual models, since all visual models are limited by two-dimensional visual space.

2. Object of research, fabrics and equipments
As an object of investigation we chose several one-component and two-component fabrics having various structural and filamentous characteristics. We paid special attention to hygienic properties of fabrics, namely: hygroscopicity and air permeability. We analyzed fifteen samples of fabrics having various physical parameters and characteristics.
Discrete fabric characteristics were as follows:
1. Webbing of the fabrics, namely: linen fabrics, serge fabrics, combined fabrics.
2. The kind of fabric finishing, namely: plain fabrics, multicolored fabrics.
Continuous fabric characteristics were as follows:
1. Closeness of texture along the fabric base (160 … 540 threads by 10 centimeters).
2. Closeness of texture perpendicular to the fabric base (160 … 540 threads by 10 centimeters).
3. Thickness of the fabric (0.25 … 0.8 millimeters).
Fuzzy characteristics were not considered. But it would be of interest to generalize the results of this research work by consideration some characteristics as fuzzy ones.
To determine the hygroscopicity the samples of the fabrics were undergone influences of various climatic conditions, namely: relative humidity was fixed at 100 % and 0 % successively and the temperature of the air was fixed at 20°C. First operation was the following. Opened box with the samples was maintained in special chamber having relative humidity about 100 %. Exposure was carried out for four hours. Then the boxes were closed and they were taken out of the chamber. Weight of the boxes was fixed. After that opened boxes were put into another chamber having sulphuric acid and relative humidity at 0 %. Second exposure was carried out for four hours too. Then the boxes were closed again and they were taken out of the second chamber. Weight of the boxes was fixed again. Finally, all opened boxes with the samples were dried in drying chamber. The hygroscopicity was determined by weight difference of damped and absolutely dried samples.
Air permeability of the fabrics was determined by means of special device having the chamber (see Figure 1) which was covered with the fabric sample. A pump which was connected with the chamber by means of the air meter caused rarefied atmosphere in the chamber. The air meter recorded the quantity of the air which passed through the sample. A manometer which was connected with the chamber too showed the difference in air pressure on both sides of the sample. Air permeability tests were conducted under the pressure equal to 50 Pa.

3. General theoretical considerations
In this paper we consider static mathematical models of multi-component systems [8]. Some limited realizations of input parameters $X = (x_1, ..., x_n)$ and corresponding realizations of output parameters $Y$ were considered as initial data of modeling. Our purpose at that stage was to identify a nonlinear correspondence $Y = F(X, A)$. 
Design of predictive geometric models is a staged process and it is realized by the following algorithm. All these models have simple generalizations onto multi-dimensional spaces.

Let us consider the general realizations \( y = (x_1, \ldots, x_m) \) are inaccessible. For example we have not enough number of specimens with various characteristics. Let’s assume that realizations of special cases are accessible only. Hence, we are able to obtain some special models \( y = f(x_1), \ldots, y = f(x_m) \). These sections may be considered as results of elimination some input parameters. If the general model has nonlinear structure the probability of differences increases.

Thus, we need a predictive geometric model which is an invariant model in regard to a set of input parameters and their realizations. Models of that kind are the co-ordinate predictive ones [9].

In order to solve the problem it is enough to use the following predictive models.

1. Let \( y = a_1 x_1 + a_{1,0} \), \( y = a_2 x_2 + a_{2,0} \), \( y = a_3 x_3 + a_{3,0} \) be special models. The co-ordinate predictive models may be linear models \( y = a_1 x_1 + a_2 x_2 + a_3 x_3 + a_0 \) or cubic ones \( y = a_1 x_1 x_2 x_3 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_0 \) and so on.

2. Let \( y = a_1 x_1^2 + a_1 x_1 + a_{1,0} \), \( y = a_2 x_2 + a_{2,0} \), \( y = a_3 x_3 + a_{3,0} \) be special models. The co-ordinate predictive models may be quadratic models \( y = a_1 x_1^2 + a_2 x_2 + a_3 x_3 + a_0 \) or \( y = a_1 x_1^2 + a_1 x_1 x_2 + a_2 x_2 + a_3 x_3 + a_0 \) and so on.

3. Let \( y = a_1 x_1^2 + a_1 x_1 + a_{1,0} \), \( y = a_2 x_2^2 + a_2 x_2 + a_3 x_3 + a_{3,0} \) be special models. The co-ordinate predictive models may have the form \( y = a_1 x_1^2 + a_2 x_2^2 + a_3 x_3 + a_{3,0} \) and so on.

