An intelligent system for customized clothing making
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Abstract: - This study presents the development of an intelligent system for customized clothing making. The system involves body dimension collection, clothing pattern generation and fabric cutting. First, body dimensions can be collected by analyzing the 3D scanning images or 2D photographs. Further, the clothing patterns can be generated by using computer-aided design (CAD) techniques based on the collected dimensions. By presenting the generated clothing patterns in DXF (Drawing Exchange Format), the CNC laser-cutting machine can then cut the fabric into pattern pieces automatically. Finally, by integrating the system with the processes of garment sewing, fitting test and final adjustment, the concept of customized clothing making can be realized. It can not only assure good fitness of the customized clothing but also reduce human efforts, costs, and production time.

Key-Words: - 3D whole body scanner; body dimension collection; customized clothing making

1 Introduction
Nowadays, there is a growing demand from consumers to purchase customized products at lower prices with faster delivery. For manufacturers, reducing production time and saving personnel expenses contribute to the increase in competitiveness and the further growth in profits. In the apparel industry, in order to meet these needs on both ends, the concept of mass customization may be among the best solutions. The critical issues are using advanced instruments to collect body dimensions rapidly, applying CAD/CAM (Computer-Aided Design/Manufacturing) technologies to generate clothing patterns and to cut fabric automatically, and developing an integrated system to facilitate efficient production.

Traditionally, body dimensions were collected by using direct measurement instruments, such as calipers and measuring tapes. Nevertheless, the precision of the measurements may be affected by intra- and inter-observer errors, and the measurement procedure tends to be tedious and time-consuming. With the advancement of modern optical technologies, it is now possible to measure human body efficiently with non-contact methods. The 3D whole body scanner is a state-of-art optical measurement system. By scanning through the human body, 3D point clouds on the body surface can be captured, and further applications such as body dimension collection can be performed [1, 5]. For the purpose of effective dimension collection, some anatomical landmarks on the human body need to be specified in advance. Previously, color markers were utilized by putting them on the locations of the landmarks to help for easy identification [9]. This method was quite effective but required much time for pre-marking and may incur human errors. In order to eliminate the requirement of human intervention, an automated landmarking method was proposed [3]. It reduces the processing time greatly and provides satisfactory accuracy and precision at the same time. However, the application of 3D scanning technology is somehow limited due to the equipment cost and the poor portability. Thus, an alternative approach is required for collecting body dimensions.

With front-viewed and side-viewed 2D photographs, it is also possible to collect some basic body dimensions, such as heights and lengths [4]. Besides, by applying some mathematical models, circumference data can be approximated. In order to obtain the quality image of human body, the color and the arrangement of the background have to be well controlled. And the camera has to be calibrated every time before a photograph is taken. The cost of a digital camera is much less, and it is much
easier to use as comparing with the 3D body scanners. However, the number of collected body dimensions is relatively limited, and the approximated circumferences may be less accurate. Therefore, there is a trade-off between using 3D scanning data and 2D photographs for body dimension collection.

For clothing pattern generation, it was usually done by skilled pattern makers based on the collected body dimensions and the shape features they observed. This requires a great amount of expertise and experience and thus induces considerable labor costs. With the development of CAD/CAM technologies, the computer software can now substitute for the role of clothing pattern generation [2, 8]. Based on the mathematical expressions for necessary measures, the computerized construction of clothing patterns can be developed [6]. Besides, with the computer-generated human body models, patterns can be created and evaluated in a virtual environment [2, 7]. Due to the consistency of computer programs, patterns can be generated using the same rule repeatedly. Moreover, the data can be stored and retrieved with ease. It has the flexibility of generating a different pattern rapidly, without taking the measurements again. As for fabric cutting, the CAD/CAM technology also enables automatic cutting of fabric based on the patterns being generated by computer programs with machines. As mentioned above, there are some potential technologies that can enable the automation of customized clothing making. However, it lacks thorough developments and efficient integration of these processes. Thus, in this study, an intelligent system was proposed for customized clothing making, including body dimension collection, garment pattern generation and fabric cutting. The two methods of body dimension collection are illustrated in the following section. Then the procedure of clothing pattern generation and fabric cutting are described in the next section. Finally, the integration and application of the system are presented.

2 Body Dimension Collection

In this study, two methods were proposed for body dimension collection. One is based on 3D scanning data, and the other is based on 2D photographs. The users may select either of the methods according to their needs.

2.1 Based on 3D Scanning Data

A Vitronic Vitus-3D 1600 whole body scanning system was employed to construct 3D digital human models and to help to collect body dimensions. Prior to scanning, the scanner has to be calibrated, whereas the lighting condition is well-controlled. For assuring the quality of scanning images, the subject was asked to wear a set of scanning attire and cap, and to adopt a standard posture for scanning.

