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Formulation of 3D shoe sizes using scanning camera and CAD modelling

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Analysis and modelling

ABSTRACT

Purpose: This paper purposes to formulate 3D shoe size by using scanning camera and link to CAD modeling.
Design/methodology/approach: The research design is divided into four groups with different ages and sex. The first group is boys and girls with 6-10 years old. The second group is teenagers with 11 – 20 years old. The third group is university students and working people with 21-30 year olds. The last group is professional working people group with 31 – 48 years old. The sample populations are selected and measured their feet both left and right sides. Each group contains ten to eighteen people except the child group which contains three to five children. The sampling sizes are 97 people. The 3D scanning camera is used in order to obtain the all sides of the feet. The process contains five steps in five foot positions; the middle foot, the 45° left foot, the 90° left foot, the 45° right foot, 90° right foot. The foot data image of all the sampling populations are classified in the same and similar sizes. Eight groups are determined that is formulated by eight sizes of the Thai shoe size. The size is started from the 19 W7.4 H6.7 to 27 W10.8 H9.1 which represents 3D shoe size.
Findings: The research result has investigated the new standard size model based on Thai local populations in 3D models. This study shows precisely the customized shoe sizes for individual people as well as the grouping shoe sizes for Thai people.
Practical implications: It can make benefits for shoe designers, customers and manufacturers.
Originality/value: This study shows precisely the customized shoe sizes for individual people as well as the grouping shoe sizes for Thai people.
Keywords: CAD/CAM; Thai shoe size; 3D scanning camera; CAD modelling

1. Introduction

The product design process presently requires modern computer technology to assist a designer who must perform fast, flexible and high quality and give high value to customer. Consumer product is one of the most concerns to customer in the aspects of health care. This paper study the shoe product design which needs to be customized in order to fit with individual personal feet features. Mass customization is widely studied in order to respond personal individual needs. Shoe plays a major role in the statement of fashion and beauty. Shoe last template is used to form the shoe shape. Normally, the shoe lasts are provided in common size and shape. They can be fit with some people, and might be not fit with the others. Hwang et al. [2] studied the derivation of template shoe-lasts for efficient fabrication of custom-ordered shoe lasts. The custom tailored products are meant by the products having various sizes and shapes to meet the customer's different tastes and needs. The concept was to collect many template shoe lasts and cast in advance. The most similar template was identified automatically from the custom ordered shoe-last, and only different portions in template shoe-last can be machined. This work believed to be a new paradigm for mass customization. Lai et al. [3] studied automatic shoe pattern boundary extraction by image processing techniques using digitizers from 3D shoe model shoe, last-bottom flattening, shoe pattern making. The aim was to develop an effective image processing method to automatically extract the boundary of shoe pattern. The histogram threshold technique was used to segment a shoe pattern from the scanned input image. 50 images were tested by different pixels of the pattern dimensions. The area, perimeter and time were calculated. Presented the application of differential semantics to structure the semantic space of causal shoes. Sixty-seven volunteers evaluated 36 shoes on 74 adjectives that formed the semantic universe. Factorial analysis of principle components was used to identify the semantic axes. The statistical index was introduced to measure subject's consensus and then used to analyze the influence of the number of volunteers in the semantic evaluation results. The results showed that comfort and quality were independently perceived by consumers. Kim et al. [4] presented a method for modifying a surface model with non-uniformly scattered displacement constraints as a module of the shoe design system and applied especially for shoe grading. When displacement vector are given as constraints to feature points on the original surface, the other points should be computed to construct deformed surface. To maintain the overall appearance and smoothness of the original surfaces, the proper relationship should be formulated between the displacement vectors of feature points and those of other points. A 3D vector field which is a set of displacement vectors is constructed base on the given constraints. Multi-level B-spline approximation technique is also used to circumvent a tradeoff between smoothness and accuracy. The technique uses coarse to fine hierarchy of control lattices. Butdee [5] studied hybrid feature modeling for sport shoe sole design. Primitive features are prepared in the library. The user can select and modify before joining them together to create a new shoe sole model. This method has ability to extend size or grading in 3D automatically. The test showed precisely that time was saved 88.4% when 12 sizes grading was performed. McPoil [6] presented the use of athletic footwear in various advantages and disadvantages. The studied components include the upper, the midsole/outsole, the last, as well as the lasting process in order to help the athlete select the most appropriate shoe. Since the various models of athletic shoes that are available to the customer can change in a very rapid and unpredictable manner, it is extremely difficult for the clinician to maintain a database of current shoe models and features. Nakhaee [7] studied the foot pressure measurement based on the complexity of the foot structure. Usually, the rate of lower extremity's injuries in sports such as running is known to be correlated with the height of foot arches.

