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A Computer-aided Production System for Mass Customization in Fashion

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***Abstract* - In order to meet the demands of the market, a computer-aided production system for mass customization in fashion is proposed. The system enables the automation of dimension collection, pattern generation and fabric cutting. By integrating the system with the processes of garment sewing, fitting test and final adjustment, mass customization can be realized in the apparel industry. For the manufacturers, the efficiency of the supply chain can be improved by reducing human efforts, costs, and production time. For the customers, better fitness with faster delivery stimulates the desire of purchase and enhances their satisfaction.**

***Keywords* - mass customization, fashion, scanning, body dimensions.**

I. INTRODUCTION

Since the industrial revolution, the implementation of mass production has made great contribution to the manufacturers by reducing processing time and operational costs. Nevertheless, in the fashion industry, this is not the optimal solution to the changing needs of consumers. Due to the diverse body sizes and personal preferences, the desire for customization has become one of the issues of most concern. To meet the needs on both sides, mass customization opens new opportunities by combining the efficiency of mass production with the flexibility of customization.

Generally, the economies of mass production are realized by developing computer-aided production systems. The critical elements include collecting body sizes more precisely and rapidly with advanced instruments, generating clothing patterns automatically based on collected body dimensions, and building final products in the shortest time. Although many efforts have been devoted to each of them, there is a lack of an integrated system to enable efficient mass production. In addition to the appropriate arrangement of dataflow, it is necessary to involve the consumers in the processes as well. Therefore, we aim to develop a computer-aided production system by integrating the key elements to facilitate mass customization in the fashion industry.

Traditionally, body sizes were collected by using contact instruments, such as measuring tapes and calipers. However, the possible intra- and inter-observer errors may affect the precision of measurement. Besides, the measurement procedure tends to be tedious and requires considerable human efforts. In the 1990s, with the advancement of instrumentation, the 3D whole body scanner made it possible to measure human body efficiently with non-contact methods. By scanning through the whole body of human beings, 3D point clouds on the surface can be captured to enable body dimension collection [1] and [2]. Prior to dimension collection, it is necessary to identify some anatomical landmarks on the human body from the 3D scanning images. Previously, the pre-marking technique was adopted by putting color markers on the location of the landmarks to facilitate automatic identification [3]. This method has the advantage of high recognition rate, whereas it takes much time for pre-marking and incurs human errors. In order to eliminate human intervention, an automated landmarking method was then proposed [4]. By analyzing the geometric characteristics of the human body, the processing time is quite reasonable, and the precision is satisfactory as well. However, the rather high equipment cost and poor portability somehow limits the use of 3D scanners. Thus, an alternative approach is required for economic body dimension collection with both efficiency and economy.

By taking 2D photographs and analyzing the silhouette of human body, some linear body dimensions can be collected [5]. In addition, mathematical models can be developed to approximate circumference data. In this case, the image quality has to be maximized to increase the precision of measurement. Further, the color and background attributes need to be arranged in standardized conditions. Moreover, calibration of the camera is essential prior to photographing. Compared with the 3D scanner, the cost of a digital camera is much lower. The other advantage is that everyone can do the job well after taking some practice, as long as a digital camera is available. Nevertheless, the number of collected dimensions is relatively small, and the circumferences are approximated with less accuracy. Therefore, there is a trade-off between using 2D photographs and 3D scanning images for dimension collection.

Clothing patterns are generally generated by skilled pattern makers according to what they measured and observed. This task requires considerable expertise and experience and thus induces great labor costs. With the development of CAD/CAM technologies, the computer software can make it more efficient to generate clothing patterns [6] and [7]. Based on the mathematical expressions for required measures, the computerized construction of clothing patterns can be realized [8]. Besides, the computer-generated human models help to visualize the fitting results of the designed clothes in the virtual environment [7] and [9]. Due to the consistency of computer programs, patterns are created according to the same rules repeatedly. Moreover, the data can be stored and retrieved with ease. It has the flexibility of generating a different type of clothing pattern rapidly without taking the measures again. Based on the patterns generated by the CAD system, fabric cutting can be then performed in an easy and rapid manner.

As mentioned above, there have been some existing technologies enabling the automation of customized clothing making. However, they lack thorough and efficient integration of the respective processes. Thus, in this study, an integrated system was proposed for mass customization in fashion, including body dimension collection, pattern generation and fabric cutting. The technical details are described in the following two sections. Subsequently, the integration and application of the computer-aided production system will be presented.

