Research Article

Guideline for Fast Creating Virtual Mould of the Flat Feet

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Abstract

It is quite difficult to quickly design the special inserts or shoes for the particular patient who faces the problem about foot's shape. Well-mould designing can make the geometric shapes of the inserts to be properly fitted to the feet, as the results, the pains can be relieved where the patient can perform the daily activities with more comfortable. To quickly copy near-net shape of the virtual model from the master part, the integrating between reverse engineering and slush casting has been applied where the Automated Selective Acquisition System (ASAS) has been applied in this research as the alternative reflective-scanning method to obtain an organized data set without applying any data reduction processes. For assisting the ASAS technique to quickly acquire the non-rigid part as feet, generating the solid feet by slush casting technique has been firstly performed where the various materials have been studied under the criteria of economical-based impression and non-skin allergic problems.

Keywords: Computer-aided design; Engineering design, Conceptual design; Product design; Design technologies, Automated Selective Acquisition System (ASAS)

1 Introduction

In the competitive market, currently, the manufacturers have paid attention to the time used for launching the products to the market where the product quality is still existed. To accomplish this demand, Reverse Engineering (RE) has become a vital technology for shortening and strengthening the product design process [1]–[4].

RE is the technology that allows 3D CAD model can be constructed quickly and directly from its physical object. In the RE process, three main steps are required: data acquisition, surface reconstruction, and surface fitting [3]. Recently, RE has been applied in medical purposes for generating the 3D virtual models of physical or anatomical parts for easily analyzing the defects (e.g., tumors) where the devices (e.g., Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI), and X-ray) apply the concept of transmissive have been applied for capturing object's surfaces [5]–[9]. Using the transimissive method may cause some effects from the exposure of radiation to the human, and this is inflexible and expensive acquisition process.

To apply non-contact acquisition method, especially, 3D laser scanner, surface preparation steps are required for eliminating shiny, transparent or fluorescence surfaces which make some mistakes during scanning process [10]. For soft part such as human body (e.g., hands, or feet), the difficulties of scanning process are occurred where the owner of that part cannot stay in the same position, and the dense patterns of references are properly required and adjusted.

Presented in this research are the integration of technology on extracting geometric shapes from the existing object by applying the concepts of reverse engineering and casting process. Using this integration

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process can enhance the performance of acquisition activity to easily induce the feature details of soft part where the entire shapes can be clearly presented. Casting is a manufacturing process where a liquid material is poured into a mould that contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part (a casting product) is ejected or broken out of the mould to complete the process. In general, casting materials are metals or various cold setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. Casting is the most frequently used for making complex shapes that would be difficult or uneconomical to make by other methods. Since the geometric shapes of the feet (curvature surface) will be extracted and studied in this research, in order to prevent any skin allergies and damages, the appropriate types of the casting and its parameters will also selected and discussed.

2 Casting Process

Casting is a manufacturing process where a solid is melt and heated to a proper temperature and then it is poured into a mould that contains a hollow cavity in a proper design shape. After pouring activity, the solidification process occurs and turns a melted material to be in a solid casting part [11], [12]. Casting, in general, can be classified into two main types; expendable and permanent mould casting, based on the way to break down the mould for producing casting part. To get casting part, the mould is ejected from or broken out of the mould. In order to get the best result of casting part the shape of desired part, type of materials, and design of the mould cavity are the main factors that have been taken into considerations. For expendable mould casting, it can produce one metal casting only where the mould that material solidifies in is destroyed to remove casting part. Sand, shell, plaster, slush, and investment castings are presented as the types of the expendable. Using this mould casting can produce various types of the complex shapes, and the final part can present smooth surface where accuracy, versatility and integrity can be maintained [11]. Comparing to the aforementioned expendable mould casting, in contrast, the permanent mould casting composes of the sections that can open and close permitting removal of the casting. This casting can be classified into four types: permanent, die, centrifugal, and continuous castings. The part shapes present as the main issue in this mould casting. The repeatability of the casting process (e.g., the dimensions of the casting part obtained) depends upon the number of parts produced. In order to generate solid parts of the particular shapes (i.e., feet) which contain some curvature surfaces and complex details, the expandable mould casting has been applied in this research.

3 Research Background

Typically, fast surface acquisition and reconstruction are desirable for reverse engineering process; therefore, non-contact acquisition methods which apply the concept of transmissive (e.g., Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI), and X-ray), or the concept of reflective methods (e.g., optical digitizer, laser scanner, and ultrasound) are recommended for more efficient in terms of speed and reducing in the human labour required [7]–[9]. The detected distances are converted into a point cloud map representing the 3D surface [5]. In the preliminary study of this research, one of the fast scanning techniques for acquiring the body part like feet, 3D laser scanner with handheld form, was applied. However, it was difficult for controlling the feet to stand and hold them in the same position during scanning process. The obtained point cloud data presented some noises and errors where the positions of some features were missed, and gaps were shown.

Point cloud data, acquired from this technique, requires pre-processing operations, such as filtering outliers, smoothing and blending of existing points before being registered into one coordinate system [13]. The difficulty of scanning process depends upon surface types (e.g., transparent, fluorescence, or shiny surfaces), object shapes (e.g., concave, spline curve surface, small holes, or undercut shapes), and object position. For constructing the surfaces with high accuracy, the organized points are required.