Mass customizations capabilities enable firms to design, produce, and deliver a high volume of differentiated products that meet specific customer needs in a timely manner and at close to mass production prices Tu et al. [8] described that a critical part of mass customization was simultaneously achieving customer responsiveness, cost effective, and high volume production in the manufacturing system. Time-based manufacturing practices are impacted on mass customization and value to customer. Silveira et al. [9] presented the literature review of mass customization which related to the ability to provide individually designed products and services to every customer through high process flexibility and integration. Mass customization has been identified as a competitive strategy by an increasing number of companies.

2. Reverse engineering

CAD technology is recently used for product design as well as tool design. A wide variety of CAD/CAM systems are currently available. Each system comes with various configurations and options to satisfy user requirements. Two processes are significant of any CAD system. They are system input device and processing data. Input devices are tools that users employ to communicate with computer system. Input technology has improved greatly over the years and a variety of input devices are available. The input device used depends on the type of information that is to be input. The possible types of information include text, graphics, and sound. Devices used for graphics input are divided into three categories locating devices, digitizers, and image input devices which were expressed by Nanua Singh [1]. The digitizer is another type of graphics input device. A digitizer consists of an electronic board with a stylus, which is similar to traditional drafting tools such as paper and pencils. However, object likes feet needs to use a special type of digitizer which is called coordinate measurement machine (CMM). It can be 3D axes machine or a robot arm. Even though, digitizer can reverse data directly from the object, it still takes more time to capture the object data processing. Therefore, graphic device is the best option to capture data from people by image processing. Image input devices can automatically captured a frame of graphics or picture into computers. The typical device is scanners. Robot vision is a potential application of this technique. When information about the shape and dimensions of an object can be extracted from a frame of a video image, the problems of robot movements in the presence of obstacles are largely solved. The paper presented the robot arm scanner to capture graphic image processing from individual different sampling population. Docchio [10] described optical three dimensional (3D) acquisition, reverse engineering and rapid prototyping of a historic automobile, a Ferrari 250 Miglia by using an optical 3D whole field digitizer based on the projection of incoherent light. The entire process consists in the acquisition such as the point cloud alignment, the triangle model definition, the NURBS creation, the production of the STL file, and the generation of a scaled replica of the car. Zhongwei [11] developed the direct integration method of reverse engineering and rapid prototyping based on the properties of NURBS or B-spline. The aim was to reduce the product development time which requires revolutionary improvements rather than gradual changes in technology. The method can resolve the difficult dilemma by using a new algorithm in order to build a bridge between scattered points and adaptive slicing.

3. Geometric modelling

The ultimate goal of any economic activity is to translate the customer's needs into salable and profitable products. One of the major activities in this process is to develop a geometric model of product from the conceptual ideas. Geometric modeling is concerned with defining geometric objects using computational geometry. The product may be defined with the assist of either a simple wire frame model, a surface model, or a solid model for proper representation. Therefore, the geometric modeling is an integral part of any CAD system. Two major activities realizing a product are design and manufacturing. The geometry of the product is one of the primary inputs to the design and manufacturing process. The geometric information about an object essentially includes types of surfaces and edges and their dimensions and tolerances. Traditionally, the geometric information about parts has been provided on blueprints by a draftsperson. Today, in an era of agile manufacturing, the emphasis is on paperless manufacturing, that is the geometric information should be directly transferred from the CAD databases to the CAM databases to enable subsequent manufacture of the part. This would significantly reduce product development and manufacturing lead time. Therefore, Geometric modeling refers to a set of techniques concerned mainly with developing efficient representation of geometric respects of a design. Therefore, geometric modeling is a fundamental part of virtually all CAD tools. It is also the basic of many applications such as mass property calculations, mechanism analysis, finite element modeling, and numerical control (NC) programming. Under these circumstances geometric modeling has a tremendous influence in the process of development and manufacturing of products. Usually, there are a number of requirements for geometric modeling. The first requirement is completeness of the part representation, both topological and geometric data. It means that the representation should provide enough data for users in the purpose of quires and analysis. The topological data represent the relationship between entities, whereas the geometric data describe the geometry of the entities.

