J Intell Manuf (2013) 24:905–917
DOI 10.1007/s10845-012-0642-9

Augmented reality-based design customization of footwear for children

Yuan-Ping Luh · Jeng-Bang Wang · Jin-Wan Chang · Shun-Ya Chang · Chih-Hsing Chu

Received: 24 February 2012 / Accepted: 3 April 2012 / Published online: 15 April 2012

Abstract This paper presents a systematic framework for design customization of footwear for children and identifies three modules related to shoe styling: shoe surface, shoe bottom, and accessory. A new module, shoe cloth, is created to allow a quick change of shoe appearance. Consumers can specify various design attributes in each module, including color, texture, embroidery, and shape. A prototype design system is implemented using augmented reality and sensing technologies based on the framework. This system consists of novel functions that support customization, design evaluation, and pattern development. The user can virtually put a customized shoe model on his/her foot in a video stream. The proposed framework not only facilitates evaluating products that are highly interactive with users, but also helps engage them in the design process. This work realizes the concept of human-centric design for mass customization.

Keywords Mass customization · Augmented reality · Shoe design · Product modularization

Y.-P. Luh
Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

J.-B. Wang · J.-W. Chang
Institute of Mechanical and Electrical Engineering, National Taipei University of Technology, Taipei, Taiwan

S.-Y. Chang · C.-H. Chu (✉)
Department of Industrial Engineering and Engineering Management, National Tsing-Hua University, Hsinchu, Taiwan
e-mail: chchu@ie.nthu.edu.tw

Introduction

Consumers have sought customized products/services since the mass production era of the late 1980s (Eckert et al. 2004). The concept of mass customization, defined as producing goods and services to meet individual customer needs with near mass production efficiency, was created to fulfill this trend (Tseng and Piller 2003). Numerous companies, such as BMW and Land Rover in the automobile industry; Dell, Fujitsu, and HP in the computer industry; and Motorola in the electronics industry, have been reported as successful practitioners of mass customization (Gunasekaran and Ngai 2005; Feitzinger and Lee 1997; Aigbedo 2007; Pine 1993). For example, Land Rover allowed its design team to collaborate with customers on customized vehicles based on original company designs (Gunasekaran and Ngai 2005). The Dell case has been considered one of the most successful adoptions of mass customization in the industry. The company helps customers configure personal computers online according to their preferences and quickly delivers the final product. Both consumers and companies have reacted positively toward the practice of mass customization (Piller 2007). Many customers have higher shopping satisfaction when their needs are more accurately satisfied. Companies benefit from the resultant high loyalty of these customers and often increase product sales.

Mass customization requires active consumer participation. As shown in Fig. 1, enterprises can deploy design processes in five domains for realizing mass customization: Customer Domain, Functional Domain, Physical Domain, Process Domain, and Logistics Domain (Fralix 2001). Hard FRs (Functional Requirements) are achieved by related physical elements. Customized designs are created by various arrangements and aggregations of physical elements. Soft FRs include software, services, process flows, and other

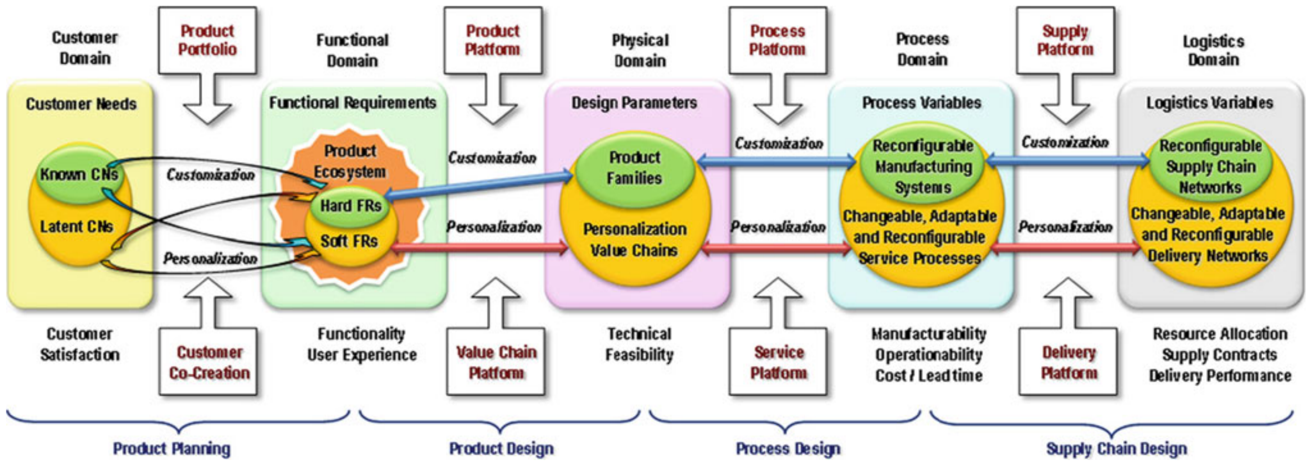

Fig. 1 Design framework of mass customization (Tseng et al. 2010)

intangible elements. Variation of these FRs is relatively easy in design and deployment costs.

Modern consumers are attracted to design elements that reflect their personality and tastes. The attributes related to consumer psychological needs play a significant role in product design. Emotional appeal invoked by product styling has a strong influence on consumer purchase decision. Aesthetic appeal of a product has become a critical factor in its success in addition to functional requirements. This is particularly true for products related to personal appearance such as wearable items and apparel (Lo and Chu 2011). The apparel and fashion industries are considered forerunners in implementing the concept of mass customization. Many successful cases have been reported in three dimensions of customization: fit, functionality, and aesthetic design (Fralix 2001).

Information and communication technology (ICT) tools have commonly been used in implementing product customization. Their applications have focused on product design, manufacturing, and supply chain management (Wang and Chu 2010). Footwear customization has received considerable attention in recent years, which is mostly concerned with designing a customized or better fitting shoe-last based on computer aided design (CAD) techniques and 3D anthropometric data (Wang et al. 2011; Luximon and Luximon 2009; Zhang et al. 2011; Luximon and Goonetilleke 2003). Most design tools are conceived from designer perspectives rather than the product user. However, successful mass customization requires active participation from end customers. Virtual and augmented reality (VR/AR) technologies provide an interactive environment that helps engage all product stakeholders in the design process (Lu et al. 1999). These technologies are particularly useful in the design evaluation of products that are highly interactive with human users. Calhoun et al. (2007) developed a virtual try-on system. An avatar is created with various cosmetic features and body measures of a user for size selection of pants and fit visualization. Chin and Kim (2010) constructed a 3D face model that can be personalized with BMI parameters. Users are allowed to evaluate how wearable products (wigs in this case) match with their faces mimicked by the model. Mottura et al. (2003, 2007) proposed a new concept of a shoe shop model. Using augmented reality based systems, Magic Mirror and Foot Glove, customers can digitally customize shoes, try on customized shoes, and then order their realization. Eisert et al. (2008) developed a similar try-on system based on augmented reality techniques for real-time visualization of customized sport shoes. The system replaced the real mirror with a large display screen that shows images of the legs and shoes of a person captured by a camera. 3D object tracking helps to precisely position the shoe model on the human feet.

