FITTIN^{TM} - Online 3D Shoe Try-on

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Abstract

Description for an easy and user-friendly computerized method for the online try-on of shoes that dynamically references a three-dimensional topological model of a foot with a three-dimensional topological model of the inner surface of footwear. A comfort level is then calculated based on the matching results. With the help of these calculations, a consumer can make a conclusion about the suitability of the footwear and make a purchase decision. The topological 3D model of a foot is reconstructed by analyzing a series of foot images taken with a mobile device (smartphone or digital camera). In addition to geometric information (such as shape and size), the topological model of the footwear's inner surface also contains information about pressure forces and tensile stiffness at different points. The present article gives a critical analysis of existing virtual shoe fitting methods.

Keywords: 3d foot scanning, virtual try-on, 3d inner surface shoe scanning, topological model

1. Introduction

These days an increasing number of footwear is being sold online. However, the perceived need for a physical fitting still serves as the main obstacle preventing consumers from purchasing shoes on the Internet. Negative stereotypes about online shopping continue to be present, and impact consumer behavior. Finding the correct footwear size to purchase from an online store is difficult due to the inability to try on the selected footwear, which subsequently leads to a high number of returns, incurring in additional shipping expenses on the seller's part. Many choose not to shop for footwear online because they cannot physically try them on and do not want the inconvenience of returning improper fitting items.
Furthermore, wearing improper fitting shoes has its own side effects, as it can lead to different health problems. Footwear, like many other consumer products, is manufactured on a large scale, where personalization is only available in the size category. In the healthcare field, on the other hand, there are special manual feet-scanning devices used for making customized shoes. This is particularly helpful in case of physical impairments, but these devices must be used by healthcare professionals, and they come at a great additional cost and with long processing times. Despite the fact that this manual feet-scanning method provides sufficiently precise measurements, its high price prevents ordinary people from using it.
One possible solution to the footwear fitting problem is the creation of a virtual try-on method. The recent coronavirus outbreak also has stimulated footwear companies to incorporate digital technologies into their retail business. Nevertheless, the unavoidable problem of checking the proper fit of shoes when shopping online still persists. With a reliable virtual try-on method based on information technology, the biggest problem is how to digitally measure feet and shoes in order to provide accurate size recommendations.
Under these conditions there is a great need for a cheaper, publicly available, efficient and improved footwear fitting method that can provide consumers with an enjoyable footwear purchasing experience and make them feel confident that reasonable and precise calculations of the comfort level of footwear will be given even when using mobile devices.
There are many feet-scanning methods that rely on depth cameras or photographs. However, there are only a few methods for scanning the shoe inner surface and hardly any methods of virtual shoe fitting provided publicly. That's why we would like to present our innovative patented ONLINE 3D SHOE TRY-ON system which includes a method, equipment and software that our company has been developing for 5 years.

2. Inner surface shoe 3D scanning

At present, several methods and devices are proposed for determining the dimensional measurements of the inner surface of shoes. A device developed by Sizeradar Corp. allows measuring a shoe and determining how tight its movable elements fit the inner surface of the shoe. The device consists of two parts: the first one is used for measuring the shoe width and girth and consists of movable elements; the second one, which is mechanically connected to the first one, is positioned in the heel section of the shoe [1]. Our experiments, together with competent shoemakers and the assistance of a podiatrist, have shown, that the length from the heel to the 1st metatarsal head (known as the Instep length), the length from the heel to the 5th metatarsal head (known as the Fibulare instep length) as well as the girth of ball of the foot, are not enough to decide whether shoes fit, as there are more parameters to be considered.

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There are two other companies that use industrial, expensive, non-scalable shoe scanning methods: OneFID uses a CT Scanner and Safesize [2] uses an X-ray scanner. In our practice, we have often encountered situations where shoes in their boxes are creased. This fact negates the prospects of using these methods, as scanning results cannot be accurate. In order to increase the scanning speed, the aforementioned developers neglect accuracy.
Technology for a virtual shoe fitting method based on the comparison of three-dimensional models of lasts and user's feet offered by Tryfit Technologies [3] also proved to be inaccurate. We have carried out a research work called "Analysis of the applicability of shoe lasts used as an initial object when building a 3D model of the inner surface of shoes for virtual fitting". In the course of it, we compared 3D models of lasts scanned using a professional 3D scanner and 3D models of the inner surface of the shoes obtained using our device. The lasts we scanned were later used for making the shoes, the inner surface of which we scanned with our device. Thus, we obtained two 3D models of the inner surface of the same shoe. The experiment showed that the digitized 3D model of the last significantly differs from the real inner surface of the shoe and does not take into account the deformation of the surface of the shoe material under pressure. These conclusions were confirmed by the shoe manufacturers we interviewed. Therefore, it is not reliable to employ lasts in shoe fitting.
Devices such as a footwear measuring apparatus resembling a foot [4] are only able to take measurements at certain points.
In contrast with the aforementioned methods, we offer a unique method for the measurement of the inner surface of shoes that creates a perfect fit for the foot. Our method allows obtaining a detailed 3D model of the inner surface of the shoe, straightens the shoe from the inside and allows to measure the stretching resistance of its top, as well as to evaluate the quality of the shoe tailoring.

2.1. 3D reconstruction of the inner surface of the footwear

3D reconstruction of the inner surface of footwear within our FITTIN™ service is done with the help of a special device, based on the combination of both a contact and a contactless method of measuring 3D objects [5]. The device is called the FITT™ Scope and consists of a camera and a set of probes.
The indicators on the probes collect the 3D coordinates while the device is being moved (see Figure 1) along the entire inside length of the footwear.