In order to measure body dimensions from 3D scanning data efficiently, an automated landmarking method has been developed by the authors [3]. After noise reduction, the whole body scan can be first segmented into body parts. Then the initial searches were performed to locate the possible positions of the landmarks based on the statistics derived from a large anthropometric database. After that, four algorithms were adopted to identify different landmarks. Each algorithm can help to extract several landmarks with similar characteristics. With the 12 landmarks and 3 characteristic lines extracted, we are able to obtain body dimensions by using the approximation methods. 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. Finally, 104 body dimensions can be collected. And the method has been evaluated with 189 human subjects and was proved to be both effective and robust [3].

2.2 Based on 2D Photographs

The alternative method for collecting body dimensions is based on the image analysis of 2D photographs. A SONY™ digital camera was used in this study. Prior to photographing, the camera has to be calibrated with the standard procedure. In order to reduce the distortion caused by the perspective effect, the calibration model has to be built in advance. A horizontal line and a vertical line with specified lengths were taped on a 2.0 m × 1.0 m frame. For
obtaining the correct value of the horizontal distance \( DH_{\text{correct}} \), the measured value \( DH_{\text{measured}} \) should be multiplied by the ratio of the specified length of the horizontal line \( LH_{\text{specified}} \) to its measured value \( LH_{\text{measured}} \). Similarly, the vertical distances can be corrected by the same method.

\[
DH_{\text{correct}} = DH_{\text{measured}} \times \frac{LH_{\text{specified}}}{LH_{\text{measured}}} \tag{1}
\]

\[
DV_{\text{correct}} = DV_{\text{measured}} \times \frac{LV_{\text{specified}}}{LV_{\text{measured}}} \tag{2}
\]

While taking photographs, the subject was asked to stand in front of a mono-color background with two photographs being taken from the front view and side view. After the two photographs were taken and verified, the images were analyzed by using the developed system. 36 landmarks can be identified manually to define the starting and ending points for collecting body dimensions. Then a total of 23 linear dimensions can be collected automatically. The 13 height and width measures were obtained from the front-viewed image (left), while the side-viewed image enables data collection of the 10 depth measures (right).

In addition, the collected dimensions were used to generate a 3D model of the subject. There had been six standard human models of different sizes for males and females. After comparing the collected dimensions of the subject with the corresponding dimensions of the standard models, the most fitted one can be chosen. Then the standard human model was 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 totally 31 dimensions obtained for clothing making with the developed system.

To evaluate the dimensions collected from 2D photographs, comparisons were made with the measurements obtained by the contact method and by the 3D scanning method. For the 10 subjects tested with the system, the differences of the measurement results among the three methods were found to be acceptable by considering the criterion given by experienced tailors [10]. In other words, the proposed system has a satisfying accuracy for the industrial uses.

3 Clothing Pattern Generation

After body dimension collection, AutoCAD™ was used to generate the drawing of clothing patterns. First a script was composed to define the process of generating the clothing pattern. The content of the script is expressing the steps that a pattern maker draws the lines and curves to create the pattern. The composition of the clothing patterns can be generated by using the knowledge collected in the pattern making books and references. In this system, several types of clothing patterns are presented, including shirts, pants, skirts, and jackets. Users may choose the desired one, and the corresponding clothing pattern will be generated automatically.

Taking a shirt as an example, the drawing of the pattern is based on chest circumference, back length, sleeve length, and shoulder width. Figure 1 illustrates part of the script that generates the pattern of a shirt. In the first row, the bust circumference, back length, and shoulder width of the customer was represented by B, BL, and SW, respectively. Then the six constants in the next row were based on the information given by the pattern making books and references. Starting from the third row, the pattern of a shirt was generated by drawing lines and curves. The lengths of the lines were determined by using the parameters mentioned above, including the body dimensions and the constants. And the curves can be depicted either by giving the starting and ending points with the curvature parameter or by setting the starting, middle, and ending points. Finally, the pattern can be obtained in the form of a simple drawing.

Once the CAD file of the pattern drawings is created, it can be exported in DXF (Drawing Exchange Format) which is compatible with the CNC laser-cutting machine. After selecting the appropriate fabric and cut it automatically into pattern pieces, it will be ready for subsequent production processes.
4 Conclusion

An intelligent system for customized clothing making has been developed in this study. The system consists of body dimension collection, clothing pattern generation and fabric cutting. Two alternatives for body dimension collection were proposed, by using either the 3D scanning data or the 2D photographs. By referring the rules of pattern making, the collected dimensions can be further converted to a graphical representation of clothing patterns in CAD format. Then the CNC laser-cutting machine can operate with the file for automatic fabric cutting. By integrating the system with the process of garment sewing, fitting test and final adjustment, the concept of mass customization can be realized. Besides, after testing on a scaled human model, the system has been proved to be feasible in industrial use. It can not only assure good fitness of the customized clothing but also reduce human efforts, costs, and production time.

Figure 1 A part of the script that generates the pattern of a shirt

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