The ability to personally design a product and instantly interact with the design result is desirable for customers. Implementing design customization in an augmented reality environment appears to be a feasible approach to achieving this goal. Following this thought, this paper presents a system framework for shoe design customization with a focus on styling. This framework applies product modularization techniques to identify three modules related to shoe styling: surface, bottom, and accessory. This work creates a new module, shoe cloth, which allows a quick change of exterior design for footwear for children. In addition to color and texture, customers can specify various design attributes for these modules. A prototype design system is developed using AR and sensing technologies based on the framework. This system provides novel functions for better interaction with and design evaluation of customized shoe models. Real-time foot tracking enables users to virtually try on a shoe model in a video stream. The model stays in position with the foot while moving. A pattern development function ensures the manufacturability of the shoe cloth design. Implementation results demonstrate how the prototype design system works. This research offers feasible methods that not only facilitate

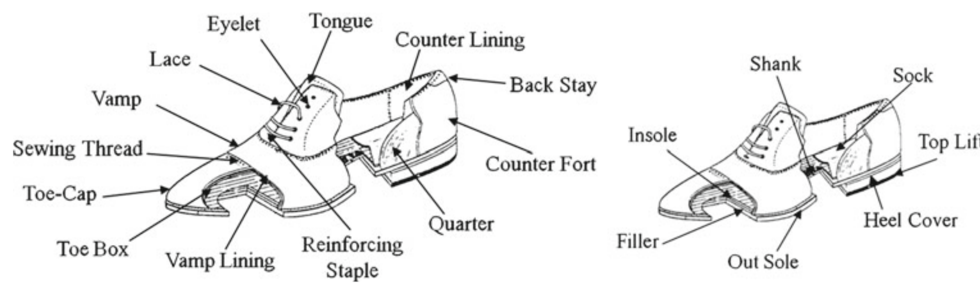

Fig. 2 Composition of a typical shoe for children (Children Footwear Design Guide 1992)

Table 1 Customization attributes of each shoe module

Surface module	Color, texture, embroidery
Bottom module	Color, texture, carving style
Accessory module	Color, texture
Cloth module	Color, texture, embroidery, shape

evaluating products that are highly interactive with human users, but also helps engage consumers in the design process.

Shoe mass customization by product modularization

Product modularization is an effective approach to creating product variants for fulfilling various customer needs (Ulrich and Eppinger 2004). In modular product architecture, each physical chunk implements one or a few functional elements and the interfaces between chunks are well defined. The functional requirements a product provides can easily change by removing or adding modules. Figure 2 shows the composition of a typical shoe for children (Children Footwear Design Guide 1992). Most components shown in the figure are related to the visual appearance of a shoe (shoe styling, rather than comfort wear or other functional attributes). These components can be grouped into three major modules: surface, bottom, and accessory. This work proposes a new "shoe cloth" module to help quickly change the look and feel of a shoe model. The model works as a piece of pattern material wrapped around the shoe body. A child shoe can thus be decomposed into four major modules and the components related to shoe styling are marked in a darker color.

The design attributes that can be changed in each module are listed in Table 1. Consumers can freely choose color and material texture for all four modules and specify the embroidery pattern for the surface and cloth modules. They can select the carving style of the bottom module among several existing ones. The shape of the shoe cloth can also be changed. Numerous shoe designs are produced by combining different design attributes. The shoe cloth idea may work in simple footwear such as shoes for children. Its practicality is limited in delicate footwear such as ladies shoes.

Another important task is to define the interfaces between the component modules (Fig. 3). The surface, bottom, and

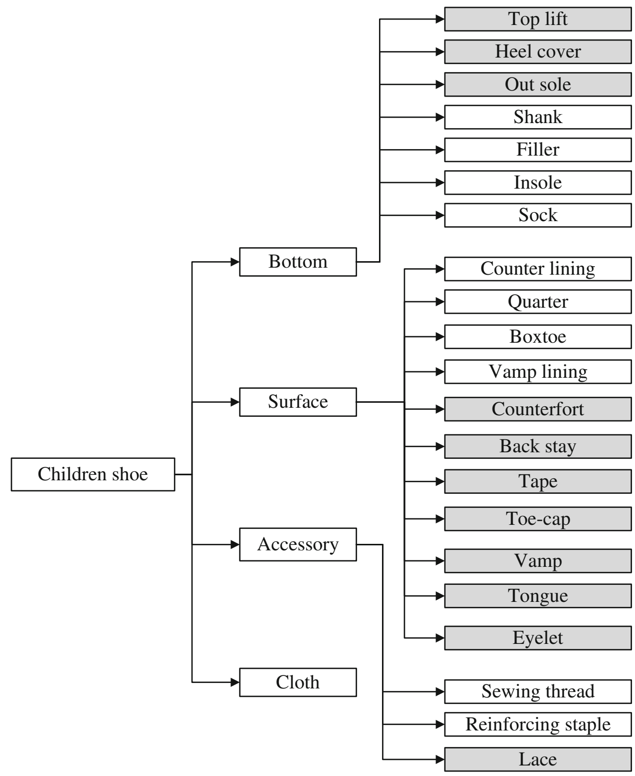

Fig. 3 Modularization of child shoes for shoe styling

accessory modules are standardized items in shoe industries (Children Footwear Design Guide 1992). They are typically connected via gluing, stitching, and sewing, either manually or mechanically. Shoe cloth is covered up on the shoe body by fastening buttons, such as those worn on clothes. Shoe cloth contains special features designed for connecting to various parts of a child shoe (Fig. 4). A cloth eyelet connects to a normal lace hole on the shoe body by inserting its flange into the hole. Shoe laces then go through the cloth eyelet and tie up the shoe in a normal way. The bottom part of the shoe cloth wraps around the shoe bottom from both sides and stays in position by fastening the bottom buckle (see Fig. 5a). The tail parts go into the shoe end and connect to each other by fastening the button in the end eyelet (see Fig. 5b). Two or multiple shoe cloths can be used for a single shoe, as shown in the figure, while they can share with one single bottom buckle.

