Three-dimensional scanning of a figure as the basis for mass customization of industrial clothing collections

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Abstract. The subject of research is clothing development according to individual design chosen by a consumer. The application of the concept of mass customization has become one of the most high-demanded areas of development in light industry. Manufacturers invest heavily in the development of software products, which can help the consumer to choose the right-sized and well-fitting clothes from industrial collections on manufacturers’ websites. While constructing clothing designs on an individual order, and then while manufacturing process under conditions of industrial flow production, exact body dimensions are extremely important. The world light industry is actively using digital technologies in order to measure shapes and determine body features (made-to-measure systems). Such systems make it possible to better take into account the individual characteristics of customers, which allow designing high-quality clothing, characterized by a good fit on a figure of a particular consumer. There is a developed system for obtaining a digital image of a shape, which based on the use of depth sensors. An experimental study of the anthropometric matching of clothes with a figure in a virtual environment was carried out by comparing scanned three-dimensional models of figures with and without clothes. The permissible values of projection gaps were revealed, within them the product visually corresponds to a figure. An approach where there is an information which consists of customers’ preferences, dimensional characteristics, shape and body type in specially created databases, which are used when it is necessary to help to create clothing products that are best suited to the consumer in size and design, is proposed.

1. Introduction
In modern society under the conditions of progressive digital automated transformation of production, the consumer has become a direct participant of light industry products’ design. Introducing digital technologies and systems of three-dimensional scanning of a figure and virtual modeling of clothing designs, manufacturers more and more prefer to use mass customization. Now a buyer can purchase a unique and individualized thing that will meet his or her personal requirements, whether it is the color scheme of the product, its design features or technological processing. Today, a number of the largest companies such as Zara, H&M, Adidas, American Eagle, Children’s Place, Gloria Jeans and others are successfully practicing the principle of mass customization, which helps them optimize design processes and, accordingly, increase their income.

The following prerequisites of using mass customization in the fashion industry can be distinguished:
- increased competition between companies which produce clothes and shoes;
- growth of customer requests;
- market transparency, caused primarily by the growth of online sales;
According to the majority of scientists, application of mass customization allows the manufacturer to retain the ability to save costs due to the economy of scale, and at the same time, products are becoming more attractive to customers. Due to this fact, the main task of customization is not just the creation of an optimal product according to the consumer view, but the offer to a customer an individual product at the price level as for mass-produced one, which is certainly a very competitive advantage in the face of high competition in the fashion industry.

2. Literature review

The topic of mass customization and the adaptation of its principles of work in the computer-aided design of garments is more and more frequently becoming an object of study for both domestic and foreign scientists, which confirms its relevance and significance in the development of production potential. By “mass customization” (mass customization of garments) is meant the manufacturing of products under industrial conditions with the possibility of adapting or modifying them in accordance with the requirements of consumers, in other words, it is a set of approaches of mass production of clothing and individual sewing of products at the same time. To implement this production concept, the “customer relationship management system (CRM)” is used. It acts as a software application designed to automate interaction with consumers in order to increase sales level and strengthen communication with the circle of clients by accumulating information about them and their purchases for future analysis and making of a product release plan and sales strategy [2].

In particular, the authors M. Khajeh, P. Payvandy, S.J. Derakhshan have developed a system for designing new clothing models using the principle of mass customization while choosing fabric samples for future models [3].

The authors N.A. Kazakova, O.V. Ivanova, E.A. Khammatova in their studies analyze and propose their own algorithm for creating new models using neoprene with author's textures, which can be performed online [4]. The application of the concept of mass customization has become one of the most high-demanded areas of light industry development. Manufacturers invest heavily in the development of software products, with the help of them the consumer can choose clothes which are appropriate in size and fit well from mass-oriented collections on manufacturers’ websites [5].

