



## Augmented Reality-Based Design of Shoes for Arthritis

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**Abstract:** Rheumatoid arthritis is a common disease found in the forefoot part. Most rheumatoid arthritis patients suffered in deformity that would change the foot shape and dimension. The deformity results problem of poor-fitting shoes that worsen the patient mobility condition. The objective of this research is to identify the foot dimension and geometry of arthritis patient using an Augmented Reality (AR) Software and design a 3-dimensional shoe model based on the design for arthritis using the dimension and geometry obtain from the AR application. The measurement was done using 3D Avatar Feet Mobile Application to measure the foot dimension of an arthritis patient. The shoes was then design using SolidWorks software with reference to the existing design from Propet Cush'N Foot. The 3D Avatar Feet generated four dimension which are Foot Length, Ball Width, Ball girth and Instep Girth. The designed features, which are produced from the design of the 3D shoe model using the dimension and geometry from the 3D Avatar Feet Mobile Application, include wide toe box, extra depth, wide heel and deep toe box. The results from the AR Software are acceptable as the percentage error calculated are less than 5%. The constructed shoe model has better fitting to the distorted feet of arthritis patients as compared to the existing products.

**Keywords:** Arthritis Patient, Augmented Reality Software, Shoe Design

### 1. Introduction

Arthritis is a common disease that can be in various forms. The common major forms are Osteo Arthritis (OA) and Rheumatic Arthritis (RA). OA is mechanically driven and can occur as an initiator due to the wear and tear of cartilage tissue which subsequently generates severe inflammation that causes a major joint problem. Therefore, the joint can lose flexibility or mobility, while inflammation, swelling and pain can cause pressure to the joint. While for RA which is known as inflammatory disease, it's due to the autoimmune disorder where our cartilage tissue is attacked by our immune system which eventually later brings pain, swelling, stiffness and deformity [1]. Women has been identified to have higher tendency to exposed to RA than men [2].

In the foot involvement, RA is widely involved in patients and estimated to be more than 50 percent [3], [4], but no formal survey determines the RA population on a random geographical selection [5]. In

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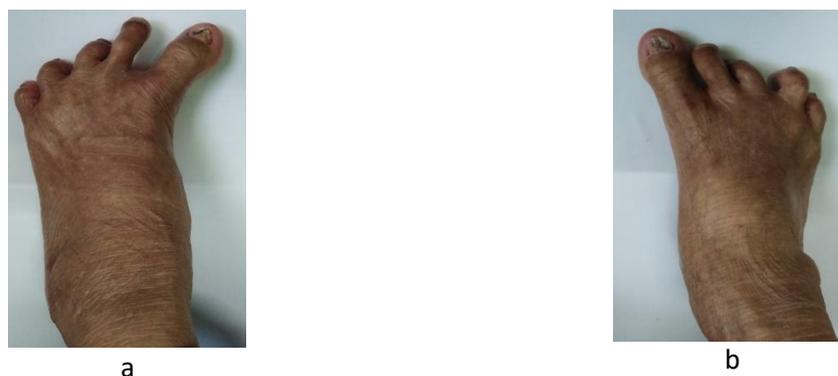
RA patients, instability of hindfoot can lead to a deformity of the forefoot like hallux valgus, subluxation, dislocation or erosion of metatarsophalangeal joint that can altered the movement of the foot and ankle and increased loading of the forefoot plantar pressure that can trigger pain during the walking period [6]. Hallux valgus are the common deformity found at the forefoot especially at the metatarsophalangeal joints [7], [8]. Other than hallux valgus, hallux varus is a great toe deformity characterised by hallux adduction and medial subluxation of the first MTP joint [9]. Hallux varus is the inverse of hallux valgus, and it is commonly associated with hallux valgus [10].

Design are one of the most important factors to determine the comfort of the shoe because its play important role for user comfort. For person with RA, orthopaedic shoes are like a support device for movement and relieve pain. For the shoes design, some studies has showed that rocker soles [11], running shoe [12], and extra depth shoes [13] play an important role in relieve pain and provide comfort.

## 2. Methodology

### 2.1 Foot Size Measurement

The measurement was conducted on 74 years old woman arthritis patient's feet. The changed in foot shape due to the deformity in the big toes gave difficulties in finding suitable (Figure 1).



