

A virtual try-on system in augmented reality using RGB-D cameras for footwear personalization

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ABSTRACT

This paper presents a system for design evaluation of footwear using commercial depth-sensing technologies. In a mixed reality environment, the system allows users to virtually try on 3D shoe models in a live video stream. A two-stage object tracking algorithm was developed to correctly align shoe models to moving feet during the try-on process. Color markers on the user's foot enabled markerless tracking. Tracking was driven by an iterative closest point (ICP) algorithm that superimposed the captured depth data and predefined reference foot models. Test data showed that the two-stage approach resulted in increased positional accuracy compared with tracking using only surface registration. Trimming the reference model using the instant view angle increased the computational efficiency of the ICP algorithm. The proposed virtual try-on function is an effective tool for realizing human-centered design. This study also demonstrated a new application of RGB-D cameras to product design.

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1. Introduction

Modern consumers seek personalized products and services in a consumer environment characterized by mass production [1]. In addition to functional requirements, designers must consider a product's emotional appeal, induced by product styling, as well as other affective attributes. The esthetic appeal of a product plays a crucial role in its success. Consumers tend to look for design elements that reflect their own tastes and allow them to differentiate themselves from other people. Evaluating whether and how much a design fits its users are critical in product customization and personalization [2]. This is particularly obvious in the apparel and fashion industries, in which designers must realize three essential dimensions of customization: fit, functionality, and esthetic design [3]. Recent progress in information and communications technology (ICT) has provided tools for realizing this challenging task.

Computer-aided design (CAD) has accelerated the product design process by automating the construction of product models, CAD also supports downstream manufacturing tasks, such as process planning and NC tool path generation. Most existing CAD tools were constructed by designers from an engineering perspective, and are not optimized for product users. Augmented reality (AR) and mixed reality (MR), in which virtual models generated based on

computer graphics are superimposed over real objects and scenes, are considered more usable interaction technologies for product design [4,5]. This is particularly useful in evaluating the design of fashion products, such as apparel, footwear, and wearable items. In one study, most users found virtual try-on systems driven by personalized avatars to be useful, but expressed dissatisfaction that the created avatars were not sufficiently realistic or accurate [6]. Facial models used in a virtual hairstyle design program exhibited the same problem [7]. Moreover, markers and special patterns have been used in most applications to position virtual objects within real scenes [8]. The presence of large markers inevitably reduces the usability of those applications, because they are occlusions that lower visualization quality. Reducing the use of markers, or reducing the size of the markers, is advantageous in evaluating fashion product designs.

2. Related works

The ability to personally design products and instantly interact with the resulting designs is highly desirable for customers. The idea of design automation has been realized for free-form products using CAD techniques [9]. Apparels can be automatically re-constructed to accommodate the differences in individual body shape and size [10]. Implementing design personalization in an AR environment is also a promising approach to achieving this goal. Recent progress in depth-sensing technologies has enabled new applications in various industries. RGB-D cameras,

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such as the Microsoft Kinect and the ASUS Xtion, have been used in robot planning [11], rehabilitation [12], and museum guidance [13]. Virtual try-on technology using RGB-D cameras has received attention because it enables users to see themselves wearing different clothes without physically changing clothes [14]. The Kinect's human pose estimation performance is adequate for real-time applications [15,16]. Most applications developed to virtually try on garments have used video streams to demonstrate the garments design [14,17,18]. By contrast, few studies have examined the virtual prototyping of footwear. Antonio et al. [18] developed a high-quality stereoscopic vision system that allows users to try on shoes from a large 3D database while looking at a “magic mirror”, and reported that footwear customization using AR improved product quality and increased consumer satisfaction. Eisert et al. [19] used AR techniques to create a virtual mirror to visualize customized sports shoes in real time, a large display screen, in place of a mirror, showed the input of a camera capturing legs and shoes. A 3D motion tracker was developed to robustly estimate the 3D positions of both shoes based on silhouette information from a single camera view.

The previous studies [18,19] have demonstrated that the idea of virtual try-on is highly valuable in realizing personalized design. However, those applications adopted specialized equipment that is not only pricy, but also inaccessible to most users. To overcome this problem, this paper presents a prototype system for virtually trying on shoes that enables users to evaluate shoe styling and appearance in an economically viable way, using automatic object tracking based on data captured using Kinect. The system allows users to try on 3D shoes in a live video stream. Several tracking mechanisms were tested and compared regarding accuracy and efficiency. Small color markers placed on the instep yielded the initial foot position based on image segmentation techniques. Markerless tracking driven by an iterative closest point (ICP) algorithm was implemented to correctly position the model with respect to the moving foot during the try-on process. Quantitative analysis of the test results revealed that a two-stage tracking method exhibited superior performance in both tracking efficiency and visualization quality, and resulted in higher positional accuracy than tracking using only markers or the ICP algorithm, particularly when foot movements were fast. Various use scenarios demonstrate how the proposed system facilitates footwear design customization. This study provides a feasible approach to allow consumers to evaluate products interactive with humans, and as well as to engage consumers in the design process. This study also demonstrated a new application of RGB-D cameras to product design.

