TDTOS – T-shirt Design and Try-On System

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Abstract— **In this paper, a new framework for T-shirt design and try-on simulation based on FPGA is presented. Users can not only gain realistic try-on experience, but also design the T-shirts all on their own. The design approach of this system consists of three major parts. First, collect relevant information from the camera and identify the position of the clothes. Second, process the retrieved data and modulate the color of the clothes with folds and shadows remained. Third, place built-in or user-designed pictures onto the clothes and simulate their deformation while the user moves arbitrarily. In comparison with existing virtual clothes fitting systems, our system provides the flexibility of designing customized pictures on the T-shirt with realistic virtual try-on simulation in real-time.**

Keywords— **Virtual clothes try-on, T-shirt design, augmented reality, Virtual fitting room, FPGA design**

I. INTRODUCTION

In the past, customers could only decide to buy a clothes or not on 2D photos of garments when shopping online. Customers could not know whether the clothes fit them well or whether the clothes look good on them until they got it. This may substantially reduce the willingness of customers to purchase apparel online. Therefore, online sales of Apparel & Accessories, a product type for which customers' desire to feel and try on items before making a purchase, was traditionally regarded as a deterrent to online shopping [1]. However, as some improvements such as free returns and innovative visualization tools have been used, online sales of Apparel & Accessories have gradually become a success. In recent years, the Internet has emerged as a compelling channel for sale of apparel. Online Apparel & Accessories sales exceeded $34 billion in 2011, and are expected to reach $73 billion in 2016 [1].

One of the most well-known visualization tools may be virtual try-on systems (or virtual fitting room). Through these systems, customers may have more realistic feel for the details of the garments. Currently, a variety of different kinds of virtual try-on systems is presented, which will be discussed later in Section II. All of them could simulate what we looks like as if we are wearing the clothes to some extent. Nevertheless, they all face the same problem that the results are not real enough. Some systems may not fit clothes on users well, and some may not react to users' motion in real time. In order to solve these problems, we present TDTOS, T-shirt Design and Try-On System.

Different from the existing methods, TDTOS comes up with some brand new ideas. TDTOS not only retrieves users' body information, but also records many useful clothes information, such as the lightness of the cloth. Through the combination of these data, TDTOS therefore can vividly simulate a real T-shirt with folds, shadows and deformable pictures on it. The virtual try-on results will also response to user's body motion in real-time.

The remaining part of this paper is organized as follow: related work is discussed in Section II. In Section III we present the system architecture. Then, in Section IV, we introduce the core techniques of TDTOS. The results are shown in Section V. Finally, Section VI concludes.

II. RELATED WORKS

In this section, we will discuss some of the recent works and implementation methods on virtual try-on systems (VTS). Zugara [1] first introduced the Webcam Social Shopper, a web cam-based VTS. Using marker detection techniques [2], it detects the marker on a paper to adjust the size and position of the clothes image. JC Penny partnered with Seventeen.com [3] also presented a VTS by attaching the clothes images on a pre-set silhouette on the screen. User can try-on clothes by placing her/himself in the right position. Both of the above two methods require only the camera on a computer to realize a VTS. However, in these cases clothes cannot change its position with user motion. In addition, clothes attached on the screen are 2-D images, so the users cannot fit the clothes in 3-D augmented reality.

Some designs allow virtual clothes to fit on the user when one is moving. Pereira et al. [4] presented a webcam VTS based-on upper body detection. Garcia et al. [5] also proposed a VTS using head detection to fit the clothes. Later version of the Webcam Social Shopper developed by Zugara also adopted head tracking to better place the virtual clothes on the user. Though body tracking techniques enable placing the clothes according to user's position in real time, the lack of 3-D information makes it difficult to create a virtual fitting system with 3-D augmented reality effect. These VTS design can only place a 2-D image on the user's body.

As body modeling techniques keep improving, more virtual try-on systems using robotic modeling or 3-D scanning model are proposed. Fits.me [6] applied the robotic science to create a VTS on the website. Once the user inputs a series of measurements of the body, the try-on results for clothes of different sizes on a robotic mannequin are shown. Instead of creating a real robotic mannequin for virtual try-on, both Styku [7] and Bodymetrics [8] adopt 3-D body scanning techniques using Microsoft Kinect or Asus' Xtion. The scanner creates a 3D virtual model of the user and allows one to analyse the fitness of the try-on clothes results through a color map. Using sophisticated robotic models or accurately measured scanning models produces realistic try-on results. As a trade-off of the accuracy, those systems cannot present try-on results with body motions in real-time.