**Figure 1: (a) Condition Patient's Left Foot (b) Condition Patient's Right Foot**

The foot was measured using the AR application which is 3D Avatar Feet Mobile Application. Before conducting the scanning process, preparation is important to avoid any issues from occurring during the foot scanning procedure. Prepare and ISO A4 paper. Then, check the surrounding and make sure it is well lit area and the floor colour are contrast with the ISO A4. It is recommended that to make sure the patient is in comfortable position before starting the scanning process. The scanning was conducted using phone camera by taking three pictures from three side starting from inside of the foot followed by top of foot and outside of foot. The camera must be aim and rotate until red and grey outline merge and become green. 4 common dimension results were obtained from the application which are foot length, ball width, ball girth and instep girth.

### 2.2 Manual Measurement and Validation

Manual measurement was conducted to validate the result from the 3D Avatar Feet mobile application and avoid significance difference of the measurement result from the real-life measurement and AR Software measurement. The manual measurement process was conducted by tracing the patient foot closely as possible to obtain the foot shape. The foot length, ball widths were measured using long ruler from the tracing result and vernier calliper while the ball girth and instep girth were measured using measuring tape and vernier calliper straight from the patient feet. The result obtained were compared with the AR application result and the percentage error were calculate using Eq.1.

$$\text{Percentage of error} = \frac{|\text{Approximate value} - \text{Exact Value}|}{\text{Exact value}} \times 100 \quad \text{Eq. 1}$$

### 2.3 Shoe Design

SolidWorks software was used to reconstruct the 3-dimensional shoe model. First, a 2D sketching images was drawn based on the dimension obtain from AR software. The dimension was drawn from the 3D geometry of the AR software that has been imported into the SolidWorks software. Then, the process was continued by drawing 3D model for the shoe design. The process of designing the shoes was also based on the Propet Cush'N Foot. The shoe was selected due to the design features like wide toe box, extra depth and rocker soles that meet the requirements for arthritis patients.

## 3. Results and Discussion

### 3.1 3D Avatar Feet Mobile Application Results

Based on the Table 1, the AR application generates 4 dimensions of the foot which is Foot Length (FL), Ball Girth (BG), Ball Width (BW), Instep Girth (IG). The generated measurement for the left foot is 242.9(FL), 224.4(BG), 88.2(BW) and 241.5(IG) while for the right foot is 234.5(FL), 218.0(BG), 89.7(BW) and 226.7(IG). Even though the AR application cannot generate all dimensions of the foot, the generated dimension is commonly used foot dimension and the AR application was acceptable to use for making custom-made shoes [15].

The geometrical dimension of the left and right feet was different due to the presence of the deformity. The difference for Foot Length (FL), Ball Girth (BG), Ball Width (BW) and Instep Girth (IG) between both feet is 8.4mm, 6.4mm, 1.5mm and 14.8mm respectively (Table 1). Even though both patient's feet are nearly the same in foot shape, the great toe positions for both feet were completely different. The great toe position of the left foot is more critical in its state as the toe adducted more than 11° from the longitudinal axis. While for the right foot, the great toe is also adducted but the adduct position is not too far from the longitudinal axis. This has affected the Instep Girth (IG) geometrical dimension as the toe position that adduct more than 11° from the longitudinal axis can cause swollen to the instep girth. Therefore, the instep girth (IG) has a big difference in the dimension result between the left and right foot. Then, both of the patient's remaining toes for both feet suffered hammer toe deformity that results in the change of the toes position from its normal position.

**Table 1: 3D Avatar Feet Mobile Application Result**

Type of Test	3D Avatar Feet Mobile Application		Difference
Type of Foot	Left	Right	
Foot Length (FL) (mm)	242.9	234.5	8.4
Ball Girth (BG) (mm)	224.4	218.0	6.4
Ball Width (BW) (mm)	88.2	89.7	1.5
Instep Girth (IG) (mm)	241.5	226.7	14.8

### 3.2 Manual Measurement Result

Table 2 shows that the actual length of the Arthritis foot is 233.4 mm. The length of the metatarsal ball from big toe to pinky toe is 87.6mm. Besides, the Length of the ball girth is 219.8mm while for the instep girth is 226.4mm. However, the data obtained may vary a little due to the human error that occurs during conducting the manual measurement method such as the patient foot sometimes are not in static condition. Besides, the tracing of the foot not too accurate because of the difficulty in trace in some of the curve parts of the patient foot. It is recommended that, to make sure that the patient is in a comfortable position before conducting the measurement and use a suitable technique in tracing the foot such as marking at the important point before tracing the foot shape to avoid the error.