4. International shoe size

International shoe size conversion chart [13] is presented by internet that is assisted buyer, manufacturer or designer in order to convert from the shoe size used in one country or region to the shoe size used in another country or region. Due to the international shoe size conversion table is captured from the internet and they are specific for each country system, the studied process might be different. The table conversion only works for men, or women but not both. It demonstrates aspect of globalizing products shoe sizes are not measured in the same units around the world. In the world of free trade with people connect to each others every where in any time, it needs to provide users with appropriate units and be clear about which are being referenced. To use shoe size conversion table, first choose the adult, boys or girls conversion. Then find the row that represents the region of the world which you want to convert the size from. The table can be explained by rows and column. The original standard shoe size was established from the mondo point sizing methodology dates back to 1324 and involves a sticky situation with King Richard II, a group of rankled tradesman and the number of barleycorns in an inch. Basically what the printed numbers tell people is that we have to try the shoe on, unless we trust in antiquates scheme based solely on the length of some temperate grain. In general international shoe size is referred by the European system. The sizes divided into 16 sizes from the size 35 to the size 48 ½. The size starts from 9 inches to 11 ½ inches and from 22.8 centimeters to 29.2 centimeters.

This paper organizes to present the process of customize shoe design for sample group of people. The shoe model is created for making shoe sole both upper and lower soles. Reverse engineering feet scanning is employed to capture feet data in 3D. The scanning processes are explained. The data is modified by CAD system. The feet size is modeled and grouped. The size of each group is compared to the standard shoe size. Finally the 3D shoe size is formulated. The results are the Thai local shoe size in 3D.

5. Research methodology

The research objective is to formulate the 3D shoe sizes for Thai people based on the international standard shoe (ISS) size. The existing ISS has been studied. The experiment research is designed by a small sampling group selection. The statistic is shown in the Table 1. The total populations in the research sampling group are 97 people. Boys and men are 51 people. Girls and women are 46 people. The total population is measured by the 3D scanning camera. The foot images are merged together. Finally, the shoe sizes are formulated. Due to the scanning image is in the form of polygon object which is started from the point object. Points include points wrap surface and points wrap volume. The polygon object is transferred to shape object and then modified to NURBS on CAD object as seen in the Figure 1.

Table 1.
The Research Sampling Group

Group	Ages (years)	Boys/Men	Girls/Women
1	6-11	3	
2	6-11		5
3	12-20	18	
4	12-20		16
5	21-30	14	
6	21-30		15
7	31-48	12	
8	31-48		10
	Total	51	46

6. Method and process of feet scanning

The section presents the method and process of feet scanning. The first step is to select the sampling groups which are divided into 8 groups based on their ages and sex. The first group is people in the 6 to 11 years old of boys, whereas the second group is the people in the ages of 6 to 11 years old of girls.