With a depth and motion capture device, such as Microsoft Kinect or Asus' Xtion, virtual try-on systems that enable real-time clothes fitting can be designed more easily. In addition, various computer graphic algorithms for clothes modeling have been proposed in the past [9]-[14]. Coming both the motion sensing and garment modeling techniques, Swivel [15], AR-Door [16], Fitnect [17], and Fitting Reality [18] all presented their different implementations of VTS. Pachoulakis et al. reviewed some of the recent examples of virtual fitting room and their implementation concepts in [19]. Those try-on systems first capture the user's body motion and then superimposed 3-D clothes models on the user's image. For this reason, although the systems enable virtual try-on in real-time, sometimes the virtual clothes images may not precisely fit the user. Besides, the only clothes that a user can try-on are limited to the garment model database. It is difficult for a user without computer graphic experience to design one's own wearing clothes.

In this paper, without using a depth and motion capture device, we utilize DE2-70 FPGA board and its camera module, combining both image processing and FPGA hardware implementation techniques to design TDTOS. This system enables real-time virtual try-on with all the folds and shadows on the shirt vividly preserved. Instead of superimposing garment models on the user image, TDTOS precisely modulate the user's clothes image to present the effect of virtual try-on. In addition, user can easily design pictures to put on the shirt by one's own drawing. The picture can also move and deform as the T-shirt is pulled or folded. TDTOS is a new solution for realistic virtual try-on and T-shirt design in real-time.

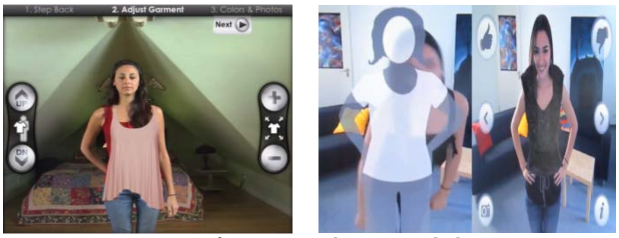

Fig. 1. Left: Zugara Webcam Social Shopper. Right: Seventeen.com virtual fitting room.

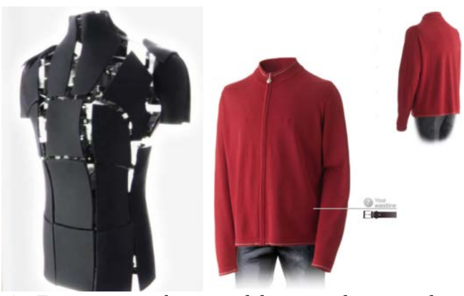

Fig. 2. Fits.me uses robotic models to simulate virtual try-on

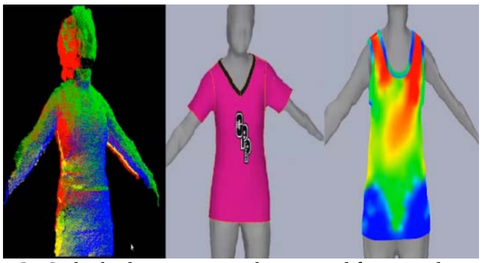

Fig. 3. Styku body scanning technique and fitness color map

Fig. 4. Bodymetrics scanning system and fitness color map

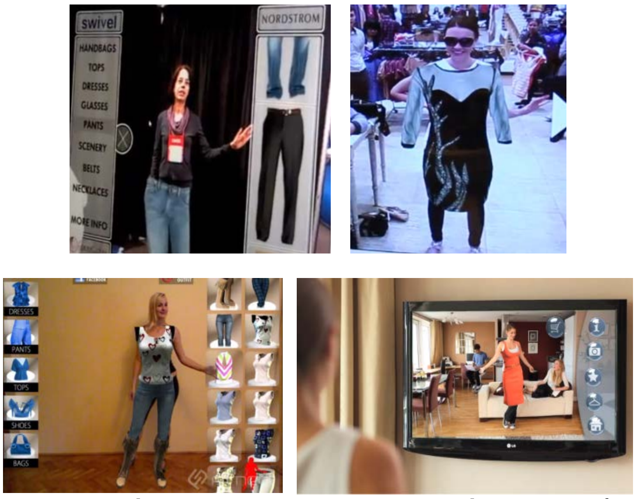

Fig. 5. Virtual try-on systems using motion sensing devices. Top Left: Swivel virtual dressing room. Top Right: AR-Door Kinect fitting room. Down Left: Microsoft Fitnect. Down Right: Fitting Reality's VIPodium.