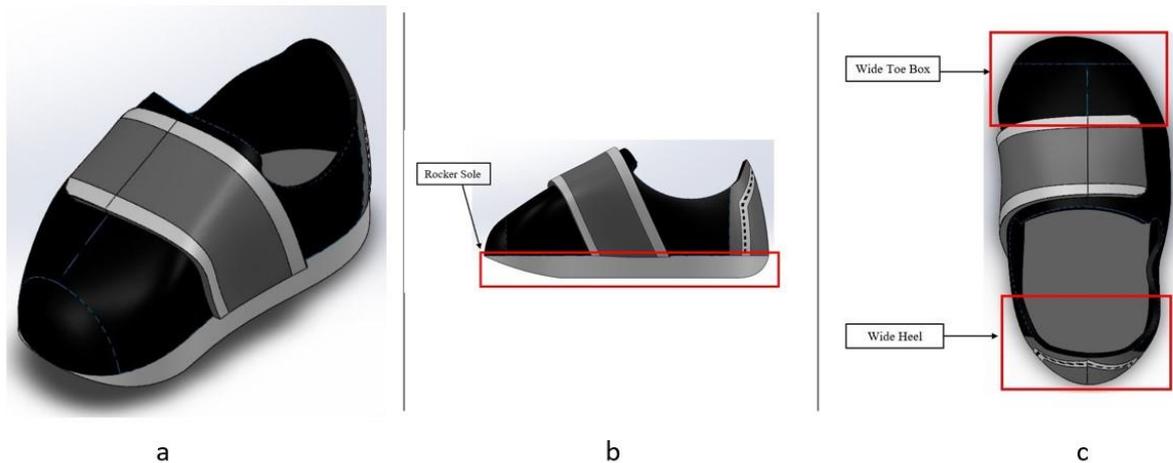
A comparison with manual measurement has been conducted and the percentage of error has been calculated in each dimension using equation 1. From both tests, the 3D Avatar Feet result shows non-significance to the manual measurement result. The comparison results are shown in Table 2. Even though the value is not the same, the percentage of error for each dimension is smaller. The percentage of error calculated for foot length, ball girth, ball width and instep girth are 0.47%, 0.82%, 2.34% and 0.13% respectively. This shows that the 3D Avatar Feet Mobile Application is acceptable to be used in measuring foot dimension as the percentage error value are non-significance.

**Table 2: Comparison result of Manual Measurement and 3D Avatar Feet Mobile Application**

Dimension	Type of Test		Percentage of Error (%)
	Manual Measurement Result (mm)	3D Avatar Feet Mobile Application Result (mm)	
Foot Length (FL)	233.4	234.5	0.47
Ball Girth (BG)	219.8	218.0	0.82
Ball Width (BW)	87.6	89.7	2.40
Instep Girth (IG)	226.4	226.7	0.13

### 3.3 Three-Dimensional Shoe Model Result

Figure 2(a) shows the 3-dimensional model that has been designed based on the foot dimension and geometry from the 3D avatar feet mobile application by using SolidWorks Software. The designs are based on the Propet Cush'N Foot Shoes. The shoe design features from the model like wide toe box, extra depth, wide heel, deep toe box, rocker soles and hook and loop adjustable strap have its own function in reducing pain suffered for arthritis patients. All of these important design features for arthritis patients can be achieved as the AR software can generate dimensions and geometry that help in the design process. From the design of the 3-dimensional model, the shoe toes features are deep and wide toe box as shown in Figure 2(c). This can provide space as well as comfort for the forefoot part as the patient toes can spread out freely and avoid unwanted contact between the deform toes and the shoes. The shoes also come with a rocker sole as shown in Figure 2(b). The sole that has a rocker angle of  $16.84^\circ$  can reduce pain while walking and provide comfort for the patient. Then, the extra depth features design can help eliminate pressure points on the toes that suffered hammertoes deformity So, the agility and balance for the patients during walking also can be improved. Same as the wide toe box which is wide heel (Figure 2(c)) of the designed shoes can avoid inflammation in the area when wearing the shoes. The extra-large hook and loop adjustable strap can help to achieve a perfect fit for arthritis and can help facilitate foot entry for rheumatoid arthritis patients because the patients sometimes suffered difficulties in wearing shoes due to the deformity and change in the foot shape.