While constructing clothing designs on an individual order, and then during manufacturing process under conditions of industrial flow production, exact body dimensions are extremely important. The world light industry is actively using digital technologies in order to measure shapes and determine body features (made-to-measure systems). Such systems make it possible to better take into account the individual characteristics of customers, which allow designing high-quality clothing, characterized by a good fit on the body figure of a particular consumer [6]. 3D scanning technologies are still relatively new and expensive technologies, and only few retail clothing stores can afford to install scanning fitting rooms. At their flagship store in central London, Levi’s has offered their customers to use this technology to choose a pair of jeans that fit them perfectly. Bodi.me Company which supplies three-dimensional scanning fitting rooms collaborates with brands such as Topshop, Forever 21, Next and some luxury brands (Ralph Lauren, Emporio Armani and Boss). The software creates a 3D avatar of a client, compares the measurements taken with the exact parameters of the clothes in order to choose the optimal size.

New technologies open up great possibilities for individual tailoring (bespoke) [7], providing the opportunity to integrate the principles of customization and the conditions of industrial apparel industry. The manufacturer collects maximum information online to create a virtual model of the client’s body. The system provides storage of data on customer preferences, size characteristics, shape and type of body in specially created databases that are used as needed to help to create pieces of...
clothing that are best suited to the consumer. Thus, a system of long-term cooperation is created. As necessary the data can be corrected if a client has lost / got some weight, but in general the process of creating clothes takes tens of times less time than before. A client can interactively model his or her clothes from a number of elements / blocks on the website after a certain period of time they obtain the ready-made product fitted to a figure [8].

Amazon acquired Body Labs Company in 2017 in order to improve the Prime Wardrobe service, which allows a wide range of goods to be sent to a client for fitting, including shoes and accessories, and after that to be returned if pieces do not suit him or her. For greater Amazon customer satisfaction and, consequently, a reduction of returns’ rate, development of new and more targeted technology can be of great benefit [9].

The analysis of modern software products proves that in the field of retail sales of clothes, modern technologies for attracting customers are developing, they aim to make choices of the most suitable products easier, as well as to manufacture products according to individual size characteristics obtained with the help of using three-dimensional scanning. Existing systems to one degree or another allow visualizing the assortment of the store and identifying the pieces most suitable for a consumer, while the reliability of determining the conformity of the actual size of clothes with the consumer's figure still remains low.

3. Methodology
In this regard, the automation of the process of determining the size characteristics of figures, and subsequently the selection of appropriate clothes from the industrial mass collection or the order a customized product is really actual task.

The perspective solutions in this area are seen in the following sequence: 1) development of scanning systems that are distinguished by simple use and low cost 2) comparison of size features of a three-dimensional avatar and a scanned model of a client’s body 3) determination of the parameters of the ready-made clothing and their comparison with the dimensional characteristics of the figure of client who makes the order 4) ordering a customized product on the manufacturer's website.

To implement the described approach, the following research was conducted:

- Development of a system for obtaining a digital image of a figure, determination of size features using a three-dimensional model of a figure;
- Development of men's shirts designs’ drawings with different options of widening of fitting freedom, and manufacturing of clothing models;
- Identification of the main dimensional features of the figure and the associated structural parameters of clothing that determine a comfortable fit on the figure;
- Development of a customer interaction interface while ordering a customized product.

Nowadays, there are a large number of different difficulty levels and different market price segments installations for obtaining a figure’s digital image. Based on the analysis of existing systems, the use of depth sensors is identified as the most promising direction, providing high accuracy and high speed of obtaining initial information about the surface shape of objects. There has been developed a three-dimensional scanning system, which is based on the Microsoft Kinect depth sensor [10]. The information and technical structure of the module of obtaining a digital image of a figure consists of a material part built on serial depth sensors and, on the other hand, of proficient software that allows using the equipment as a module. Two versions of the module for obtaining a digital image of a figure are proposed. The first option involves rotating the figure around its own axis while the scanning process takes 60 seconds (figure 1).
Figure 1. Diagram and appearance of a system for obtaining a digital image of a figure with two sensors

It is suitable for use as a portable complex, measurement error is 3 mm. The creation of digital image of human body to full height occurs when two scanned three-dimensional models are combined together – the upper supporting surface and the lower supporting surface.