Fig. 1. Scanning process of the inner surface of footwear performed with the FITT™ Scope

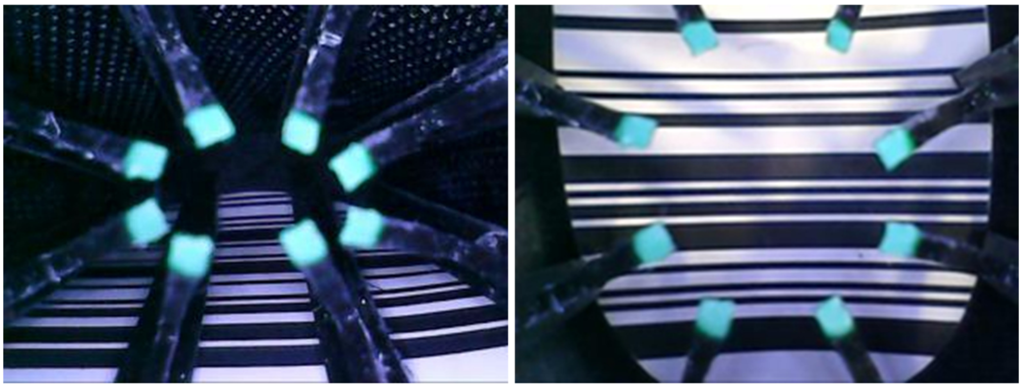

Fig. 2. Images from camera of shoe scanning device

With the integrated mini-video camera with backlight, information is collected about the position of each probe in real time. In each frame indicator probes allow us to get information about the sections of the inner surface. In this image from the camera (see figure 2) both a flat marking strip and indicators are clearly visible. With the sequenced images it can obtain an array of sections of the inner surface – a point cloud.
Scanning of the footwear can be done with a different opening of the probe (see figure 3), which results on a scan with a different level of force. There are at least three levels of retraction of the probe opening: open, half open (50%), almost wide open (angle of 100 degrees).

Fig. 3. Scanning process of the inner surface of the footwear with probes in the retracted and opened position

After the footwear is measured a number of times applying different levels of force, it is possible to calculate the expansion rigidity of the shoe vamp. This describes the resistance of a cross section of the footwear around the metatarsophalangeal joint when the shape changes. This kind of stiffness appears while a person is standing or walking which is connected to the pressure force of the rear and lateral surfaces of the foot on the vamp of the shoe. Knowledge about shoe stiffness in each section allows us to make the topological 3D model change during the process of the virtual fitting, stretching materials of the shoe vamp, thereby securing a high level quality of the measurements.

By the end of the scanning process the created images are transmitted to the server and go through post production, which include the following procedure:

1. thinning of the sections and uniform spreading by their length
2. leveling of the sections
3. deletion of the inside partition

The results of the postproduction generate a Signed Distance Function (SDF), on the base of which the 3d model is constructed in the .obj format (see figure 4).

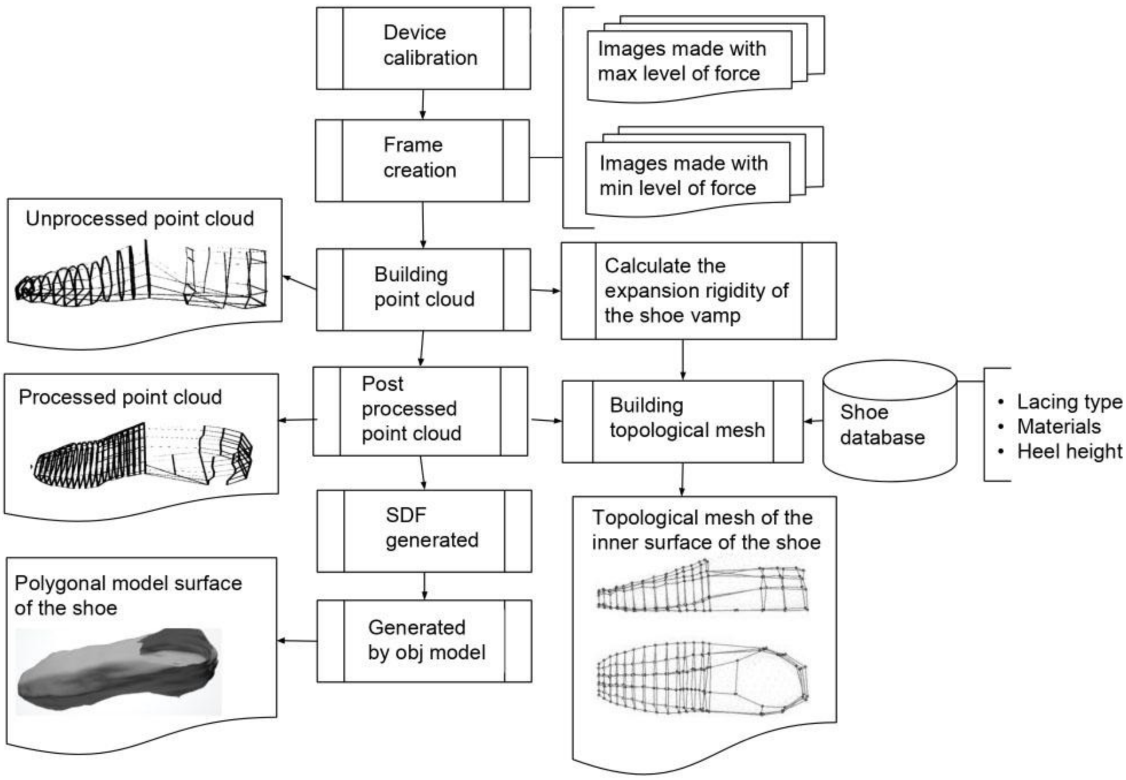

Fig. 4. Flowchart for constructing a topological model of a shoe.