II. Body Dimension Collection

The first step of customized clothing making is to collect body dimensions precisely. This relates to the level of fitness for the final product and hence affects the extent of customization from the physical aspect. At this stage, the computer-aided production system allows the user to select any among the three methods for body dimension collection. If the user has been measured previously, he/she may directly input the given data. Otherwise, the body dimensions can be collected either by using the 3D scanner or by taking 2D photographs.

A. From 3D scanning data

A Vitronic Vitus-3D 1600 whole body scanning system was employed to facilitate body dimension collection from 3D scanning data. Prior to scanning, the scanner has to be calibrated with a standard procedure, whereas the lighting condition is well-controlled to minimize noise. For assuring the integrity of 3D scanning data, the subject is asked to wear a set of scanning attire and cap, and to adopt a standard posture during scanning.

In order to measure body dimensions from 3D scanning data efficiently, an automated landmarking method has been developed by the authors [4]. By analyzing the natural geometry of the human body, no markers are placed on the body surface. After noise reduction, the whole body scan is segmented into body parts. Then the initial searches are performed to locate the possible positions of the landmarks based on the statistics derived from a large anthropometric database. After that, four algorithms are adopted to identify different kinds of landmarks. Each algorithm can help to extract several landmarks with similar characteristics.

With 12 landmarks and 3 characteristic lines extracted, 104 body dimensions can be obtained automatically. Linear dimensions such as heights, breadths, and depths can be measured by calculating the Euclidean distance between two landmarks. The circumferences and contour lengths can be calculated by using the convex-hull polygonal approximation method. The methods of landmarking and dimension collection have been evaluated with 189 human subjects and were found to be both effective and robust [4].

B. From 2D photographs

The alternative method for collecting body dimensions is to analyze the body silhouette extracted from 2D photographs. In this study, a SONY™ DSC-P9 digital camera was utilized for photographing. In order to ensure the image quality, a standard calibration procedure is adopted prior to photographing. Moreover, a calibration model is also built to reduce the distortion caused by the perspective effect.

The subject is required to stand in front of a mono-color background, with two photographs taken from the front view and side view. After the photographs are verified, the silhouette of human body is extracted for analysis. 36 landmarks are then identified manually to define the starting and ending points for a total of 23 linear dimensions. The calibration model is then applied to the calculated Euclidean distance to obtain the true values of the length, breadth, and depth measures. 13 height and breadth measures can be obtained from the front-viewed image, whereas the side-viewed image enables data collection of 10 depth and height measures.

Further, the collected dimensions are used to generate a 3D human model of the subject. This is achieved by building standard human models in advance and using the technique of template mapping to generate customized human model. There are six standard human models of different sizes for males and females respectively. By comparing the collected dimensions of the subject with the corresponding dimensions of the standard human models, the most fitted one can be identified as the template for the subject. Then the standard human model is deformed based on the key dimensions of each body segment. Thus, a customized 3D human model is constructed for the subject, which helps to collect 8 circumference measures. In other words, there are a total of 31 dimensions obtained for clothing making with the developed system.

To evaluate the dimensions collected from 2D photographs, comparisons were made against the body measurements obtained by the contact method and by the 3D scanning method. Ten subjects were measured with the three methods. The results showed that the measurement differences among the three methods are acceptable by considering the criterion given by experienced tailors [10]. In other words, the estimates of the circumference measures can be applied in apparel uses.

III. Pattern Generation and Fabric Cutting

After collecting body dimensions by using 2D photographs, 3D scanning images, or direct input, AutoCAD™ was then utilized to draw the patterns in electronic format. This is enabled by composing a script that defines the procedure of pattern drawing. Following the script step by step, the patterns can be drawn automatically with lines and curves. For different types or styles of the desired clothes, there is a variety of script models to choose from. In this study, script models of shirts, pants, skirts, and jackets are generated from a database which includes the information obtained from the pattern making books and the experience of skilled pattern makers. Further, each type of clothing also contains four to five styles with different script models. Subsequently, the parameters of the script model are specified based on the collected body dimensions. Taking the shirt pattern as an example, body dimensions such as bust circumference, back length, and shoulder width are required. As these key parameters of the script model are given, the lengths of the lines and the curvature of the curves can be calculated. Afterwards, it is ready to perform pattern drawing by using AutoCAD™.