III. System Architecture

In this section, we are going to introduce the design architecture of our system. Figure 6 is the data flow diagram, which provides a simple view of how our system functions. Figure 7 is the system block diagram, in which the relationships between modules are shown. These modules can be roughly classified into four parts: Image Retrieval, Memory Control, Image Processing and Detection, and Input/output Interface. A brief introduction of each part is as follow:

A. Image Retrieving

A 5-Mega Pixel Camera is used to capture images. Together with modules *CCD Capture* and *RawtoRGB*, we could get the RGB values of all pixels, which will be the data of the following process.

B. Memory Control

The retrieved images mentioned above are temporarily saved in SDRAM, and the built-in pictures are saved in

FLASH memory. In order to achieve real-time processing results on VGA output, SSRAM is used as the buffer memory for data to be processed. Both the built-in pictures and the user-designed pictures will be buffered in SSRAM before processing.

C. Image Processing and Detection

This part can be view as three steps. First, *Clothes Detection* uses skin color to filter out the skin part and identify the boundary of the clothes. Second, after knowing the region of the clothes, *Color Adjusting* changes the clothes' color with folds and shadows retained. Third, *Pattern Adjusting* analyzes the customer's motion and adjusts the picture's looks with proper deformation in real-time.

D. Input/Output Interface

Using switches and keys on the DE2-70 FPGA board, users can control the systems with desired command. The final try-on simulation results will be output through *VGA controller* to the monitor.

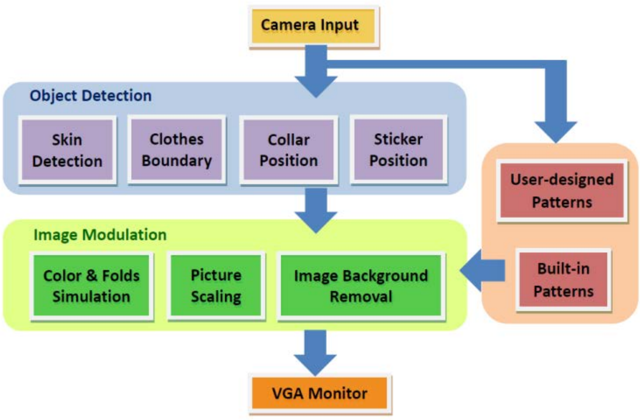

Fig. 6. Data flow diagram

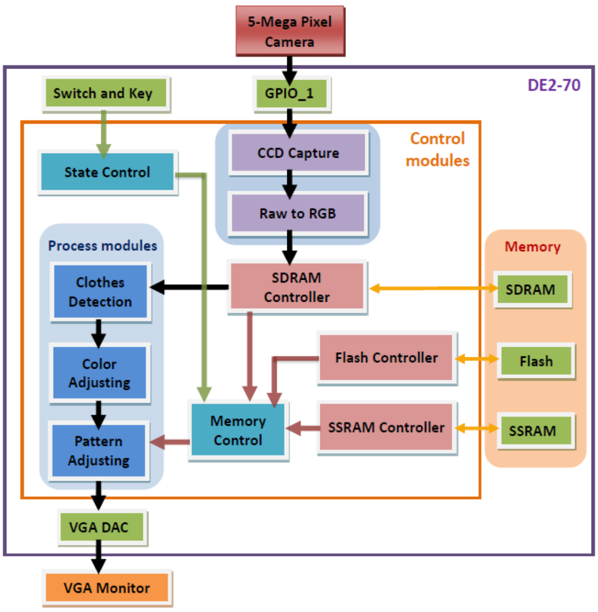

Fig. 7. System block diagram

IV. TECHNIQUES

A. Key Concept

For the existing wearing try-on simulation systems, one of the major problems is that how to make the clothes moves, rotates, and even folds according to our body motions. The traditional way is to modify an existing target clothes image and superimpose it onto the image of the users, such as how Fitnect and VIPodium do. The outline of the target clothes usually does not match the outline of the user body. Even if the image is scaled to the size of the body, there are still many positions that the outlines do not coincide and the clothes seem weird on the users. What's more, the folds and shadows have to be created according to the body motions, which is extremely difficult and requires lots of computation. The clothes eventually seem unreal because the shapes are mismatched and the folds and shadows are disappeared.

However, we do not need to create the folds and shadows actually. The folds and shadows already exist on the original T-shirt that the users are wearing. Besides, the outline of the original T-shirt is also perfectly matching the body of the users. Therefore, our key concept is that, instead of modifying the target T-shirt to fit the body motions, we combine the folds and shadows information from the original T-shirt with the color and pattern of the target T-shirt to simulate a real T-shirt vividly. As a result, the new T-shirt on the user is perfectly matching and folding according to the body motions.