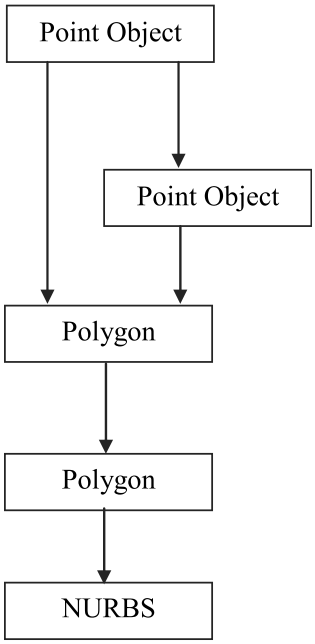

Fig. 1. The Transition of Polygon Object to NURBS

The third and the fourth groups are the people in the ages of 12 to 20 years old of men and women. The fifth and the sixth are the people in the ages of 21 to 30 years old of men and women. The seventh and the eight groups are people in the ages of 30-48 years old. The camera scanning method is employed. The picture is then modified by CAD. The 3D camera scanning, namely Konica Minonta of VIVID 910 fx model is used. The polygon editing tool is assisted in order to joint and modify the picture of the scanning surface. The scanning process consists of five steps as shown in the Figure 1. In this study, only one foot is scanned. The first position is in the middle. The second position is 45°on the right hand side. The third position is another 45° from the step two. On the other hand, the fourth step is on the left hand side. It is 45° from the first position. The final step is move 45° from the step 4 or 90° from the step one. However, the focus of the scanning camera must be defined. The suitable distance which was found in this study is 1.5 m between the camera and foot. Figure 2 shows the shoe parameters. The definitions are as the followings:

- FL = the foot length
- H = the foot height
- Z = the foot width
- L = the distance between the head foot to the most width foot
- X_1 = the distance between the neutral line and the left corner line.
- X_2 = the distance between the neural line and the right corner line.
- L_1 = the diagonal line from the head foot to the left foot width.
- L_2 = the diagonal line from the head foot to the right foot width.

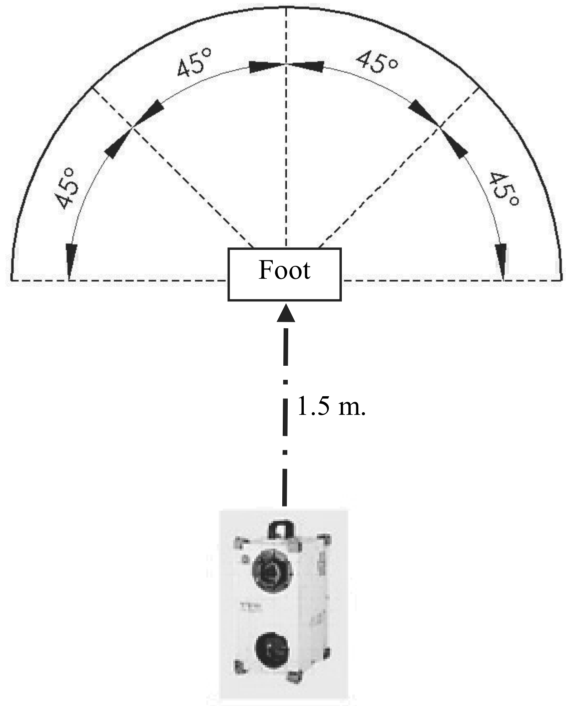

Fig. 2. The Feet Scanning Positions

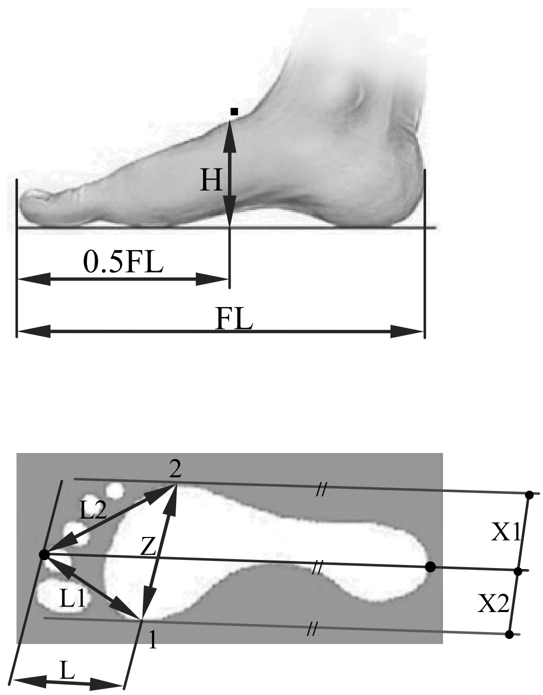

Fig. 3. The Shoe Parameters

7. Experimental study

This section describes the experimental processes. The first step is measuring and collecting data. The scanning camera is linked to the CAD software in order to capture foot data. Figure 3 shows the measuring process by 3D scanning camera. This process is decided to fix the camera but the foot is moved by 5 positions. The right foot is only selected.