The method allows scanning a wide range of shoes including sneakers, boots, high-heeled shoes, open-toed shoes such as ballet flats and sandals. Figure 5 below shows a high-heel shoe and a 3D model of its inner surface.

a. b.
Fig. 5. High-heel shoe and the 3D model of its inner surface.
a. high-heel knee high boots b. high-heel ankle boots

2.2. Topological mesh of the inner surface of footwear

We have developed a knowledge base with a decision tree that assigns adjustment factors to each node of the topological shoe model when calculating forces depending on the upper material, heel height, shoe type, lacing type, etc.

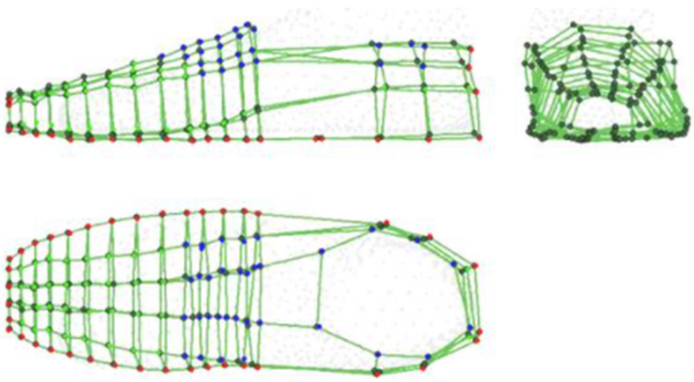

Fig. 6. Topological mesh of the inner surface of the footwear

The red nodes (see Figure 6) are adjacent to the sole and the heel, and therefore have the greatest force coefficient while the blue nodes (lacing) have the smallest. Lace-up shoes are scanned with tightly tied laces and loosely untied. The bonds with the least forceful impact stretch more.

3. Mobile vs stationary 3D foot scanning

Among the simplest and most affordable solutions for 3D foot reconstruction is “3D avatar feet” mobile application and its clones, iDfits, Scan&Fit and others, developed by Biomechanics Institute of Valencia. Generally, such 3D reconstructions of the foot model are based on the modification of the template of a 3D foot model and further matching it with flat contours of the foot [6]. As a result, the real shape of the user’s foot is not fully reflected in the foot model constructions, thus producing a fitting error. The application allows creating a 3D model of the foot with the help of 3 photographs taken with a smartphone camera. The images are sent to the server, where they are compared with 3D models of feet from the existing database. As a result, 3D reconstruction of the foot is performed and about 20 of its parameters are determined. Unfortunately, as our experiments have shown, the accuracy of the foot parameters obtained in this way is extremely low. The final shape of the 3D model does not correspond to the shape of the real foot, especially to the shape of toes.
Also, there are stationary foot scanners made using RGB-D cameras for making precise leg models (by Volumental, Safesize and others), but their high expense hinders the possibilities for their application.
Based on the information mentioned above, it is relevant to use inexpensive equipment such as conventional digital cameras, including those built into smartphones, and the ability to work with uncalibrated photographs which are taken in unobserved conditions (i.e., manually by the user himself).
In the next chapters we introduce the approach used by FITTIN^{TM} for an automatic reconstruction of 3D models from photographs, and present the results of applying the proposed approach in practice. The method that we are offering makes the process of a virtual fitting cheaper, simple, and precise which will

increase customer satisfaction and reduce the percentage of returns based on wrong size claims.
At first, we developed and successfully implemented a mobile application for feet scanning. Then we took into account the proposals of our partners who wanted to have stationary scanners in their stores and delivery points. Over the course of a year, we have developed, tested and brought to commercial operation a stationary foot scanner, which is not inferior in accuracy to its analogs, while the cost is its main advantage. In the case of the app, the A4 sheet corners are used to calibrate each view. In the stationary 3D foot scanner, the cameras are already calibrated.

3.1. 3D foot scanning

In order to obtain the 3D foot model, the user should install a special app on their mobile device or scan the foot using the stationary scanner. To scan the leg, the user should place his foot on the middle of an A4 or US Letter sized white sheet of paper (or near any basic element the sizes of which are commonly known such as ruler, coin, bank card, paper money, etc.) lean on your leg and take multiple shoots from different angles, equally distributed around a circular curve of 200 degrees from one side of heel to the opposite side of heel. The desirable movement should be from knee level, that will give more precision during the three dimensional model construction. However, this method of measurement guarantees enough precision if the movement of the device will be 10 centimeters high from the surface the person is standing on. The scanning process is shown in Fig. 7.

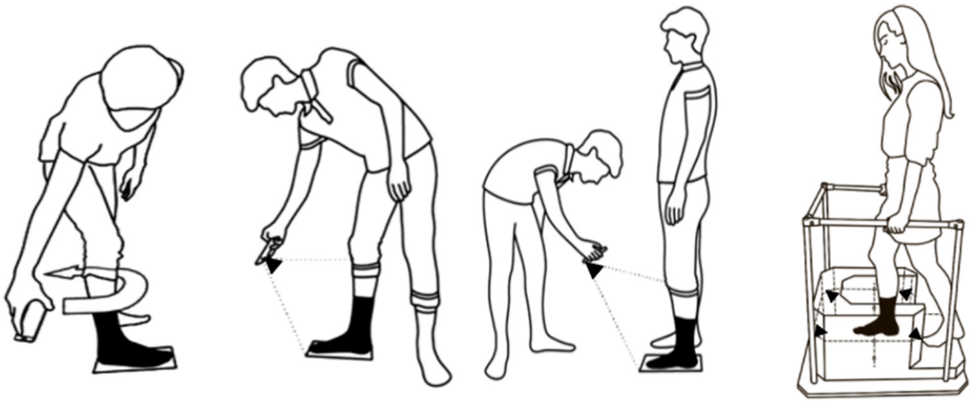

Fig. 7. Example of the scanning process for a user's foot.