Fig. 8. Key concept for TDTOS's design

B. Skin Detection

To identify the original T-shirt on the users, skin detection is required to filter out the skin part. According to the research of Basilio et al. [21], the color of skin is more explicit in YCbCr color space. Therefore, we transform the color of each pixel to YCbCr color space and determine whether it is skin by the following conditions.

$$\begin{cases} Y > 50 \\ Cb < 120 \text{ or } Cb > 150 \\ Cr < 200 \end{cases}$$
$$\text{where } Y, Cb, Cr = [0,255]$$

The thresholds are slightly modified because of the different races. The conditions are designed to work well on the Asians. In Figure 9, the left image is taken from a user and the skin part is detected and colored red in right figure.

Fig. 9. Skin detection result. The Skin part is detected red in the right figure.

C. Clothes Positioning

After the skin is detected, the region of the T-shirt could be identified as well. The image is scanned row by row from top to bottom. For each line, after filtering out the background and the skin part, the remaining part is treated as the T-shirt. However, in order to tolerate the inevitable noises and skin on the T-shirt, we apply the maximum sub-array algorithm. Therefore the outline of the T-shirt could be precisely determined even if there is some noise or false detection of skin on the T-shirt. The pseudo code of the maximum sub-array algorithm is shown as following.

```
Procedure IdentifyShirtRegion
Input: a Boolean array indicating whether each pixel in a line is clothes' color
Output: Left, Right, two indexes indicating the T-shirt region

sum = 0; max_sum = 0; start = 0; end = 0; Left = 0; Right = 0;
For each pixel in the line from left to right
        If the pixel is clothes' color Then sum += 5
        Else
                If sum>1 Then sum -= 2
                Else sum = 0
                End-if
        End-if

        If sum == 0 Then
                start = index of the current pixel
        End-if
        end = index of the current pixel
        If sum > max_sum Then
                Left     = start
                Right    = end
                max_sum  = sum
        End-if
End-for
Return Left, Right
```

Fig. 10. The clothes identification maximum sub-array algorithm.

D. Folds and Color Changing

After identifying the region of the T-shirt successfully, we could modify the color according to the target color. As mentioned before, the original color is not simply replaced by the target color. On the contrary, the target color is mixed with the original one by the following formula. The new RGB values of each pixel are calculated by the formula, which considers both the brightness of the shirt image and the target color. Therefore, not only the T-shirt turns out in a new color, the original folds and shadows are also shown as well.

$$New_X = Target_X \times \frac{(Orig_R + Orig_G + Orig_B)/3}{1024},\ X = \{R, G, B\}$$

E. Picture Selection

We provide two ways to choose a pattern of the target T-shirt. The first method is choosing from our built-in pictures. Each picture is 500 pixels in height and width, and is 0.5 MB in total. Therefore an 8MB Flash memory could store 16 pictures. In addition, since built-in pictures are stored in the Flash, reading data from flash has delay problems. Therefore we use the SSRAM as a buffer. After copying the data in Flash to SSRAM once, we could use SSRAM instead of flash to achieve real time performance.

The second way is to use a user-designed picture. One could arbitrary draw its own T-shirt picture in his/her own way, and then use our camera to take a picture of the drawing. After taking the photo, the image will be processed. First, the white background will be removed so that when changing T-shirt color, the image will not have the white background. Second, we apply a series of complex memory manipulation on SSRAM, sharing the buffer memory resources with both flash and SDRAM, so that the users could still switch between built-in pictures and user-designed picture easily. Finally, the user could put the user-designed picture on the T-shirt.

F. Picture Placement

After choosing a picture, one could place the picture by two ways as well. The first method is using collar detection and hand gestures. In this mode, the picture would be place under the collar by default. We could detect the position of the collar by maximum sub-array algorithm as before. If the skin part is less than 100 pixels and the clothes width is larger than 800 pixels, the center of skin line would be identified as the position of collar. One could also set the position of the picture by gestures. When pointing down with hands, the position of fingers can be detected by a similar method of collar detection. The system will remember the displacement between the position specified by gestures and the collar, so the picture could be placed to the desired place afterward.

In the second method, users could not only move the picture, but also scale the picture to any size simply by 3M stickers. The positions of the stickers could be detected by maximum sub-array algorithm as described before. The top left red stickers specifies the position of the top left corner of the picture, and the right green sticker and bottom red sticker specify the right and bottom edge of the picture. The picture is scaled both in width and height accordingly. To overcome the delay of calculation, we use pipelines to maintain real time performance.