During scanning, a person stands straight without any tension and clamps in the body, heels are put together and toes are separated. The position of the legs should be stable, calm and comfortable for the person being measured. Hair is collected revealing the back of the neck. The second option of the system consists of six sensors; a person stands motionless during scanning process (figure 2). Obtaining a digital image of the human body to full height occurs when six separate scanned sections of the surface of the human body are combined together.

Figure 2. Diagram and appearance of a system for obtaining a digital image of a figure with six sensors

The visualization technology of the scanned object, proposed by the specialists of the Department of Art Modeling, Design and Technology of Garment of the RSU named after A.N. Kosygin, allows getting reliable anthropometric characteristics (figure 3): projection, circumferential, arc measurements; to perform an assessment of the quality of fitting; to identify the presence of defects; to assess the conformity of the ready-made product and a sketch [11].
The assessment of the anthropometric compliance of designer’s clothing is based on a list of parameters that require monitoring. To determine this list, a survey was conducted with 110 people as experts, including light industry quality control experts and retailers. Chest girth and neck circle are determined as the leading dimensional parameters of men's shirts. There were designed and manufactured 17 models of men's shirts. Nine models were made with a change in widening of chest girth. Eight models were made with a change in widening of neck circle.

One of the main tasks in assessing ready-made clothing models is the visual correspondence of a figure with a product and the anthropometric correspondence of sizes of clothes with a figure. At the next stage, we compared the scanned three-dimensional models of the figure wore shirts with undressed models in a virtual environment. To do this, initially a model of the item was put on a motionless human figure (figure 4, c) and was scanned. Then the product was being removed and re-scanning of a person wore underwear (Fig. 4 a, b) was performed. After that we combined virtual images of the figure wore the investigated clothing and without it.

At the next stage of the experimental research the projection gaps between the figure and the product were studied using the Size Reader program [12], which allows two models to be loaded simultaneously in .ply format and displayed in two windows at the same time. When pointing to the desired area, the program draws a section and shows a comparison of two sections in the third window by geometric overlapping (Figure 5). For research and taking of measurements in a virtual environment, sections of the chest and hips were selected as the largest in size. It was revealed that the optimal value of widening of chest girth is a range from 2 to 9 cm. The most suitable models due to the neck area for the consumer were products with widening of 3 cm to the total neck circle, then with widening of 2 cm and widening of 1 cm. According to the results of study, the choice of widening of the neck circle in the range of 1–4 cm allows ensuring visual conformity of a product to a figure of a person in the neck area.
Figure 5. Comparison of 3D models wore clothes and without clothes on horizontal sections of the figure at a chest level

At the next stage, a consumer is implemented for the automated design of custom interaction interface optimized garments. The system collects information about customers' preferences, size characteristics, shape and type of body in specially created databases, which are used when it is necessary to help create clothing products that are best suited to the consumer in size and design, is proposed.

Before starting product design, the user is invited to watch a brief video review how to work with the program, which describes each stage of creating a new model. On the start page of the program it is proposed to determine the product being designed, for this we need to select one of the categories “Women / Men / Children” and indicate the required one from the list that appears. After the selection, the user goes to the design section, where it is proposed to select one or more design solutions in the categories “Front”, “Back”, “Sleeve”, “Collar” (figure 6). In the lists of subcategory options of the design section, one of them is indicated automatically. The user can change the default options or add the necessary ones to the existing. The selected option(s) of the “Silhouette” subcategory of the “Front” category automatically generates the same option(s) of the “Back” category. Similarly, subcategories of the design section are formed that are structurally and technologically connected at the front and back of the product (for example, “Belt”, “Product Length”, “Decomposition”, “Decorative Elements”, etc.).