Fig. 4. The Measuring Process by 3D Scanning Camera

Figure 4 shows capturing picture from the 3D camera. The picture is shown in polygon. There are total five pictures in five positions. Then, they are merged together to become a foot image. The foot length and width can be measured by CAD. The measuring data is then combined and calculated based on the group of similar sizes and ages. Table 2 shows the calculation of the foot length and grouping. There are 9 groups starting from group of 19 mm., 20 mm., until 27 mm.

Fig. 5. The Capturing Picture from 3D Camera

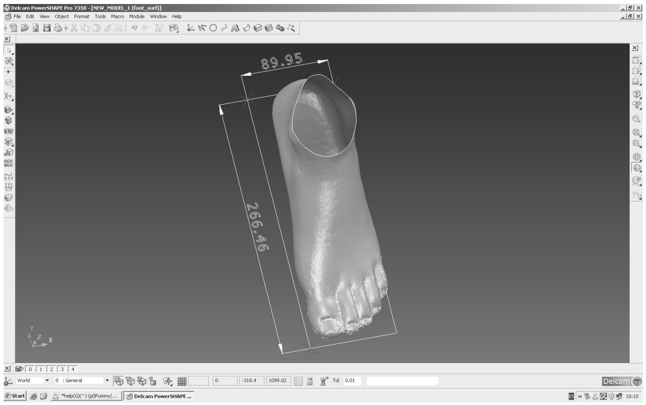

Fig. 6. The Foot Merging Image

Table 3 shows the women foot size classification. The women (W) foot size can be clustered by the size 22 to 27, whereas the men (M) are grouped by the size 20 to 23. It is clearly seen that Thai foot size are started by the size 20 to 27. However, there are few sampling people in the 19 and 27 foot size. Therefore, this project emphasizes on the Thai foot size 19 to 27. As the result, it can conclude that the size 22 can be the neutral size for the standard Thai shoe size.

Table 2.
The Calculation of the Foot Length and Grouping

Size mm.	19	20	21	22	23	24	25	26	27
(½) FL	9.5	10	10.5	11	11.5	12	12.5	13	13.5
Z	8	7.5	7.1	7.6	7.5	8.0	8.7	9.4	9.5
X1	7	7.7	8.2	8.5	8.9	9.1	9.9	10.2	10.5
X2	5	4	4.4	4.5	4.5	5.1	5.2	5.6	8.5
L	5	4.1	4.1	4.4	4.3	4.5	4.8	5.6	6.5
L1	6	6.1	6.8	7	7.4	7.5	8.7	9	9
L2	6	6.8	6.9	7	7.6	7.7	8.0	8.8	9

Table 3.
The Women Foot Size Classification

Sex	Ages	19	20	21	22	23	24	25	26	27
M	6-11			1	2					
M	12-20				1	2	5	5	3	2
M	21-30				3		3	7	1	
M	31-48				1	2	4	4	1	
W	6-11	1	3	1						
W	12-20		1	6	6	3	1			
W	21-30		2	5	5	3				
W	31-48		1	2	3	2	2			
Total	M	0	0	1	7	4	12	16	5	2
	W	1	7	14	14	8	3	0	0	0