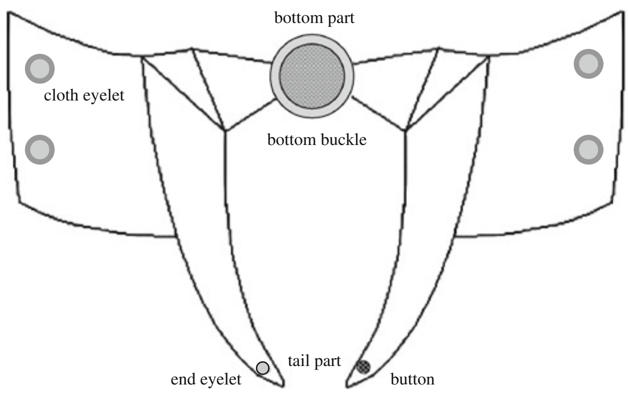

Fig. 4 Shoe cloth design

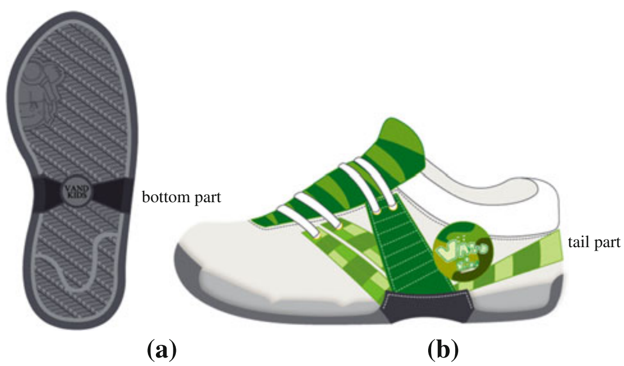

Fig. 5 Connecting shoe cloth to various parts of a child shoe. **a** Bottom part; **b** tail part

Customization design system for child footwear

A prototype design system was implemented for child wear customization with various technologies. This system consists of several functional modules (Fig. 6). A database contains geometric models of all variants for the four shoe modules. These files were created by 3ds MAX™ and converted into triangle meshes. The shoe customization module in the figure was implemented in Unity3D™ (Chu et al. 2009), an integrated development environment for games and other interactive software. Unity3D™ utilizes a component-based architecture and supports multi-platform deployment to provide useful development tools for creating visualization effects and interaction behaviors of 3D objects. Multi-media data can be easily integrated into the environment.

Customization module

The customization module provides an augmented reality environment for users to design shoes. This environment simulates a display booth in a shoe store by placing 3D models on a real shoe frame. The shoe models are properly positioned in the real scene with tracking markers (Fig. 7). Users specify the design attributes of each shoe module via pop-up windows and dialogues. Behaviors of the customization module are controlled by JavaScript. Each function of customization design is constructed as follows:

- *Color*: Unity3D™ provides a RGBA model for color adjustment of 3D objects. R, G, and B represent the light intensity of red, green, and blue, controlled by an integer between 0 and 255. A stands for alpha that determines an opacity channel. If a pixel has an alpha value of 0, it is fully transparent, whereas a value of 100 % gives an opaque pixel.
- *Texture*: Unity3D™ allows realistic rendering in computer graphics supported by bump mapping techniques and uses a height map for simulating small local displacements of the object surface that change the surface normals in lighting calculations. The texture customization function contains a set of pre-defined displacement patterns with which users produce different rendering effects of the shoe model.
- *Embroidery*: users change the embroidery pattern by specifying a 2D image for UVW mapping in computer graphics. UVW mapping is a mathematical technique that allows texture maps to wrap in complex ways onto irregular surfaces. Users can perform mapping on the fly through a GUI in a Unity3D™ application.
- *Carving style*: the bottom part of a child shoe normally contains bumps of different shapes and sizes, referred to as carving style. This style is related to functional and aesthetic performance of the shoe. Users modify the carving style for a shoe bottom by replacing its mesh model with a different one. The system offers several pre-defined shapes for users to choose.
- *Shape*: the shape of shoe cloth is modeled as a ruled surface. Similar to customized carving style, users change it by choosing a different ruled surface from existing ones. The shoe model is updated with the chosen shoe cloth on the fly.

Virtual try-on module

In any customization design system, it is important for users to quickly evaluate their design and give feedback. This is imperative for products that are highly interactive with humans, such as apparel and shoes. The proposed prototype system provides a virtual try-on module in which users can virtually put on a customized shoe model and interactively evaluate its design. This module is implemented by ARToolKits™ and resides as an add-on in Unity3D™. ARToolKits™ is an open-source software library for building Augmented Reality (AR) applications (http://www.hitl.washington.edu/artoolkit/). These applications involve the overlay of virtual imagery on the real world. This library provides real-time object tracking functions that