Figure 6. Design section of the program

At the next stage of designing, the user determines necessary materials for the product model in the relevant categories of “Upper fabric”, “Lining fabric”, “Accessories / Buttons”. The principle of operation in the "Materials" section is similar to the "Design" section. In each category of the “Materials” section, it is necessary to select the type of fabric / material in the “Select” field, located
under the name of the category of the section (natural fabrics, synthetic fabrics, mixed fabrics, etc.). Subcategory options are indicated by default. We can leave, remove or add others from the proposed list. By specifying fabrics / materials for one of the categories, it is possible to automatically exclude some samples for other categories (types of fabrics / materials, their properties can “argue” with each other during technological processing of product units).

In all sections of the program, there is a demonstration of graphic images of the designed product model with selected options and / or default options for each subcategory of the available design sections.

The selected number of options in each subcategory automatically generates the corresponding number of sketches in the lower part of the demonstration field, and also in the “Final Models” section.

The signs (the name of the subcategory of the structural element of the garment) are denoted by Sn, and the solution’s options are denoted by St. While choosing the necessary options, the selected features are combined, thus obtaining various conceptual sketches of the designed models (S¹1 * S¹2 * S¹3 * S¹n ...... Sⁿ1 * Sⁿ2 * Sⁿ3 * Sⁿn).

Based on the matrix method, the program creates all possible variants of sketches of the designed product, combining structural elements of clothing selected by a user.

The user can see all the options for the graphic image of the designed product in the “Final Models” section in accordance with previously selected options for the subcategories of the “Design” and “Materials” sections.

Graphic images of the models are divided into the “Classic” and “Creative” groups. The “Classic” group presents models in the classical style, but the “Creative” group contains other styles. The process of dividing sketches into groups occurs depending on the structural elements of the product, which form the common style of the item.

Each group can be minimized and maximized by clicking on the appropriate buttons next to the name of the group. There are scroll bars at the left side of each block in case all drafts could not be fitted on the screen. To mark the desired sketch, we have to click on a cell located in the upper right corner of the sketch (when we click on the cell a checkmark will be displayed). To select all the options, use the “Mark all” button in the lower right corner of the block (the checkmark will appear on all options). In the right area of the program section, selected models are shown with the ability to enlarge images, as well as see information about the model (type of fabric, fabric composition, article, etc. at the discretion of the manufacturer). In the lower right corner of the program section there are buttons “FITTING” and “ORDER”. The client has the opportunity to go to the “ORDER” section after demonstrating the model without trying on and order the product after choosing the size, or use the virtual trying on by pressing the “FITTING” button (figure 7).

Figure 7. Virtual trying on of the designed model
Marked sketches in the “Final coat models” section form the “Basket” block of the “Virtual fitting” section. The section has two subsections, “Standard Model of a Person” and “Individual Model of a Person”. When choosing the subsection “Standard Model of a Person”, we should indicate the values of the parameters “Size” and “Height”, selecting the one from the proposed list (press the “Ellipsis” button in the “Select” field). When choosing the “Individual Model of a Person” subsection, we should indicate the values for the parameters “Height”, “Chest Girth”, “Waist Girth”, “Hip Girth”, after that a model is being selected in order to demonstrate the designed product. It is also possible to download a ready avatar made with the help of appropriate devices and applications.

4. Conclusion

The developed systems of the three-dimensional scanning make it possible to obtain reliable anthropometric characteristics: projection, girth, and arc measurements; to assess the conformity of the ready-made product and the dimensional characteristics of the consumer’s figure. The conducted studies allow substantiating the rational values of permissible gaps at given horizontal levels in order to correctly determine the correspondence of different clothing models with the sizes of each figure in the three-dimensional virtual environment. The proposed approach provides the consumer with the opportunity to try on various types of products on his or her three-dimensional avatar so that the reading unit of the program independently selects the most suitable clothing model from the offered list, based on the correspondence of the design parameters of the product and the dimensional characteristics of a particular person. Thus, a buyer has the opportunity to create a unique customized product, taking into account his or her consumer requirements for the desired model.

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