**Figure 2: (a) 3-Dimensional Shoe Model Isometric View (b) Rocker Soles Design Features (c) Wide Toe and Wide Heel**

### 3.4 Comparison of 3D Avatar Feet Mobile Application Result with Design Measurement of 3D Model

The foot length, ball girth, ball width and instep girth measurements are taken and compare with the 3D Avatar Feet Mobile Application result. The comparison as shown in Table 3. The dimension in the shoe model was larger than the measurement of the 3D Avatar Feet Mobile Application. There was some tolerance given in the shoe model due to the fact that the patient's toes suffered hallux varus deform and irregular from time to time.

**Table 3: Comparison result of 3D Avatar feet Mobile application and Design measurement of 3-dimensional shoe model**

Dimension	Type of Test	
	Design Measurement of 3-dimensional Shoe Model (mm)	3D Avatar Feet Mobile Application (mm)
Food width	107.73	104.4
Foot Length (FL)	255.78	234.5
Ball Girth (BG)	220.12	218.0
Ball Width (BW)	108.08	89.7
Instep Girth (IG)	243.09	226.7

The design for the shoes must be wide especially at the toes part to provide comfort. Length also increases by 21.28 mm to the 3D Avatar Feet Mobile Application result for the shoe length. The value have slightly bigger difference as the custom made shoes can give more space for the foot whether on the toe part or the heel part and avoid unintentional contact between the shoe and the deforms toe. The ball girth is nearly the same. However, the dimension for the 3-dimensional model is slightly bigger than the AR application. The difference in value because the arthritis big toes are adducted from the longitudinal axis of the MTP joints. So, the ball for the big toes is also will be changed a little. By raising the ball girth dimension of the shoe model, the patient metatarsophalangeal ball can have a slight space and avoid contact during moving. For the instep girth, the value is very different from the AR application. Patient having difficulty to entry the foot due to the hallux varus deformity. By enlarging the instep girth dimension, the patient's difficulty in inserting the foot to wear shoes can be reduced.

### 3.5 Advantages of Shoe Design using AR Software

From all the results obtained from the designed model, designing shoes using AR software can give a lot of advantages and benefits. The AR software can consider the swelling and geometry change of the foot of an arthritis patient. AR software can help in assisting the process of design as it can generate commonly used dimensions and geometry of the foot. The AR software are available to use and cheap and available to the public, compared to other 3D scanners. Arthritis patient foot can be measured at home rather than measured at the shop as this software can get from the Appstore.

However, the AR software also has some limitations to the user to use due to the lack in some part of the produced result. The limitations of the AR software are as the following: The AR software only generated 4 dimensions. Even though the dimension generated are sufficient, other remaining dimensions such as foot height, heel width and heel girth were also important as the increase in the number of dimensions can result in more accurate results. The AR software also depends on the camera of the phone itself. Camera with optical image stabilization is recommended as it can avoid unintentional movement during conducting the measurement process.

## 4. Conclusion

Throughout this research, the approach in determining the foot measurement for arthritis patients using an Augmented Reality Application was used. The study was completed by conducting a measurement using AR application and construct the shoe model. For the first objective, the AR application can generate the result of foot length, ball width, ball girth, instep girth and the 3-dimensional model. All dimension generated was crucial and commonly used in foot measurement. The result produces are acceptable as it has been validated with the manual measurement method. As for the second objective, the 3-dimension shoe model presented in this study is more suitable for the use of arthritis patients as compared to the existing products like Propet Cush'N Foot. The features of the shoes for arthritis patients like wide toe box, rocker sole have been considered in the design.

The software can be used in determining foot dimension for arthritis patient and the SolidWorks software are acceptable in designing the shoe model for arthritis patient. Therefore, the recommendation has been proposed for future research. First, proposed a better Augmented Reality Application that used a high-end 3D scanner or camera to obtain more accurate results. The foot length, foot height, foot width, ball width, ball girth and instep girth result dimension can be determined more accurately depending on the quality of the camera or the scanner. Then, proposed a software that can fully utilize the function in designing the shoes to obtain a better 3-dimensional result. The 3-dimension girth result can be determined accurately using software that can consider the shoe last as its girth curve can be designed exactly as the patient foot girth. Investigate more patient deformities that can be changed in the foot shape that can affect the design of the shoes. The deformity of patient foot is not consistent more data is needed.

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