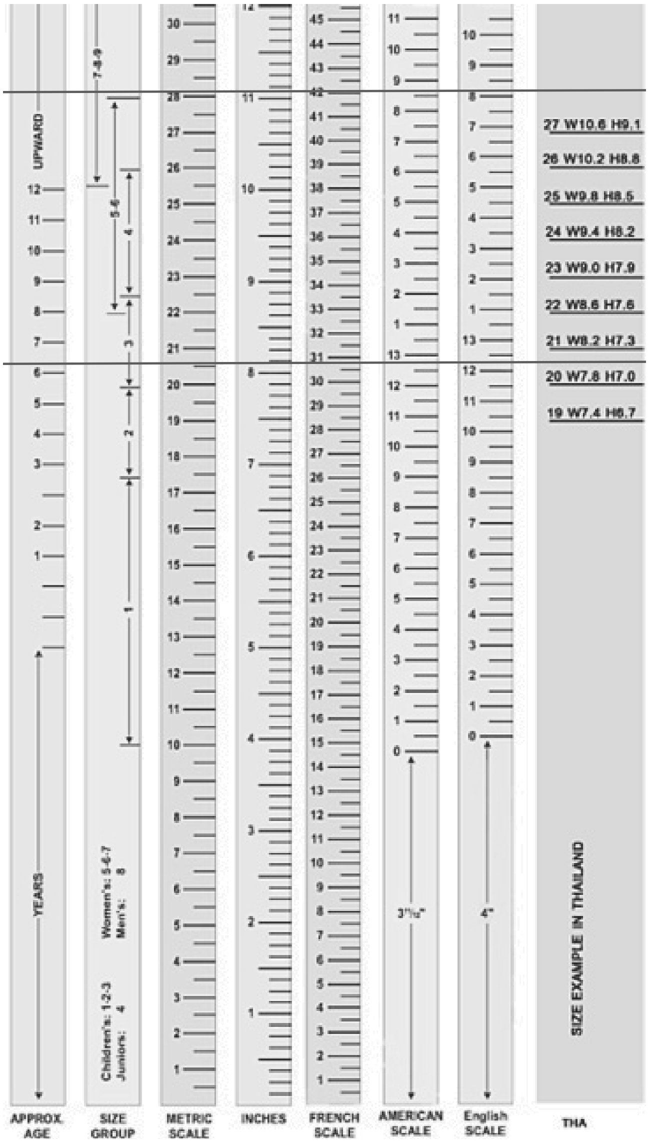

Fig. 7. Formulation 3D Thai Shoe Size

Table 4.
The Calculation foot Grading Dimensions for the Thai Standard Size

Length	19	20	21	22	23	24	25	26	27
Height	6.7	7.0	7.3	7.6	7.9	8.2	8.5	8.8	9.1
Width	7.4	7.8	8.2	8.6	9.0	9.4	9.8	10.2	10.6

Table 4 shows the calculation foot grading dimensions for the Thai standard size. Three dimensions are shown. They are the length, height and the width. At the reference size of the 22, the height equals 7.6 and 8.6 mm. from the experiment. The principle for grading is to examine the different value between the maximum and minimum value and divided by the number of size.

In the case of height, the maximum value is 9.1 mm. and minimum value is 6.7. The different value is then 2.3 mm. The number size is eight according to the Table 2. Therefore, each size alters ± 0.3 mm. The grading size is shown in the second row of the Table 3. It is started by 6.7 mm. height to 9.1 mm. height. Similarly, the grading width of the show size is examined by the same principle. The maximum value is 10.6 mm. and the minimum is 7.4 mm. It is 2.8 mm. different values. Therefore, the grading width range is ± 0.4 mm.

8. Formulation of 3D Thai shoe size

The standard shoe size for Thai people is purposed in 3D. Therefore, the dimension shows by x, y, z axes. The x and y represent the width and length respectively, whereas the z axis represents the height foot. Figure 7 shows the formulation 3D Thai shoe size. There are eight sizes. It starts from the 19 mm. size to the 26 mm. size. In the Thai shoe size represents 3D. For example, the 19 mm. size is shown by 19 W7.4 H6.7 which means 19 mm. length, 7.4 mm. width and 6.7 mm. height. The Figure 7 also shows the comparison among other scales such as France scale, American scale and English scale. It is noted that the American and English scales start from the lady size and then jump to the men size. On the other hand, the France scale starts from the small size to the big size directly which mixes the size of lady and men together.

9. Conclusions

The formulation of 3D shoe size for Thai people has been presented. The scanning camera is used in order to capture picture from the sampling populations. The foot picture images are first received by polygon object which are then modified by a NURBS CAD surface. The foot images are classified into 8 groups. The lady size is started by the 20 to 22 size, whereas the men size is begun by the 22 to 26 size. This study shows precisely the customized shoe sizes for individual people as well as the grouping shoe sizes for Thai people. It can make benefits for shoe designers, customers and manufacturers.

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