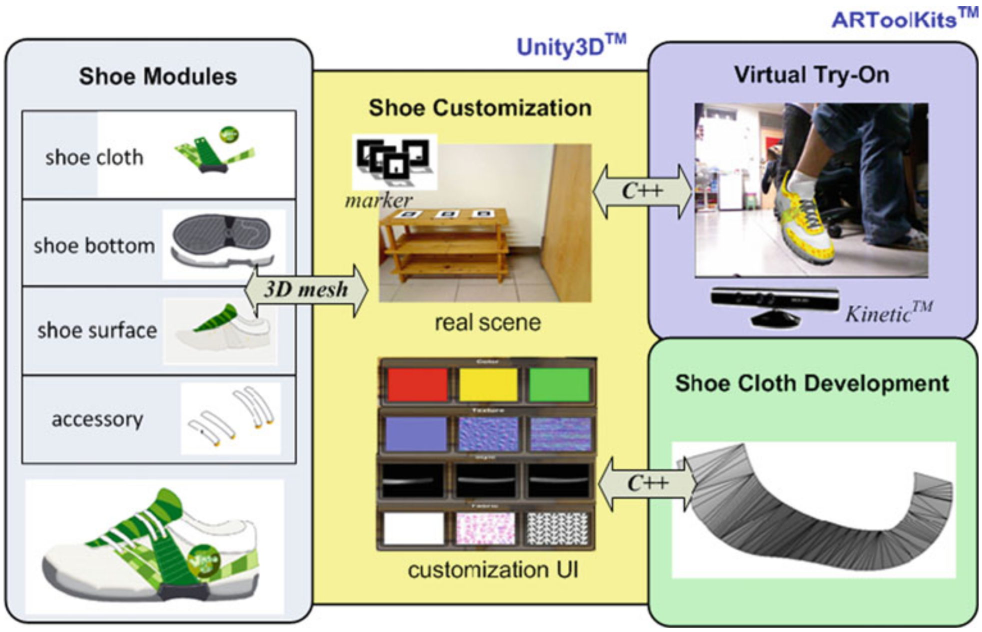

Fig. 6 Framework of the customization design system for child footwear

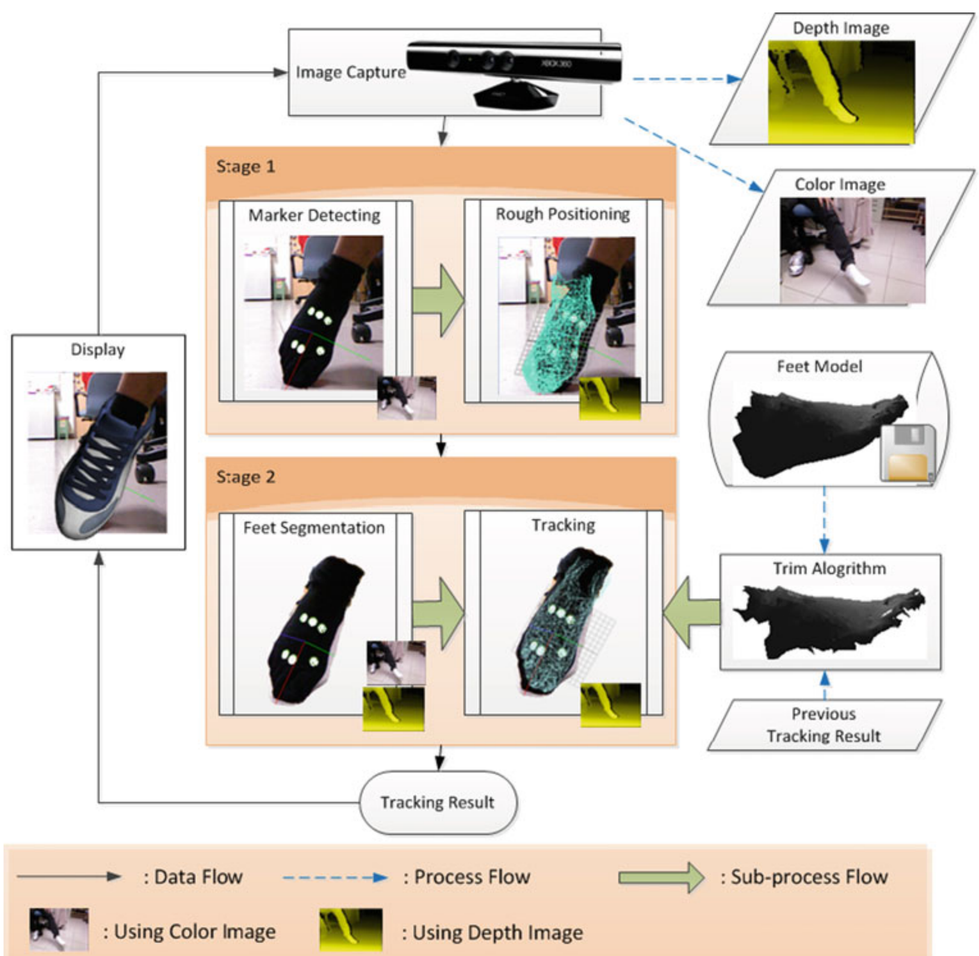

Fig. 7 Functional structure of real-time foot tracking

enable easy development of a wide range of AR applications. The tracking functions provided by ARToolKits™ calculate the actual camera position and orientation relative to physical markers in real time. A major limitation, however, is that these markers must typically lie on a plane or a planar object. The positioning accuracy and tracking robustness with planar markers on a curved object is not satisfactory and thus not suitable to virtual shoe try-on. A better solution is to integrate with markerless tracking or other sophisticated methods.

Automatic object detection is a foundation for markerless tracking from images or video streams and an active research topic in computer vision and image processing. To precisely identify the foot location in 3D space is a challenging task. The main difficulty is that a human foot does not contain sufficient features for automatic detection from its images and cannot be easily distinguished from a background scene or a limb, unless the person is wearing socks with a pre-defined color or graphic pattern. Unfortunately, this condition cannot be guaranteed in real applications. Additional information is needed for tracking human foot motion. Recent advances of sensing technologies provide feasible solutions for tracking objects from their range data. For example, Microsoft Kinect™ serves as a reliable and economical technology for capturing depth information of 3D objects in real time. This technology has been successfully used in the gaming industry and has begun to find applications in other industries.

The functional structure of the virtual try-on module is shown in Fig. 7. A two-stage tracking method is proposed to locate the foot position. This method utilizes both marker and markerless tracking. Their tracking functions are based on the depth and image data of 3D objects, both captured by Kinect™. The first stage of tracking is to approximately estimate the foot location with markers. Six green landmarks are attached on the instep of a foot. Three of them are placed around the 1st–3rd cuneiform bones and the others are around the head of the 1st–3rd metatarsal bones (see Fig. 8a). These green markers are fairly distinctive from other objects in the background and can be easily recognized from the image data. The recognition result is shown in Fig. 8b. The corresponding pixels of the landmarks are shown as white in the result.

The landmark pixels identified from the scene cannot precisely determine the foot location, because the depth information is still missing. Similarly, placing markers on only one side of a foot is not sufficient for correct alignment of the shoe model on the foot. A second and more precise tracking procedure is thus needed. The current study proposes a tracking function based on the depth data of 3D objects. The working principle of this function is described as follows. To precisely align a shoe model onto a foot is highly difficult. This becomes even more challenging when the depth information of the foot is only partial data as in our try-on case, due to the limited camera view angle. A better solution may be to position a foot model to the location of a real foot recognized from the scene. The idea is that alignment of two similar shapes is relatively simple. This work adopts a template foot model as a reference to position the customized shoe model. The relative position between the template and the shoe model is defined prior to tracking.