While finishing pattern drawing, the system provides graphical preview of the patterns along with the specifications. This is for the user to have a glance at the generated pattern drawings. Once the user is satisfied with the outcome and agrees to proceed, the system will transfer the drawing into DXF (Drawing Exchange Format), which is compatible with the CNC laser-cutting machine. Going on to the next step of fabric cutting, human intervention is required to put the large piece of the selected fabric on the operation platform. Then the DXF file is loaded, and the CNC laser-cutting machine starts to perform the operation. After all, the pattern pieces can be obtained automatically in a short time. Then they will be ready for subsequent production processes, including sewing, fitting test, and final adjustment.

In order to shorten the processing time of pattern generation, the user is not able to make modification on the pattern drawings. Once the body dimensions are given with the selected fabric and style, the process is fully automated till the pattern pieces are cut out. Nevertheless, for the purpose of mass customization, the system allows the administrator to enrich the database of the script models for different styles or types of clothing. As the designer creates new style of clothing, it is necessary to compose the corresponding script model while the pattern maker generates the pattern for this new product. By updating the database in this way, the computer-aided production system continues to meet the changing demands in fashion.

IV. System Application

By integrating the above processes with garment sewing, fitting test and final adjustment, the customized clothing can be generated rapidly with little human effort. Thus, mass customization can be realized in the fashion industry. The flow chart of the computer-aided production system is illustrated in Figure 1. First, the user status is identified as either registered or not. For a registered user, the body dimensions that have been collected previously can be directly obtained from the database. If the user has not registered, he/she needs to sign up for a new account by entering the required personal information. Then, the body dimensions can be collected by 3D scanning, 2D photographs, or direct input. In the next step, the user selects the fabric and style as the parameters of pattern generation. After that, the clothing patterns are drawn automatically based on the body dimensions, as well as the selected fabric and style. By transferring and exporting the pattern drawings into DXF file, automatic fabric cutting is performed by the laser cutting machine. Subsequently, the pattern pieces are sewed by experienced staff. Finally, fitting test and adjustment are made to create the final product.

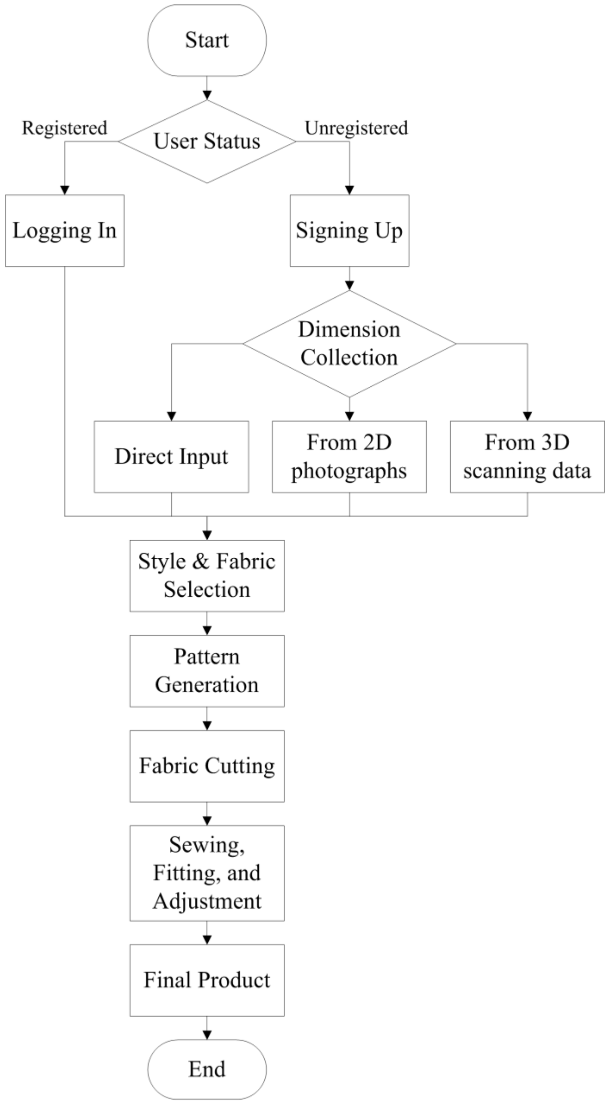

Fig. 1. Flow chart of the computer-aided production system

In order to provide a better understanding about how the system is implemented and what benefits it brings to us, two scenarios of mass customization with the computer-aided production system from the customer’s perspective are described in the following section. Scenario 1 is a case of shopping at a store, which is similar to the traditional shopping pattern. Scenario 2 is based on the use of Internet, which enables online shopping of customers. These scenarios help to illustrate how the computer-aided production system contributes to the realization of mass customization in the fashion industry.