All these models have simple generalizations onto multi-dimensional spaces.

Design of predictive geometric models is a staged process and it is realized by the following algorithm.

**Step 1:** Geometric model structure for the system as a whole is determined. Geometric structure depends on input parameter types and their mutual dependence. If all input parameters are mutual independent ones the base of the structure is a hyper-parallelepiped. It restricts the area of system input parameter existence. If all input parameters have linear mutual dependence the base of the structure is a multi-dimensional simplex. If input parameters of the system belong to various types the area of system parameters is a multi-dimensional poly-top which is a pooling of hyper-parallelepipeds and simplexes.

**Step 2:** Identification of special models having a constant ratios. Identification is realized on the structure sub-areas having maximal admissible dimension.
Step 3: Design of special co-ordinate predictive models on the structure sub-areas which dimension is 2, 3 and so on units more then maximal admissible dimension. Ratios of special models are described by functions on ordinary input parameter. The process is gone on until the dimension of the model is less then the dimension of the system structure as a whole.

4. Predictive models for hygroscopic properties

We received the samples of two-component fabrics to carry out physical experiments related to hygroscopic properties. Our results are the following.

1. When we analyzed wool fabrics we get the result as follows: \( y = 0.1511x_1 + 0.7649 \). Here \( x_1 \) is percentage of wool fibres in the fabric.

2. Analysis of viscose fabrics gave us the following result: \( y = 0.1455x_2 + 0.9568 \), where \( x_2 \) is percentage of viscose fibres in the fabric.

3. The result of testing some cotton fabrics are described by \( y = 0.0714x_3 + 0.8571 \), where \( x_3 \) is percentage of cotton fibres in the fabric.

One can see these models are not co-ordinate ones. Processes of co-ordination the models and recalculation of parameters gave us the following result:

\[ y = 0.1496x_1 + 0.8596, \quad y = 0.1468x_2 + 0.8596, \quad y = 0.0714x_3 + 0.8596. \]

Since these special models are linear ones, we may assume the linearity of general model. It may be given by

\[ y = [(a_1 + b_0)x_1 + (a_2 + b_0)x_2 + (a_3 + b_0)x_3 + b_0x_0]/(x_0 + x_1 + x_2 + x_3), \quad x_0 + x_1 + x_2 + x_3 = 100. \]

Here \( x_0 \) is percentage of polyether fibres in the fabric.

Substitution of special co-ordinate models gives

\[ y = [(0.1496 + 0.8596)x_1 + (0.1468 + 0.8596)x_2 + (0.0714 + 0.8596)x_3 + 0.8596x_0]/(x_0 + x_1 + x_2 + x_3), \quad x_0 + x_1 + x_2 + x_3 = 100. \]

The hypothesis of general model linearity may be confirmed or refute by means of analysis a great number of simples. It is essential to have three- or four-component fabrics as the simples. As for the model of hygroscopicity it takes into account only for continuous parameters, namely the multi-component composition of the fabrics [10]. If we will take into account the closeness of texture along the fabric base (\( x_4 \)), the closeness of texture perpendicular to the fabric base (\( x_5 \)) and the thickness of the fabric (\( x_6 \)), we will be able to create six-dimensional model of hygroscopicity. Figure 2 shows the structural base of the model. Analytical form of the model is the following

\[ y = [F_1(x_4, x_5, x_6)x_1 + F_2(x_4, x_5, x_6)x_2 + F_3(x_4, x_5, x_6)x_3 + 0.8596x_0]/(x_0 + x_1 + x_2 + x_3), \quad x_0 + x_1 + x_2 + x_3 = 100. \]

To find the model it is necessary to have 100 experimental data at the minimum. Moreover, it is necessary to plan the experiments. There are no suitable technical means and software to visualize that kind of models.
5. Predictive models for air permeability of fabrics

We used the same two-component samples for experimental investigation of air permeability. As a result we got the following.

1. Special quadratic models:
   \[ y = 0.2162x^2 + 6.5038x - 27.205 \] is the model of air permeability for wool and synthetic fabrics;
   \[ y = 0.7792x^2 - 1.7667x + 39.187 \] is the model for cellulose fabrics.

2. Special linear models:
   \[ y = 14.738x - 99.732 \] is the model for wool and synthetic fabrics;
   \[ y = 23.422x - 121.95 \] is the model for cellulose fabrics.