3. System framework

3.1. Object tracking for virtually trying on shoes

A design personalization system must allow consumers to quickly evaluate designs. The proposed virtual try-on system enables users to virtually wear shoe models and interactively evaluate designs in an MR environment. This function relies on automatic foot tracking in a video stream. Object tracking methods can be classified according to their use of physical markers. Most MR systems identify locations using markers in the real environment, which often contain special patterns that allow the camera position and orientation to be quickly calibrated in 3D space. However, one major limitation is that markers normally lie on planar objects, and do not offer satisfactory positioning accuracy or tracking robustness when lying on curved objects. Tracking using physical markers is thus poorly suited to virtually trying on shoes, because of the curvature of the human body. The integration of markerless tracking or other sensing technologies is thus necessary.

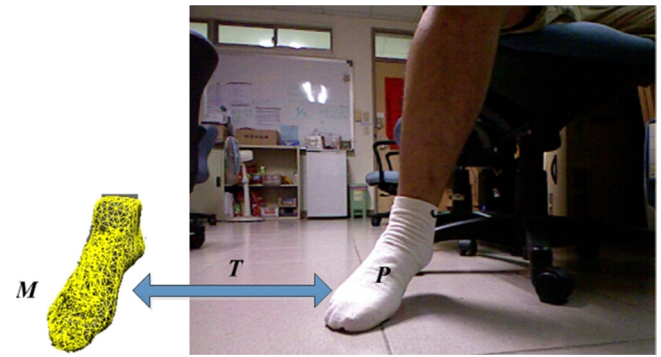


Fig. 1. Problem definition of virtually trying on shoes.

Markerless tracking requires automatic detection of objects based on color images. This topic has recently received much attention in computer vision and image processing; precisely identifying the location of a foot in a live video stream without use of markers is a challenging task. The main difficulty is that a human foot does not provide sufficient feature information that can be used by automated systems to identify it in images. Feet cannot always be distinguished from background objects or limbs, unless a person is wearing socks with predefined color or graphic patterns; thus, additional information is required to track feet in motion. Recent advances in depth-sensing technologies have provided effective solutions for tracking objects based on range data. This study implemented both marker and markerless tracking, and fully used color and depth images captured using an RGB-D camera; this hybrid approach provides a tradeoff between positional accuracy and computational efficiency in automatic object tracking.

3.2. Problem definition

This study involved tracking human foot motion based on color and depth images captured using Kinect. Precisely positioning a shoe model onto a human foot in real time is difficult, particularly because of the limited view angle of the depth camera, which allows only partial data to be captured for moving feet. Another difficulty arises from the need to determine whether a particular shoe comfortably fits a particular foot [20], allowances between the geometric shapes of feet and shoes are necessary to account for the free movement of the foot within the shoe.

Using data captured from foot motion to position foot models prevents these problems. A template foot model was adopted as a tracking reference because aligning similar shapes is more feasible than aligning two distinct shapes. The relative positions between the reference model and the shoe model to be displayed were defined prior to tracking. As shown in Fig. 1, the foot tracking task is described as follows:

$$\text{Min} \sum_{i=1}^n ||\mathbf{m}^* - \mathbf{p}_i \cdot \mathbf{T}|| \quad (1)$$

where the depth data $\mathbf{P}$ instantly captured using Kinect contains n points and $\mathbf{M}$ is the point cloud comprising the reference model. A best match Ω between $\mathbf{P}$ and $\mathbf{M}$ can be obtained using various techniques. The term $\mathbf{p}_i$ is a point in $\mathbf{P}$ and corresponds to $\mathbf{m}^*$ from $\mathbf{M}$ in Ω , $\mathbf{T}$ describes a 3D coordinate transformation matrix determined according to Ω , and is decomposed into a rotation matrix $\mathbf{R}$ and a translation matrix $\mathbf{t}$. It was necessary to identify $\mathbf{P}$ in a live image.

The foot tracking process flow is shown in Fig. 2. A two-stage tracking method was proposed to continuously identify the location of a foot based on the Kinect-captured video stream. The video

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