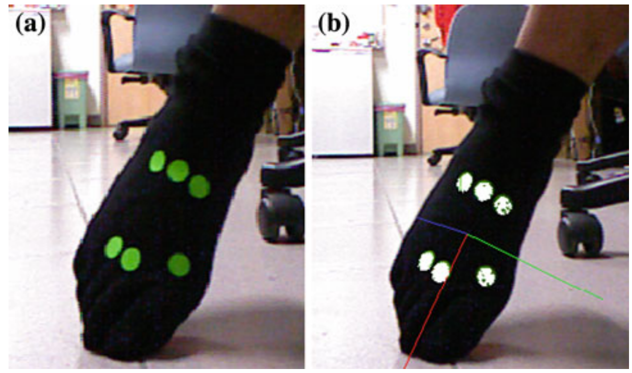

Fig. 8 **a** *Green landmarks* attached on the foot instep and **b** recognized pixels are shown as *white* in the image (Color figure online)

(a) **(b)**

Fig. 9 **a** Shoe cloth defined by two curves on the 3D shoe model and **b** shoe cloth constructed as a ruled surface

The problem induced by the limited view angle still needs to be solved. The view angle can be estimated from the landmark positions recognized in the previous stage. The template foot model is trimmed based on the estimate result, that is, the meshes that cannot be seen from the view angle are removed from the model (see Fig. 7). This research then applies the iterative closest point (ICP) algorithm (Besl and McKay 1992) to superimpose the trimmed model on the depth data captured by Kinect™ from the scene. The ICP algorithm is commonly used in computer vision for registration of two 3D shapes. This method continuously adjusts the position of a first shape through the minimization process of its deviations to the other shape. The effectiveness of such an optimization-based approach depends on the quality of the initial solution. A good initial solution for the ICP algorithm is the tracking result obtained from the first stage.

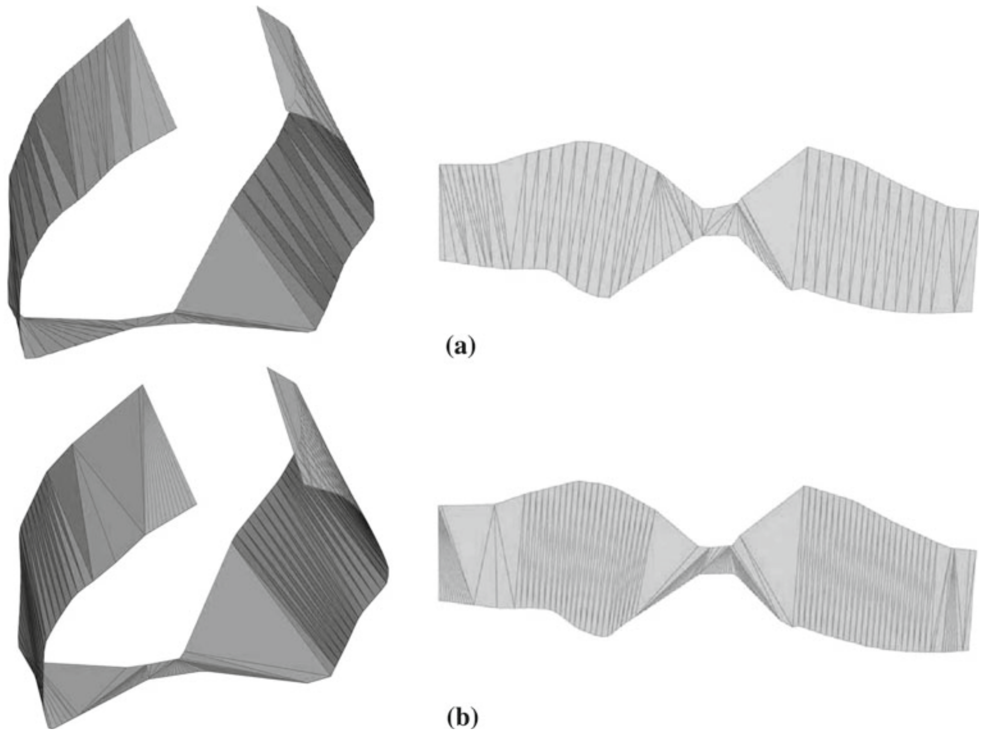

Fig. 10 Development of shoe cloth under various test conditions **a** number of sampling points = 100 and **b** number of sampling points = 200

Shoe cloth development

Shoe making is a complex engineering process involving various technologies such as shoe last design, mold making, pattern fabrication, sewing, knitting, and finishing. Shoe customization methods that do not significantly complicate the existing shoe making process are advantageous. This is a major concern in the success of mass customization that must be considered in the shoe cloth idea. Its design and manufacturing should be simple and cost effective. This study defines shoe cloth as a piece of fabric material wrapped around the shoe body for decoration purpose. The shape of the shoe cloth is assumed to be a ruled surface defined by two boundary curves. These curves need to be constructed from a 3D shoe model so that the resultant surface can fit the shoe well. The construction of shoe cloth in this condition is a typical strip design task (Chu et al. 2008).

A key for reducing the manufacturing complexity of shoe cloth is to increase its manufacturability. The manufacturability of such pattern materials (fabrics and sheet metals) can be characterized with the developability of their 3D shapes (Chu et al. 2011). A major function of this module is to maximize the developability of the cloth shape designed by the user. This problem has been well studied by Wang and Tang (2005) as a problem of optimal bridge boundary triangulation (BBT), briefly described as follows. Let $C1$ and $C2$ be two simple C1 continuous curves in space. Together with the two line segments connected between their respective two ends, they form a *strip*. The objective is to find a developable (or near developable in most cases) surface that will interpolate a given strip. The interpolation task is simplified as finding a suitable mapping function $f(u)$ given the two curves $C1$ and $C2$ that will result in an approximate geometry with maximal developability. A feasible approach is to approximate the strip by a collection of triangles whose vertices lie on the boundary curves. The resultant strip should be accessed quantitatively based on given criteria, depending on specific applications. These criteria also work as optimization objectives in calculating those triangles. Energy is considered a good objective for optimizing surface developability (Chu et al. 2011). Bending energy is adopted as the objective to be minimized in the strip approximation process. Estimation of the bending energy existing between successive triangles involves the edge length shared by the two triangles, the surface area, and the material property (please refer to Wang and Tang 2005).

Figure 9 illustrates an example of shoe cloth defined by two curves on a 3D shoe model. The resultant strip is shown as a simple ruled surface superimposing on the shoe model (Fig. 9b). The development (or flattening) result of the strip depends on the number of triangles used to interpolate the boundary curves. A greater number of triangles produce a material pattern that more precisely approximates the shoe cloth when the pattern unfolds in 3D space. Figure 10 shows the results generated by minimizing the surface bending energy (Chu et al. 2011).