The reconstruction of the three dimensional foot model by an array of pictures is divided in the following stages:

3.1.1. Resize and cropping of images.
To provide predictable conditions while processing the images and minimize the amount of internet traffic during the process of transfer of the images to the server, all the taken images are resized by a factor of 2, as many times as needed to reach a size of 480 x 640 pixels. The images that already have the resolution 480x640, are cropped so the A4 sized sheet of paper is situated in the center of the image.

3.1.2. Defining the closed outline of an A4 sized sheet of paper.
The process of resizing and cropping the images is accompanied by the defining of the closed outline of the A4 sheet of paper or any other basic element.
Multiple brightness-contrast corrections (from 10 to 20 iterations) are performed to improve the separation between light and dark areas and to convert the image from gray-scale to black and white [6].

3.1.3. Defining the positioning and orientation of the camera.
The task of defining the camera parameters (coordinates in space x, y, z, angles of orientation cameras α, β, γ and focal length f) is placed as an inverse task of the previous stage: as a need to adjust the camera parameters, so the predicted placing of the A4 sheet of paper (or any other basic element) will coincide exactly with the real position of the image. The camera parameters are further used when cutting the 3D-model from the voxel array.

3.1.4. Recognition of the closed outline of the foot and shin.
At one of the stages of 3D shoe model reconstruction that our competitors [7], [8] use the process of defining the contour of the foot is performed. Our method, on the other hand, has its own peculiarities.
On this stage, on each image the closed outline of the foot and shin is recognized between the dark sock, the A4 sheet of paper and the background, with use of the evolutionary method.
To search for the closed contour of the foot and shin the method of dynamic particles was adapted. The

idea behind this method is that during the outline stretch on the foot area the points initially situated on the edges of the A4 sheet of paper a “physical interaction” is calculated and also the “mechanical movement “of the points. Conditional forces of attraction, acting between adjacent points, lead to the tightening of the points on the leg, keeping the distance between the points approximately constant. To find the outline of the foot the force that is added is proportional to the numerical estimate of the second derivative of the intensity from the image across the outline. This intensity is defined for a pair of points situated inside and outside of the outline and distributed by the relation to the outline.
The main variation in the choices is the lightning, in the area of the foot arch usually the shadow is present, which makes it difficult to define the connected area of the foot and the shadow. With help from this method there is a possibility of reconstructing and calculating the height of the arch of the foot – a parameter which is necessarily useful in the footwear choice for people who suffer from flatfeet. Without a precise definition of the foot arch a 3D model cannot count as anthropometrically precise.

3.1.5. Clipping of a personal voxel
With each frame of a voxel array, that initially had the shape of rectangular cuboid situated over the A4 sheet of paper, the voxels that are out of the volume are cut out, on a boundary from a conic section with a vertex in the point of the camera position and guide line that received in the previous stage outline of the foot. In each frame you can clip out from the voxel array the projection of the outline of the foot constructed earlier. As the excess voxels are cut off from different angles, a very accurate voxel 3D model (see Figure 7) of the leg is formed.

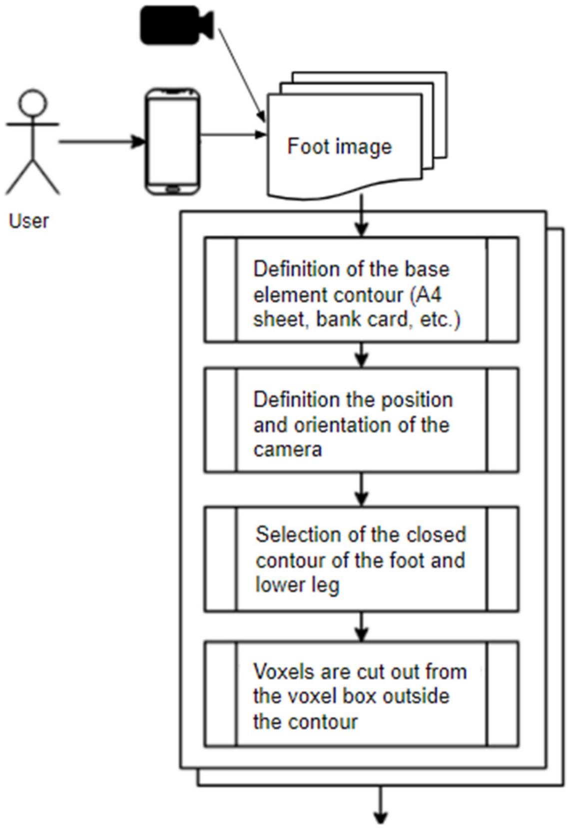

Fig. 7. A flowchart for the construction of a voxel 3D model of a foot metrical model with multiple photo images of a foot

3.1.6. Voxel to polygon mesh conversion
For visualization and subsequent storage in a more compact form the model is converted from voxels to a polygonal format (see Figure 8). During this process the mesh is regularized and the model is additionally smoothed.
During the processing a space is filled with a foot area in advance, key points spread around the outer surface of the field based on maximizing the surface coverage, then they are smoothed with edges.
Due to the use of a field approach the model becomes smoother.