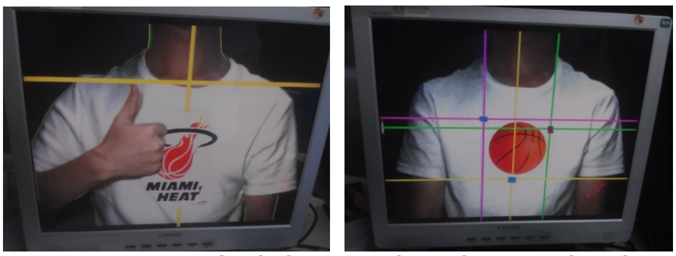

Fig. 11. Two ways to place built-in or user designed picture on the T-shirt. Left: Picture placed by collar detection and adjusted by user gesture. Right: Picture placed by sticker detection with deformation simulation

V. Results

A. Color Changing

The color of the T-shirt could be changed to arbitrary color by users. In the demo pictures, Figure 12, we showed how it is changed to the primary colors and their combinations. The simulated T-shirt has the folds and shadows as well. In addition, both hands can move freely in front of the T-shirt and do not affect the coloring effect at all. In Figure 13, it is shown that even when the user turns back, the T-shirt is colored as well.

Fig. 12. The original white T-shirt and transformation of different colors.

Fig. 13. The back of the user is fully colored.

B. T-shirt Pictures

After color changing, we can choose the picture to put on the T-shirt from built-in pictures and user designed pictures.

1) Built-on Pictures: The system provides up to 16 built-in pictures for users to place on to the T-shirt. The pictures are automatically placed on the chest of the users. The following figures show two example pictures. Please note that even the hands are in front of the T-shirts, the pictures are not affected just like a real T-shirts.

Fig. 14. Try-on results with built-in pictures

2) User-designed Pictures: Users could draw their own pictures and easily put them onto the T-shirts. This feature allows anyone to design its own T-shirt and try it on immediately. By using our system's camera to take a photo of the picture, the picture is saved by the system and placed on the chest by default. The following figure shows one of the designed T-shirt on our own.

Fig. 15. Left: Draw a picture and take a photo by the camera. Right: The user-designed picture is then on the T-shirt.

C. Picture placement

The picture is placed on the chest by default. However, it is convenient to move the picture to the desired position. We provide two ways to move the picture: Using gestures and using stickers.

1) Placement by Gestures: This is the simpler way to move the position of the picture. By pointing down the target position, the system will detect and memorize the desired position. After the gesture adjustment, the picture could be placed to the any desired position at any time.

Fig. 16. The picture is moved along with the hand gesture.

2) *Placement by Stickers*: In this method, the picture position could be conveniently indicated by three 3M stickers. The picture will be scaled and placed in the sticker-specified area. Therefore, it is easy to shrink or enlarge the picture as well, which makes the design of T-shirts more conveniently. In addition, because that the picture is placed in the stickers, it could moves, shrinks, expands, deforms or even rotates with the body motions of the users. All the folds and shadows in the region of the picture will also retain as the picture deforms, which makes the try-on results highly realistic.

Fig. 17. Using stickers to indicate the position and size of the picture

Fig. 18. Left: The picture deform with folds and shadows retained. Right: The picture rotate as the user is rotating one's body

VI. CONCLUSIONS

In this paper, we presented TDTOS, a new framework for T-shirt design and try-on simulation based on FPGA implementation. Instead of modifying the existing clothes models to fit the body motions, we utilize the information from the original T-shirt image to simulate the virtual try-on results realistically. The color of the T-shirt could be changed arbitrarily with all the folds and shadows retained. Built-in pictures or user-designed pictures could be placed on the T-shirt by hand gestures or 3M stickers. When we use stickers to locate the picture, all the folds and shadows on the picture will also retained as the picture deforms with user's body motion. Combining the new design concepts with implementation techniques, TDTOS provides the flexibility of designing customized pictures on the T-shirt with highly realistic virtual try-on simulation in real-time.

ACKNOWLEDGMENT

We would like to express our gratitude to Altera® Inc. and Terasic® Inc. for their sponsor and support for our project in the Innovate Asia Altera Design Contest 2012. Moreover, we also wish to acknowledge Professor Shao-Yi Chien and Department of Electrical Engineering, National Taiwan University for the excellent training and providing us with the chance to fulfill this project.

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