Fig. 11 **a** Shoe display using AR technologies and **b** main customization screen

Implementation results

This section highlights how the proposed design system helps consumers customize shoe models. The customization process starts with a user choosing a shoe model in an augmented reality environment that simulates real shoe display. Virtual models are combined with a real shoe frame in this environment using AR functions provided by Unity3D^{TM}. A webcam captures the video stream of the shoe frame. Markers with special tracking patterns are placed on the locations in which the shoe models are displayed. Figure 11a shows three different styles of shoe models positioned on a wooden shoe frame with the tracking result of the markers. Figure 11b shows that a new screen pops out after the leftmost model is selected for customization. The system prompts the user to decide which shoe module among shoe surface, bottom, cloth, and accessory he/she wants to work with. Each module contains different design attributes that can be modified (see Table 1). The main purpose of showing the virtual shoes in augmented reality environment is to simulate shoe display in a real store. It is true that the rendering of shoe surfaces does not reflect the environmental lighting. To generate photorealistic rendering with actual lighting condition involves heavy computation and is thus not suitable to real-time applications such as product customization.

Three different embroideries are available for the shoe surface design (Fig. 12). The user can also change the color of any chosen embroidery, as shown in Fig. 13. The system provides three different texture patterns for controlling the rendering effect of the shoe surface (see Fig. 14). The color and texture of the other modules (bottom, accessory, and cloth) can be similarly modified, and thus the corresponding customization results are omitted. The carving style is an important attribute related to the shoe bottom design. The user is allowed to choose a desirable style from three existing ones offered by the system, shown in Fig. 15. The system provides two different shoe cloths from which the user can choose. Their color and embroidery can be tailor made and the results are shown in Fig. 16. The customization results of accessory items are shown in Fig. 17.

The user can initiate the virtual try-on function directly from the customization module once the shoe design is completed (Fig. 18). The customized shoe model is exported into an ARToolKits^{TM} application program embedded as an add-on in Unity3D^{TM}. A Kinect^{TM} device is connected to and calibrated in the application program. The webcam used in creating the shoe display (Fig. 11) serves as an image- capturing device that continuously generates the video stream of user's foot motion. As previously described, the customized model is automatically put on the foot and stays in a correct position while the user moves his/her foot. This mimics a real footwear try-on process in a shoe store (see Fig. 19 for various foot orientations). Such a human computer interaction function facilitates evaluation of the customized design, particularly its outlook and visualization quality. The user may want to re-start the customization process if the evaluation result is not satisfactory.

Conclusion and future work

Modern consumers are attracted to products that reflect their individual taste. Mass customization has thus become an effective strategy in product development. Product customization requires active participation by consumers. For fashion related products such as apparel and footwear, product aesthetic appeal has become a critical factor in fulfilling customer requirements. Although footwear customization has commonly used information and communication technologies, most applications have been conceived from designer perspectives, rather than the product user. Consumers who can personally design a product and instantly interact with the product prototype create a highly desirable advantage for product customization. Recent progress of augmented reality

Fig. 12 Results of shoe surface customization with various embroideries (Color figure online)

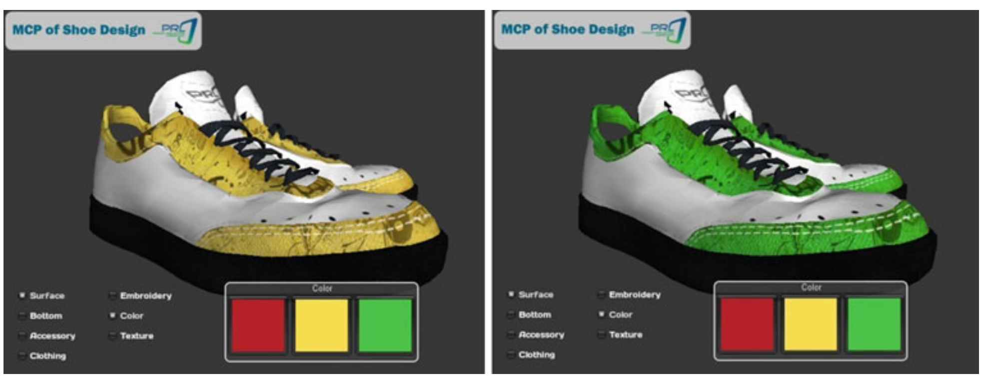

Fig. 13 Results of shoe surface customization with various colors (Color figure online)

and real-time sensing technologies provide feasible tools for achieving this goal. This paper proposes a system framework for shoe customization with a focus on product appearance. This framework identifies three shoe modules related to shoe styling: shoe surface, bottom, and accessory. A new module, shoe cloth, was created to allow a quick change of exterior design for child footwear, which involves a piece of fabric material wrapped around the shoe body for decoration purpose. Customers can choose different colors and textures for all four modules. change the embroidery of the shoe surface and cloth, specify the carving style of the shoe bottom, and adjust the shape of the shoe cloth. A prototype system of footwear customization for children was developed based on the framework. This system provides several novel functions for users to customize shoe models and evaluate the customized results. The main customization function was implemented in an integrated environment for interactive software development Unity3D™. A virtual try-on function was developed using ARToolKits™ and Kinect™ technologies. This function contains a two-stage approach to automatic object tracking that allows the user to virtually wear a shoe model on his/her foot in a video stream. Both image and depth data were used simultaneously to locate the foot position in 3D space. A pattern development function was also constructed