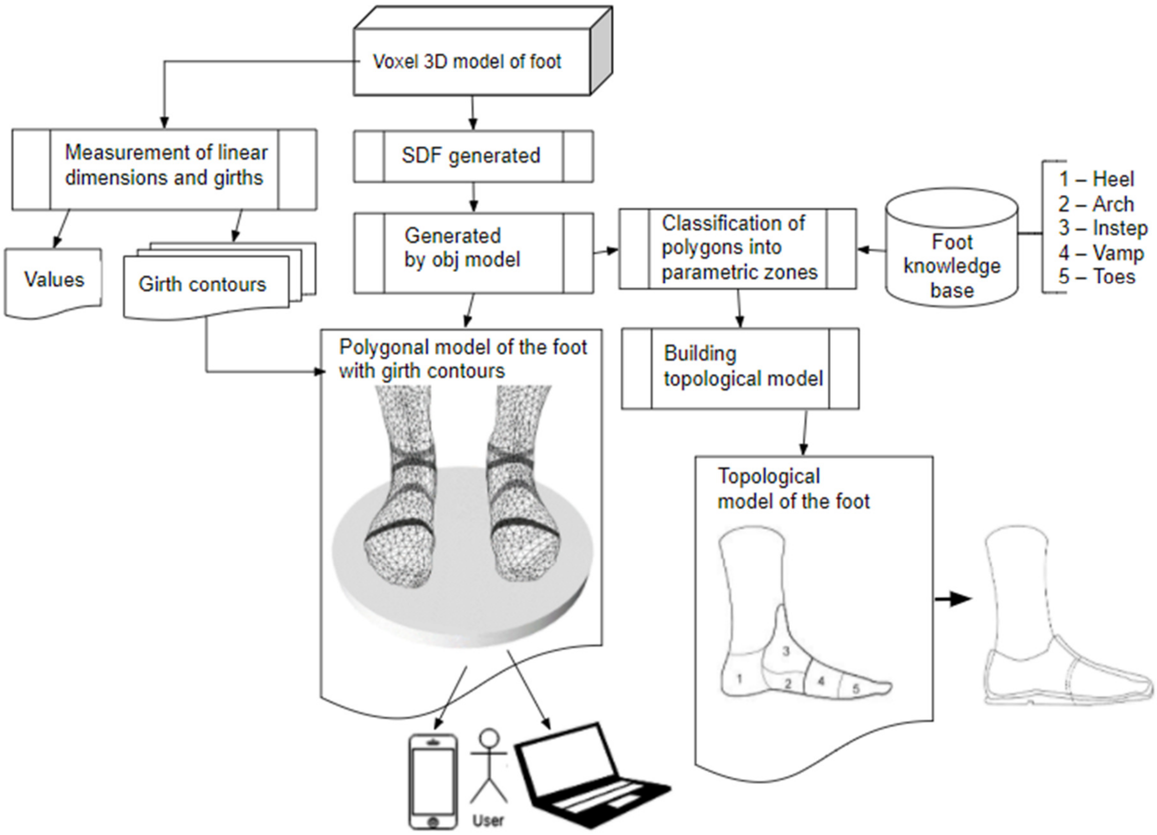

Fig. 8. A flowchart for creating a topological model of a foot using the foot knowledge base and the 3D foot model, converted from voxel to polygonal format

3.2. Topological mesh of the foot

Topological mesh (see Figure 9). of the foot is a digital 3D polygonal foot model that includes a description of the vertices and polygons, in which each polygon in addition to spatial data (geometric properties) carries information about sensitivity zones of the foot, permissible values of shoe pressure in each of the sensitivity zones, permissible limits of change in linear dimensions and girths, etc.

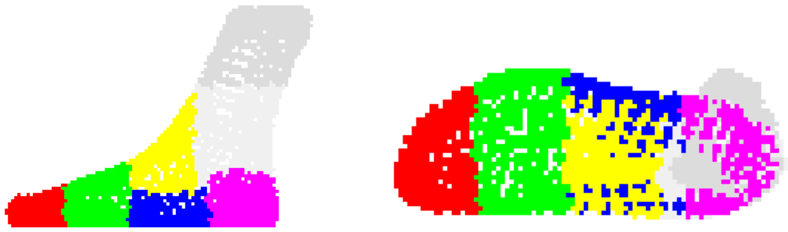

Fig. 9. Topological mesh of the foot

The topological mesh is essential for correctly calculating the comfort level of shoes for a particular foot model. Without calculating the permissible pressure values in different anatomical zones of the foot, the correct virtual fitting is not possible.

4. Online fitting of footwear

In our case, our fitting algorithm TRYFITT™ is a complex of different methods applied for different purposes. For marketplaces we have developed a quick static fitting. It takes 0.5 seconds to calculate the foot measurement as on average this time is enough for a product card to be loaded on the website. Then, if the user wants to get more accurate recommendations, we perform a dynamic fitting in the course of which a comfort level the FITTRATE™ is calculated and a fitting map is built (the so-called "heat maps"). For the second and subsequent fittings we offer a fitting method based on neural network technologies. We believe that only this approach can provide correct size recommendations for real users, as it was not developed in laboratory conditions. We emphasize that our knowledge in different areas such as footwear production, podiatry, sports, engineering, mathematical modeling, etc. and practical experience in commercial operation allows us to constantly improve our technology.

4.1. Dynamic vs static fitting

Recently, IEEE 3D Body Processing (3DBP) Standards Association, which brings together various experts, whose task is to develop an international standard for working with 3D human models within the framework of the IEEE SA Industry Connections program, has raised the “Static versus dynamic fit” issue. We have been paying careful attention to this matter and would like to discuss this issue in more detail. Static fitting is undoubtedly easier and a number of methods have already been developed [9], [10], [11]. Static fitting involves matching the 3D model of the foot with the 3D model of the inner surface of the shoe and calculating the deviations between them.