A. Scenario 1: Customer shopping at the store

Following the traditional shopping pattern, the customer goes to the store, takes a look at the samples, takes body measurement, specifies personal preferences, and then makes decision. The difference is that the customer may use this system to shorten the processing time of customized clothing making. In the beginning, the system asks the customer either to log in as a registered user or sign up for a new account, as shown in Figure 2. For a registered user, the body dimensions can be retrieved from the database just after logging in to the account. Of course, if the user finds that the stored dimensions are no more fitted for him/her, it is possible to adopt either of the two methods for dimension collection. For a new user, after creating a new account, the whole body images can be taken and analyzed to collected body dimensions from 3D scanning data (Figure 3) or 2D photographs. Alternatively, the user can choose to make direct input, as long as the required dimensions have been collected in advance. Going on to the next step, the user selects the preferred fabric and style (Figure 4), and the collected body dimensions can be applied to generate pattern drawings immediately. As illustrated in Figure 5, a window will pop out to show the pattern sketch. After the system transfers the pattern drawings into DXF file, the customer may leave the store and just wait for the fitting test and adjustments. During this period, the pattern pieces are cut automatically by the laser-cutting machine and sewed together by experienced tailors. With this computer-aided production system, the production time and labor costs can be greatly reduced. Thus, the expense for customized clothing making can be reduced and hence leads to a lower price. With the realization of mass customization, the customers are able to purchase fitted clothing at lower price and faster delivery.

B. Scenario 2: Customer shopping online at home

Alternatively, the customer may choose to shop online at home. One possibility is to adopt the dimensions that were collected previously. Another possibility is to take the 2D photographs from both front and side view by the user at home. Of course, it is necessary to follow the standard procedures, so that the photographs can be in required format and quality. After uploading the images to the system via the Internet, the system will analyze the images and produce the required body dimensions for the user. Subsequently, the user continues the following process as described in scenario 1. The difference is that the customer only has to go to the store for fitting test and final adjustment. In this case, the computer-aided production system benefits the customer more by providing a shopping-at-home service.

Fig. 2. User logging in or creating a new account

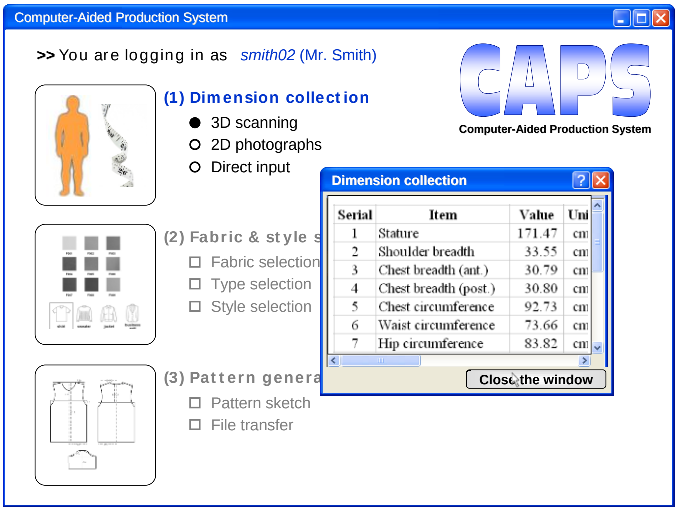

Fig. 3. Dimension collection from 3D scanning data

V. Future Research Directions

The developed computer-aided production system automates the processes of dimension collection, pattern generation, and fabric cutting. However, human efforts are still required to sew the pattern pieces. If the process of garment sewing can be computerized, the production system can be integrated in a better way to realize fully automated production of customized clothing. Further, collecting body dimensions from 2D photographs requires some human intervention in landmarking.