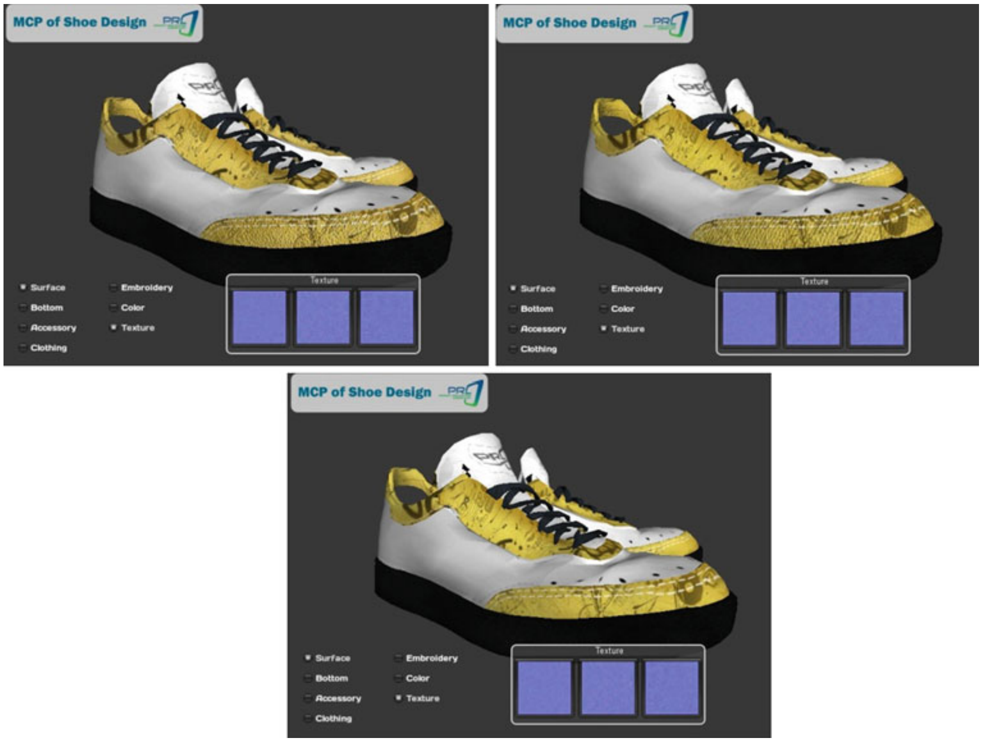

Fig. 14 Results of shoe surface customization with various textures (Color figure online)

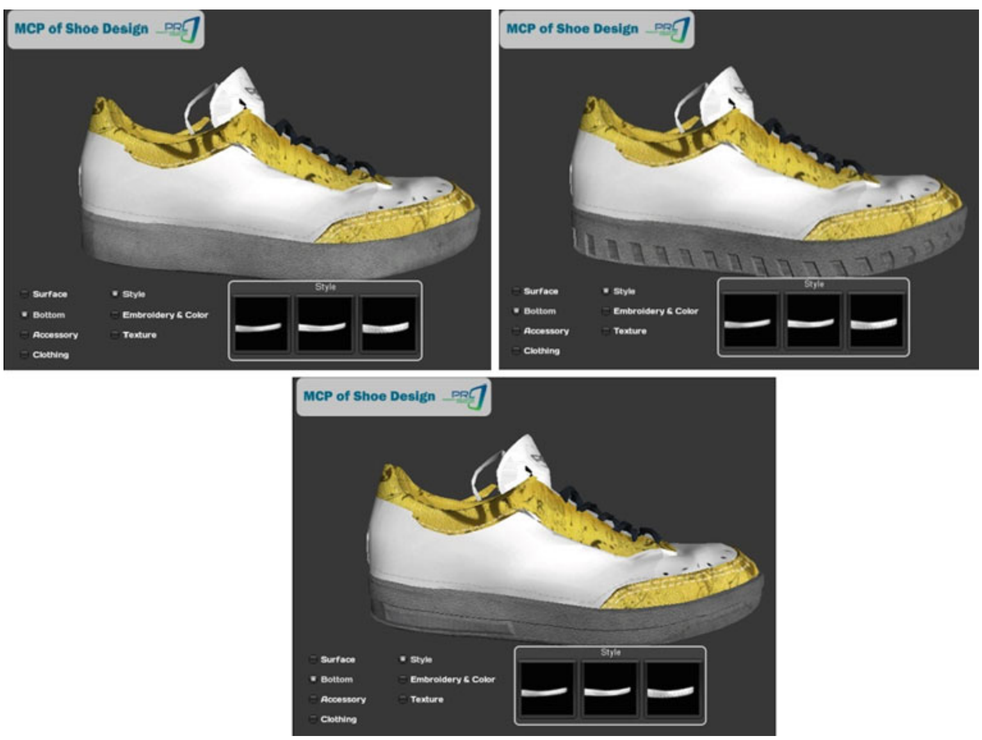

Fig. 15 Shoe bottoms with various carving styles

to maximize the developability of the user designed cloth shape. The maximization process of the surface developability was modeled as an optimal bridge boundary triangulation problem. This function supports the idea of mass customization by assuring the manufacturability of customized shoe cloths. Finally, a complete shoe customization process