Our company supports the opinion that “there is a need in the art for a system and method of enabling a user to select footwear that matches both static and dynamic characteristics of his feet, without having to try on the shoes physically." [3]

The ratio of the shape and size of the foot to the shape and size of the inner surface of the shoe depends on a combination of factors. These include the spacer rigidity of the structure. The stiffer it is, the less optimal the shoe matches the foot.

With the model of the shoe and the model of the foot of a user, the next process for measuring the comfort level of a shoe and choosing a comfortable shoe is a virtual fitting and the simulation of the foot and the shoe interacting during motion (see Figure 10). The obtained user’s foot model is zoomed out: reduced in width, length and height. These deformed foot models are then embedded into the topological mesh of the inner surface of the shoe. The deformed foot model may be further aligned inside the shoe model. After fitting a foot model into a shoe model and aligning it, then the foot is zoomed in up to its original size. Now the topological mesh of the inner surface of the shoe is deformed, fitting tightly the foot model. When the nodes of the topological mesh of a shoe move, and the forces are calculated continuously, the calculation is repeated until the forces are balanced. The algorithm and calculation continues while the shoes mesh vertex moves. When all the forces are balanced, and the shoes mesh vertex are stopped based on the topological model of the foot the forces acting on the grid nodes are calculated.

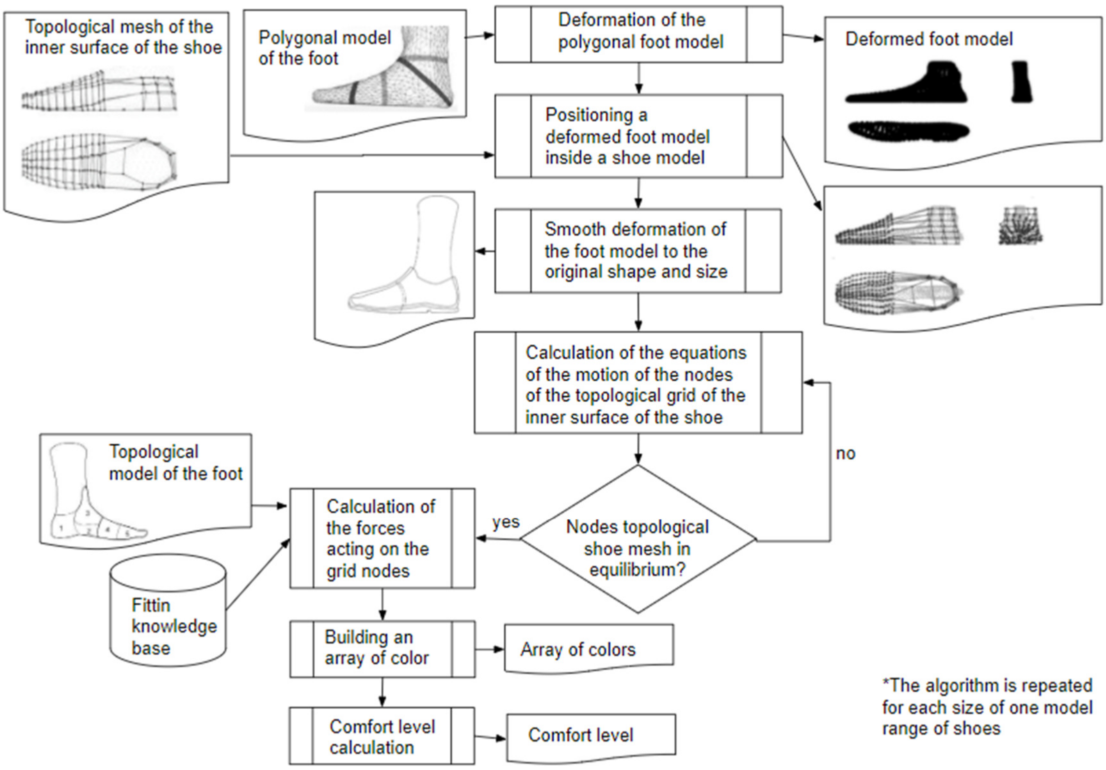

Fig. 10. Flowchart for calculating the comfort level of a 3D foot model inside a topological shoe model

The calculation of forces takes into consideration such factors as the shoe vamp materials, the presence of shoelaces, the type of footwear, and others factors provided from the shoe knowledge database.

The simulation includes the foot motion (see Figure 11)., the cross-sections of a shoe, having a particular size and form, pressures against a foot model, having a certain resistance to it. Herein conditional forces are calculated between the vertex node points on the foot model and the topological shoe model. The forces calculated include the force of resilience and soft interactions of the nodes, the force of the interacting elements of the leg pressing on the nodes, the bending forces of the bonds when a node is displaced in relation to the neighboring nodes.

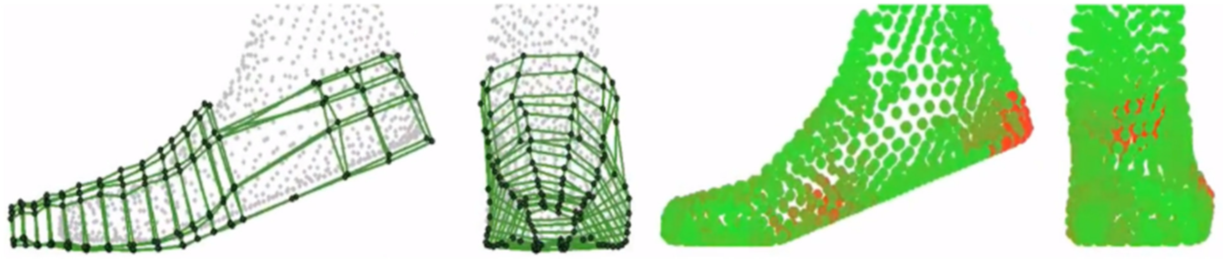

Fig. 11. The calculation of foot comfort level with foot motions

Depending on the amount of force in each vertex of the polygonal model of the foot, an array of color is built and the level of comfort is calculated. The calculated level of comfort FITTRATE™ and an array of colors characterizing the level of comfort of shoes are transferred from the server to the mobile application or to the widget (see Figure 12). As a result of transferring color values to the 3D model of the foot, each unprepared user receives information in a visual form, according to which he can choose the most comfortable shoes.