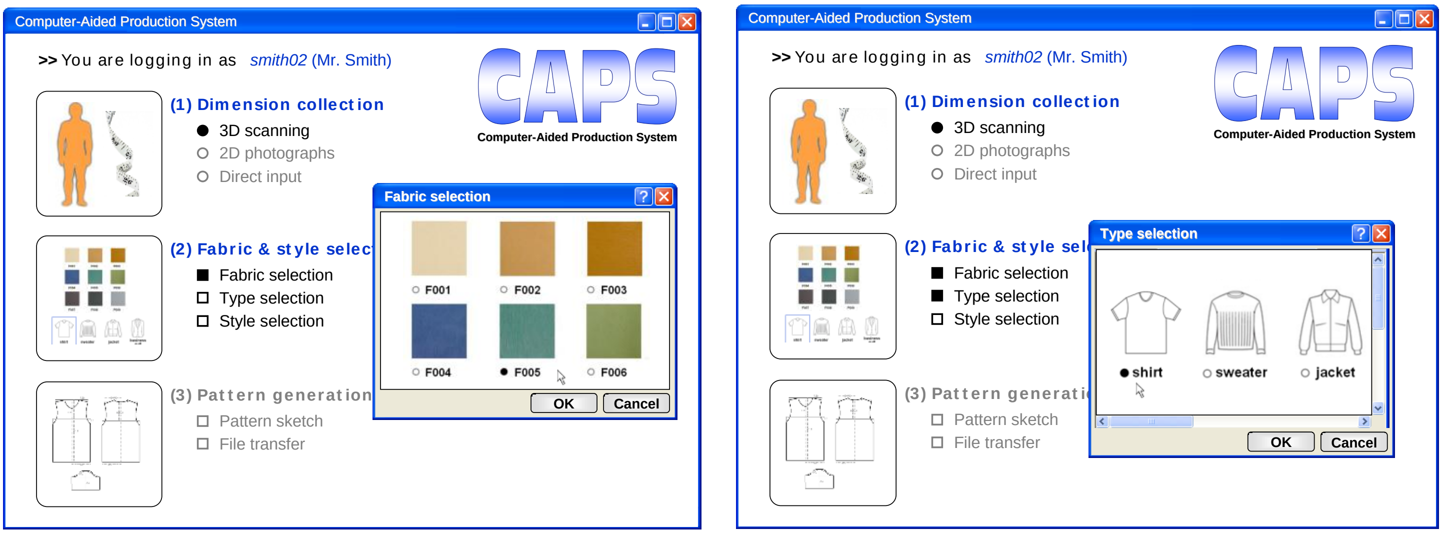

Fig. 4. Selection of clothing fabric (left) and style (right)

It is necessary to develop a fully-automatic method for landmarking from 2D images. Moreover, virtual try-on opens opportunities for enabling the customer to try on 3D clothing in the virtual environment. It requires the development of both human models and clothing models. While using the 3D scanning images or 2D photographs to collect body dimensions, the 3D human model should be further constructed to achieve this goal. In addition, the 2D pattern pieces can be assembled in the 3D environment to make 3D clothing. Subsequently, collision simulation of clothing and human body can realize virtual try-on. These issues are important topics in the development of computer-aided production system. And they give future research directions for mass customization in fashion.

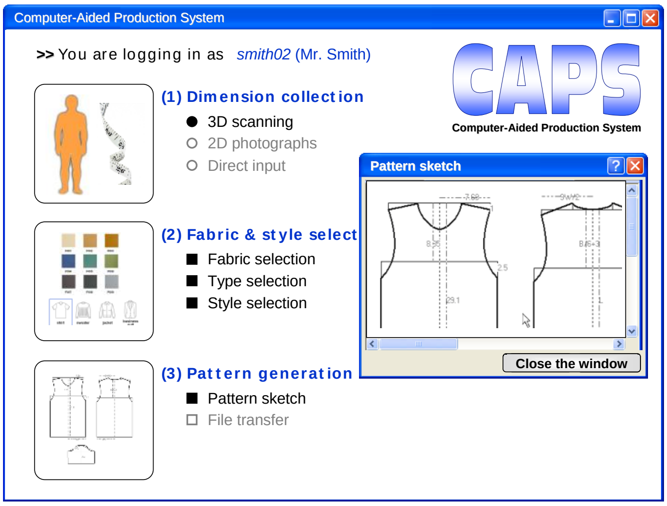

Fig. 5. Sketch of the generated pattern

VI. Conclusion

A computer-aided production system has been developed for mass customization in fashion. The system involves body dimension collection, pattern generation and fabric cutting. Body dimensions can be collected by using 3D scanner, 2D digital camera, or direct input. For different types of clothing fabric and style, patterns can be generated based on the collected dimensions. After transferring the pattern drawings into DXF file, the CNC laser-cutting machine cuts the fabric into pattern pieces automatically. Integrating the system with processes of garment sewing, fitting test and final adjustment, mass customization can be realized in the fashion industry. By enhancing the fitness while reducing labor costs and processing time, the computer-aided production system can improve not only customers' satisfaction but also the manufacturers' profits. In the future, further studies are required to achieve the full automation of mass production for a revolutionary change in the fashion industry.

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