Fig. 16 Various shapes of shoe cloth

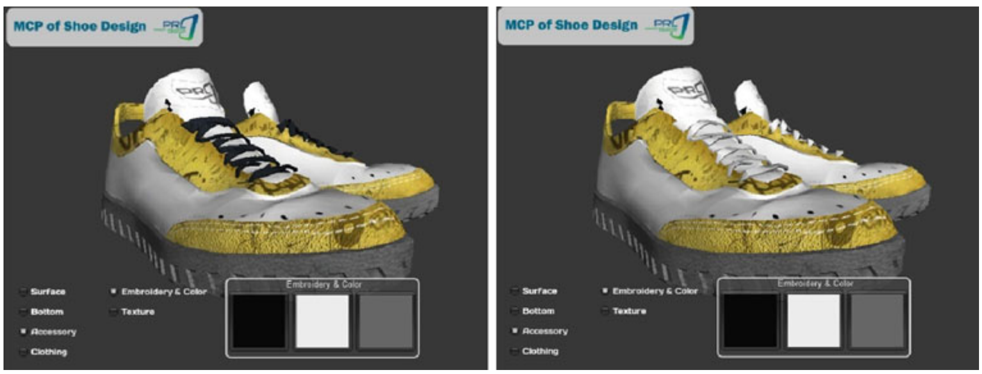

Fig. 17 Results of accessory customization

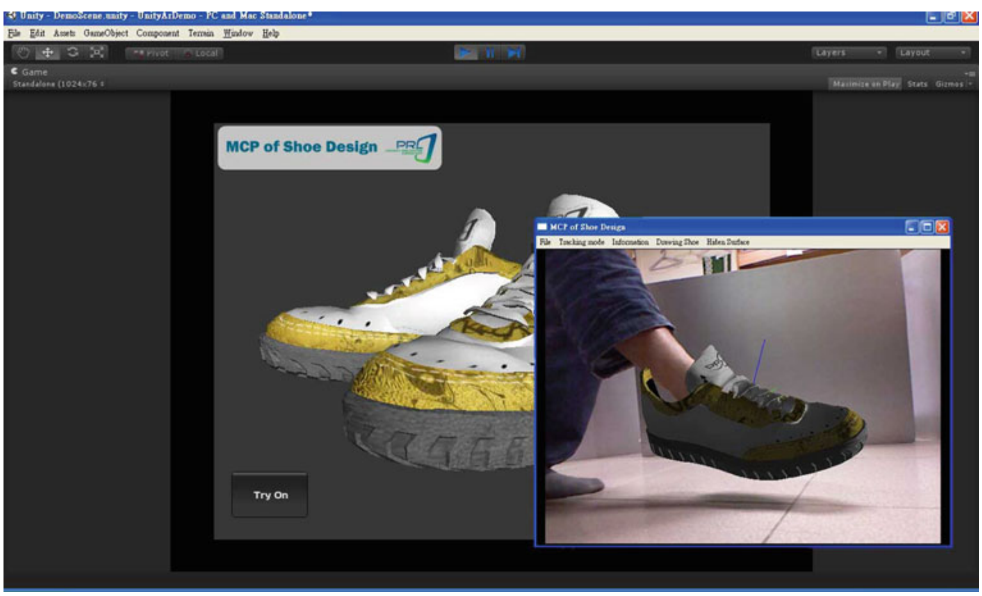

Fig. 18 Start the virtual try-on function directly from the customization module

demonstrated how the prototype system works. The design framework and the customization methods proposed by this research not only facilitate evaluating products that are highly interactive with human users, but also help engage them in the customization process. The idea of mass customization for human-centric products has been thus realized. Future work could offer functional evaluation of shoe design to estimate and improve wear comfort. Simulating deformation of a shoe model subject to various foot motions is another extension work.

Fig. 19 Virtual try-on of a customized shoe model

Acknowledgments This work was supported by National Science Council of Taiwan under the grant number NSC 100-B0160JB. It is also partially supported by Footwear and Recreational Technology Research Institute of Taiwan.

References

Aigbedo, H. (2007). An assessment of the effect of mass customization on suppliers' inventory levels in a JIT supply chain. *European Journal of Operations Research, 181*, 704–715.

Besl, P., & McKay, N. (1992). A method for registration of 3-D shapes. *IEEE Transactions of Pattern Analysis and Machine Intelligence, 14*, 239–256.

Calhoun, E. L., Lyman-Clarke, L., & Ashdown, S. (2007). Virtual fit of apparel on the internet: Current technology and future needs. In *Proceedings of world conference on mass customization & personalization*.

Children Footwear Design Guide. (1992). Footwear and Recreation Technology Research Institute, Taichung, Taiwan. (in Chinese).

Chin, S., & Kim, K. Y. (2010). Facial configuration and BMI based personalized face and upper body modeling for customer-oriented wearable product design. *Computers in Industry, 61*(6), 559–575.

Chu, C. H., Wang, C. C. L., & Tsai, C. R. (2008). Computer aided geometric design of strip using developable Bézier patches. *Computers in Industry, 59*, 601–610.

Chu, C. H, Wang, C. C. L., & Tsai, C. R. (2011). Strip approximation with Bézier patches in conical form for design and manufacturing of developable materials. *International Journal of Computer Integrated Manufacturing, 24*(3), 269–284.

Chu, C. H., Wu, P. H., & Guan, G. X. (2009). Online parametric configuration of 3D product based on triangulation model. *Journal of Engineering Manufacture, 223*(3), 231–246.

Eckert, C. M., Clarkson, P. J., & Zanker, W. (2004). Change and customization in complex engineering domains. *Research in Engineering Design, 15*(1), 1–21.

Eisert, P., Fechteler, P., & Rurainsky, J. (2008). 3-D tracking of shoes for virtual mirror applications. In *IEEE conference on computer vision and pattern recognition*, Anchorage, USA.

Feitzinger, E., & Lee, H. L. (1997). Mass customization at Hewlett-Packard: The power of postponement. *Harvard Business Review, 75*(1), 116–121.

Fralix, M. (2001). From mass production to mass customization. *Journal of Textile Apparel Technology and Management, 1*(2), 1–7.

Gunasekaran, A., & Ngai, E. W. T. (2005). Build-to-order supply chain management: A literature review and framework for development. *Journal of Operations Management, 23*, 423–451.

Lo, C. H., & Chu, C. H. (2011). An investigation of the social-affective effects invoked by appearance-related products. Human Factors and Ergonomics in Manufacturing & Service Industries (in press).

Lu, S.C.-Y., Shpitalni, M., & Gadh, R. (1999). Virtual and augmented reality technologies for product realization. *CIRP Annals, 48*(2), 471–495.

Luximon, A., & Goonetilleke, R. S. (2003). A 3-D methodology to quantify footwear fit. In M. M. Tseng & F. Piller (Eds.), *The customer centric enterprise, advances in mass customization and personalization*. New York: Springer.

Luximon, A., & Luximon, Y. (2009). Shoe-last design innovation for better shoe fitting. *Computers in Industry, 60*(8), 621–628.

Mottura, S., Greci, L., Sacco, M., & Boër, C. R. (2003). An augmented reality system for the customized shoe shop. In *MCPC 2003,* *2nd interdisciplinary world congress on mass customization and personalization*, Munich, Germany.

Mottura, S., Greci, L., Travaini, E., Viganò, G., & Sacco, M. (2007). MagicMirror & FootGlove: A new system for the customized shoe try-on. *The Future of Product Development, 8*, 441–450.

Piller, F. T. (2007). Observations on the present and future of mass customization. *International Journal of Flexible Manufacturing System, 19*, 630–636.

Pine, B. J. (1993). *Mass customization*. Boston: Harvard Business School Press.

Tseng, M. M., & Piller, F. T. (2003). *The customer centric enterprise, advances in mass customization and personalization*. New York: Springer.

Tseng, M. M., Jiao, R. J., & Wang, C. (2010). Design for mass personalization. *CIRP Annals, 59*, 175–178.

Ulrich, K. T., & Eppinger, S. D. (2004). *Product design and development, 3rd edn*. New York: McGraw Hill.

Wang, C. C. L., & Chu, C. H. (2010). Soft products development. *Computers in Industry, 61*(6), 511–512.

Wang, C. C. L., & Tang, K. (2005). Optimal boundary triangulations of an interpolating ruled surface. *Journal of Computing and Information Science in Engineering, 5*, 291–301.

Wang, J., Zhang, H., Lu, G., & Liu, Z. (2011). Rapid parametric design methods for shoe-last customization. *International Journal of Advanced Manufacturing Technologies, 54*(1–4), 173–186.

Zhang, Y., Luximon, A., Ma, X., Guo, X., & Zhang, M. (2011). Mass customization methodology for footwear design. Lecture Notes in Computer Science (6777/2011), pp. 367–375.