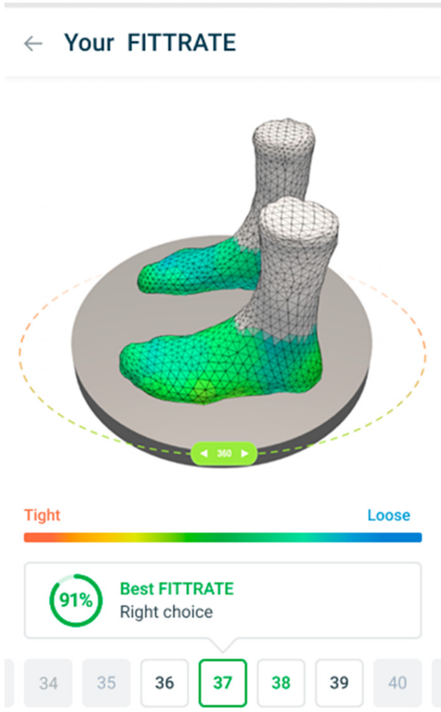

Fig. 12. Elements of the mobile application interface with the results of online fitting

4.2. Calculated vs predicted fitting

Some known shoe provider services give recommendations for selecting footwear based on data from try-on experiences of other users with similar anthropometric measurements. These probabilistic methods are based on user co-purchase data and generated a brand-brand relationship graph. In simple terms, these systems translate the sizes of one brand into the size system of another brand. But there is no guarantee on the precision of these measurements, thus, they are not suitable for evaluating the comfort level of footwear for a particular consumer and recommending the correct shoe size.

5. Results

Unfortunately, because of the article format the space is limited, so we can only acknowledge the accuracy and reliability of our method for scanning feet and the inner surface of shoes. The accuracy of virtual fitting is an extensive topic, and we will talk about it in the future.

5.1. Foot scanning

At the writing of this article, the stationary foot scanner can scan with an accuracy of 1.5 mm. Each scanner goes through a series of tests prior to being commissioned. The main test is the scanning of a 3D model of a reference dummy in multiple occasions, of which the exact dimensions are known. Then, the same measurements are taken by humans. Linear and circumferential measurements of the 3D reference model of the foot, measured manually, are shown in Table 1.

Table 1. Linear and girth measurements of the reference model, measured by hand

Length, mm.	Ball width, mm	Instep height, mm	Ball girth, mm
250	98	229	230

Table 2 shows the accuracy of the measurements taken by the stationary scanner FITT[TM] Scanner.

Table 2. Accuracy of the measurements taken by the stationary scanner

FITT[TM] Scanner	Foot length, mm		Ball width, mm		Instep height, mm		Ball girth, mm	
	Dimension	Deviation	Dimension	Deviation	Dimension	Deviation	Dimension	Deviation
№1	248,3	-1,70	99,69	1,69	227,41	-1,59	228,15	-1,85
№2	248,4	-1,60	99,69	1,69	227,27	-1,73	228,01	-1,99
№3	248,5	-1,50	99,59	1,59	227,71	-1,29	228,23	-1,77
№4	248,5	-1,50	99,59	1,59	227,43	-1,57	228,18	-1,82
№5	248,5	-1,50	99,59	1,59	227,76	-1,24	228,06	-1,94
№6	248,5	-1,50	99,59	1,59	227,74	-1,26	228,04	-1,96
№7	248,5	-1,50	98,49	0,49	227,60	-1,40	228,17	-1,83
№8	248,5	-1,50	99,59	1,59	227,80	-1,20	228,21	-1,79
№9	248,5	-1,50	99,59	1,59	227,41	-1,59	228,75	-1,25
№10	248,5	-1,50	99,59	1,59	227,35	-1,65	228,08	-1,92
Amplitude of deviations	0,2		1,20		0,53		0,74	
Standard deviation	0,07		0,36		0,19		0,21	

Scanning feet in the stationary scanner is more accurate than using the mobile application, because in the stationary scanner we have created the ideal conditions: cameras are fixed precisely in optimum angles and there are no shadows. When scanning with a smartphone, the decisive factor for accuracy is adhering to the instructions, the shooting conditions and how still the foot is held during the scanning process. And although we have significantly improved and simplified the shooting process, unfortunately, it is quite difficult to control the user's actions.

Table 3 shows the calculation of the deviation between 3D foot models obtained with the stationary scanner and with the mobile application. The standard deviation of linear dimensions is within 1.5 mm. The standard deviation of the girths is within 3.5 mm.