Here \( x \) means percentage of superficial porosity \( Rs \) of the samples. We have \( 5\% \leq x \leq 30\% \).

If we agree with the hypothesis that our general predictive model is linear model we may have

\[ y = \left( (14.738x - 99.732)x_1 + (23.422x - 121.95)x_2 \right) / (x_1 + x_2), \quad x_1 + x_2 = 100. \]

Here \( x_1 \) means percentage of wool and synthetic fibres in the fabrics and \( x_2 \) means percentage of cellulose fibres.

For quadratic model we have

\[ y = \left( (0.2162x^2 + 6.5038x - 27.205)x_1 + (0.7792x^2 - 1.7667x + 39.187)x_2 \right) / (x_1 + x_2), \quad x_1 + x_2 = 100. \]

If we will take into account the closeness of texture along the fabric base (\( x_3 \)), the closeness of texture perpendicular to the fabric base (\( x_4 \)) and the thickness of the fabric (\( x_5 \)), we will be able to create five-dimensional model of air permeability. Analytical form of the model is the following

\[ y = \left( F_1(x_0, x_6, x_1) + F_2(x_0, x_6, x_2) \right) / (x_1 + x_2), \quad x_1 + x_2 = 100. \]

To find the model it is necessary to have 102 experimental data at the minimum. Also, it is necessary to plan the experiments.

6. Conclusions

We have obtained several analytical models of air permeability and hygroscopicity for fabrics. Air permeability depends upon superficial porosity of fabric. The superficial porosity is easy determined by closeness of fabric texture in longitudinal and transverse directions, line thickness of the threads and raw material composition.

Hygroscopicity of fabrics depends upon the multi-component fabric composition. Using the investigations we can motivate our selection of components and the structure of fabrics which are used for manufacturing the special closes. Using the analytical descriptions of
hygroscopicity and air permeability we can forecast its values before manufacturing. The method of predictive geometric models is one of the modulus of software HYPER-DESCENT and it allows us to solve the predictive problems [11].

Throughout the paper we have required the linearity of the model. Taking into account the linearity of our models we may note the partial solution of the problem of searching optimal correlation between structure properties of fabrics and hygienic properties of the clothes. We think that general solution of the problem needs further investigation. Another direction in which the theory could be generalized is to investigate the problem of designing multi-component fabrics having beforehand given properties. Also, it would be of interest to generalize the results of this research work by consideration some physical characteristics as fuzzy ones.

7. References

[1] Plante A M, Holcombe B V, Stephens L G Fiber hygroscopicity and perceptions of Dampness. Part I: Subjective trials 1995 Textile Research Journal 65(5) 293 – 298
[2] Plante A M, Holcombe B V Fiber hygroscopicity and perceptions of Dampness. Part II: Physical mechanisms 1995 Textile Research Journal 65(6) 316 – 324
[3] Wang Z, Li Y, Kowk Y L and Yeung C Y Mathematical simulation of the perception of fabric thermal and moisture sensations 2002 Textile Research Journal 72(4) 327 – 334
[4] Keiser C, Becker C, Rossi R M Moisture transport and absorption in multilayer protective clothing fabrics 2008 Textile Research Journal 78(7) 604 – 613
[5] Scherbatov I A, Protalinskii O M and Esaulenko V N Analysis and Modelling of Complex Engineering Systems Based on the Component Approach 2013 World Applied Sciences J. 24 (Information Technologies in Modern Industry, Education & Society) 276 – 283
[6] Holland J H Studying Complex Adaptive Systems 2006 Journal of Systems Science and Complexity 19(1) 1 – 8
[7] Yurkov V Yu Mathematical simulation of monoidal linear surfaces 2015 Omsk Scientific Bulletin 2(140) 5 – 7
[8] Litunov S N, Chijik M A, Yurkov V Yu and Skuba P Yu Nonlinear net models of multi-parametrical systems and processes 2019 Dynamics of systems, mechanisms and machines 7(4) 122 – 128
[9] Yurkov V Yu Identification of co-ordinate geometric models for multi-parametrical systems 2018 Dynamics of system, mechanisms and machines 6(2) 288 – 294
[10] Chijik M A, Yurkov V Yu and Dolgova E Yu Empirical frame hyper-surfaces as a models of multi-parametrical technological processes 2020 Problems of machinery 458 – 463
[11] Chijik M A, Moskovtsev M N, Monastirenko D P and Dorkin D V 2014 State registration certificate of software HYPER- DESCENT 2013618421/69