Table 3. Comparison of measurements of the stationary scanner and the mobile application

Users	Foot length, mm			Ball width, mm			Ball girth, mm		
	FITT Scanne	Mobile app	Deviation	FITT Scanner	Mobile app	Deviation	FITT Scanner	Mobile app	Deviation
user1 left feet	241	240	1	104	104	0	239	242	-3
user1 right feet	242	242	0	106	107	-1	249	249	0
user2 left feet	259	259	0	98	100	-2	236	239	-3
user2 right feet	254	254	0	99	102	-3	237	241	-4
user3 left feet	274	273	1	102	102	0	246	245	1
user3 right feet	276	274	2	101	102	-1	246	246	0
user4 left feet	259	259	0	110	111	-1	263	263	0
user4 right feet	261	260	1	108	110	-2	262	259	3
user5 left feet	267	267	0	107	109	-2	257	262	-5
user5 right feet	264	263	1	105	105	0	253	250	3
user6 left feet	281	281	0	111	113	-2	266	271	-5
user6 right feet	278	280	-2	112	113	-1	270	273	-3
user7 left feet	295	294	1	119	119	0	289	286	3
user7 right feet	296	294	2	122	119	3	290	287	3
user8 left feet	234	235	-1	92	92	0	212	217	-5
user8 right feet	233	234	-1	91	91	0	212	217	-5
user9 left feet	246	246	0	95	96	-1	222	224	-2
user9 right feet	246	245	1	96	99	-3	227	232	-5
user10 left feet	243	240	3	103	104	-1	241	242	-1
user10 right feet	242	244	-2	101	100	1	234	239	-5
Amplitude of deviations			**5,0**			**6,0**			**8,0**
Standard deviation			**1,3**			**1,5**			**3,1**

5.2. Shoes scanning

At the time of this article's release, the FITT[TM] Scope inner surface shoe scanner allows scanning with an accuracy of about 1 mm and a speed of up to 3 articles per hour (speed when using one scanner).
During R&D, we repeatedly checked the measuring accuracy of the inner surface of the shoe, including the following ways: a comparison was made with the dimensions of the inner surface of the shoe, taken using hand-held measuring instruments; its own control and measuring instruments were developed; X-rays were taken during the scanning process of the inner surface of the shoe in several projections to control the repetition of the surface contours. The company established a quality and control department. As a result, the procedure for verifying the accuracy of the FITT[TM] Scope before being put into commercial operation was reduced to a double scan of a special cone-shaped device with known dimensions that simulated the inner surface of the shoe. Table 4 shows the dimensions of the 3D reference model of the inner surface of the shoe, measured with a hand-held measuring tool.

Table 4. Linear and circumferential measurements of the reference 3D model of the inner surface of the shoe

Length, mm.	Ball width, mm	Instep height, mm	Ball girth, mm
271,5	73,5	47	218

At the moment, the scanning process has been significantly improved, usability has been enhanced, elements have been added to help scanners. These actions have resulted in a significant reduction in errors and have increased scan accuracy. We almost eliminated the human factor, the whole process from scanning to checking and accepting a 3D model of the shoes is automated. Table 5 shows control measurements with the FITT[TM] Scope.

Table 5. Control measurements with the FITT™ Scope

FITT™ Scope	Length, mm	Deviation mm	Ball width, mm	Deviation mm	Instep height, mm	Deviation mm	Ball girth, mm	Deviation mm
№1	270,5	1	73,3	-0,2	47,5	0,5	219,5	1,5
№2	270,3	-1,2	73,6	0,1	46,5	-0,5	217,5	-0,5
№3	271,5	0	73,7	0,2	47,2	0,2	219	1
№4	270,5	-1	73,3	-0,2	46,5	-0,5	218	0
№5	271,3	-0,2	73,7	0,2	47,2	0,2	219	1
№6	272,2	0,7	73,9	0,4	47,5	0,5	218	0
№7	272,6	1,1	73,7	0,2	47,2	0,2	217	-1
№8	271,4	-0,1	73,7	0,2	47,4	0,4	218,5	0,5
№9	271,1	-0,4	73,6	0,1	47,3	0,3	218	0
№10	271,7	0,2	73,9	0,4	46,4	-0,6	217	-1
Amplitude of deviations	**2,3**		**0,6**		**1,1**		**2,5**	
Standard deviation	**0,77**		**0,21**		**0,43**		**0,85**	

For the FITT™ Scope, we have defined the following tolerances.
1. Lenght indicators should be in the range from -1.5 mm to 1.5 mm.
2. Width and height indicators should be in the range from -1 mm to 1 mm.
3. The index for the ball girth should be 218 mm, + -1.5 mm. (216.5-219.5)

It takes 1 week to train the human scanners. There are no special requirements for the qualifications of the scanners. We are ready to train scanners and organize the remote scanning of shoes.
All devices undergo routine accuracy checks. if the accuracy does not meet the permissible limits, then the probes are replaced and recalibrated.

6. Conclusions

FITTIN™ is a major advocate of real foot scans rather than the parametric foot models that our competitors utilize. We stand up for honesty and understand that absolutely identical feet do not exist. Feet vary in size including length, width, height, girth, shape of the toes, and other irregularities that occur with age or injury. We understand that the foot is a mobile system of bones and muscles. We scan loaded feet, while our competitors scan unloaded feet. At the moment, we are working with a number of marketplaces and shoe sellers in Russia. Our next step will be the foreign market, that's why we are looking for experts and scientists who can cooperate with us in order to improve our methods and increase consumer confidence in the virtual fit technologies.
The development process continues and a much more complex recommendation system is coming soon. We strongly believe that systematic hypothesis testing and product improvement are our recipe for success. We started by recognizing the length and width of the user's foot from two photographs. Now we are able to get an accurate 3D model of feet using our stationary foot scanner and mobile application. At first, we had a simple prototype of the shoe scanner, now our solution allows to scan up to 2 articles of shoes per hour and a commercial scan of shoes is being carried out. In terms of profitability FITT™ Scope has no analogues. We first did the selection of suitable shoes by comparing the linear dimensions which are length and width, then statically matching the 3D model of the shoe with the 3D model of the foot, now we have a multi-stage decision tree with 10 parameters that is based on neural networks. We continue to add new parameters and improve the percentage of successful fittings by inventing new fitting ways and looking to the future with optimism.

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