4 The Automated Selective Acquisition System (ASAS)

Illustrated in Figure 1 is the Automated Selective Acquisition System (ASAS) that has been developed and presented as the alternative channel for non-contact

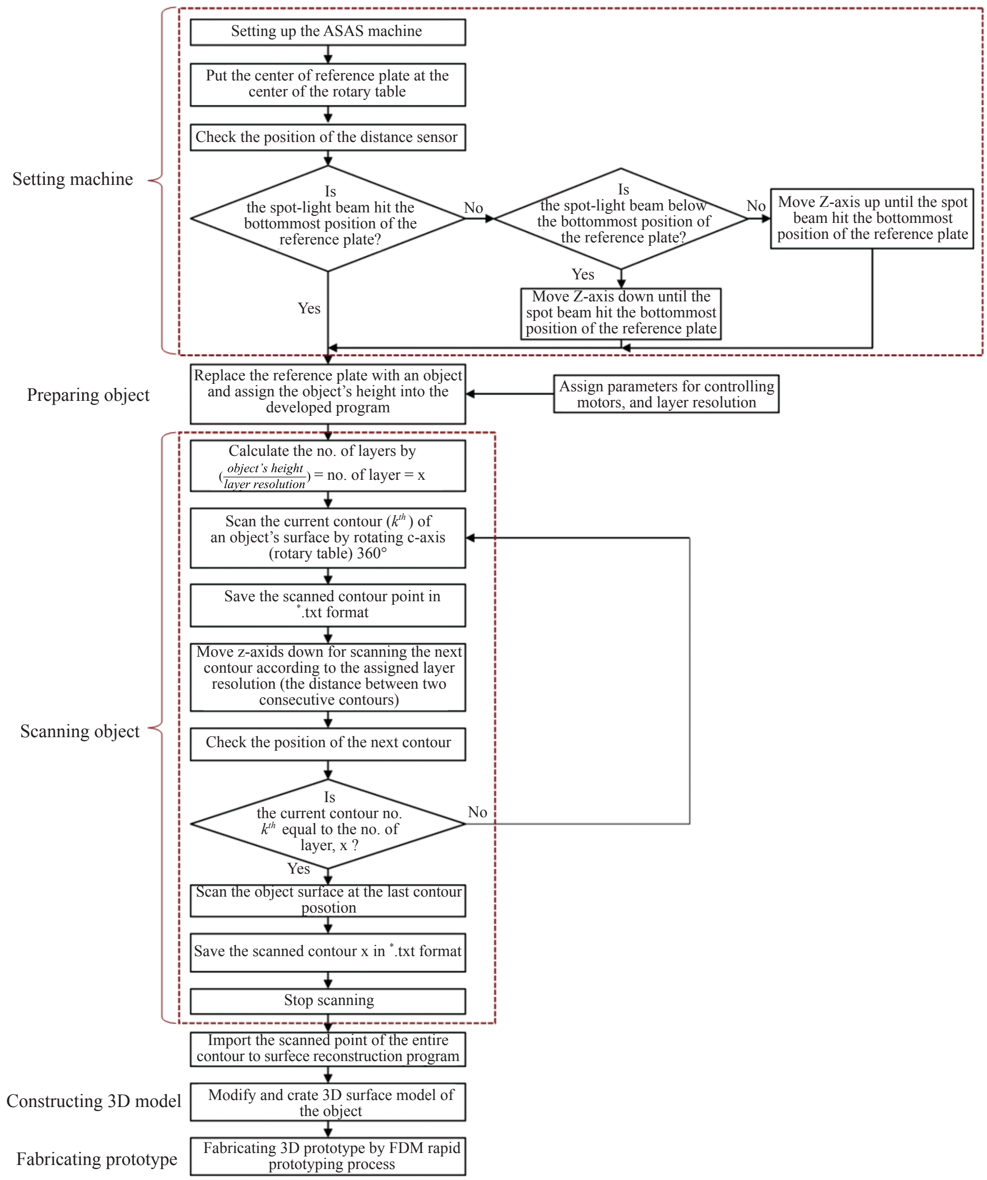


Figure 1: The process of ASAS.

acquisition technique where the data is selectively and locally scanned contour by contour without performing data reduction process [14], [15]. The working process algorithm of the automated selective acquisition system can be categorized into 5 main steps: *Setting the machine, Preparing the physical object (input), Scanning the physical object, Constructing 3D model, and Generating a prototype*.

In order to operate ASAS for acquiring object's surface, at the initial stage, all axes are set the zero positions. The displacement sensor (i.e., the acquisition device) is mounted on X-axis which can be moved in and out for properly acquiring object's surface. This X-axis is located on Y-axis for moving in left and right direction. To move the object in vertical direction, Z-axis is applied. Since the expected results in this proposed process should be formed as the contour points where the boundaries of the object can be easily acquired, the rotary table (i.e., c-axis) is used as the platform to locate the object. This rotary is mounted on Z-axis. For setting the distance between acquisition device (on X-axis) and object (on the rotary table), the spot-light beam from the device will hit the bottommost position of the reference. The measuring result will show in the form of numeric value on the provided monitor.

To continue with a scanning process, the ASAS program start to generate the demand for running the machine, and the number of layers (x) equals to the object's height divided by layer resolution as shown in Eq (1).

$$No.of\ layers = \frac{object's\ height}{layer\ resolution} \quad (1)$$

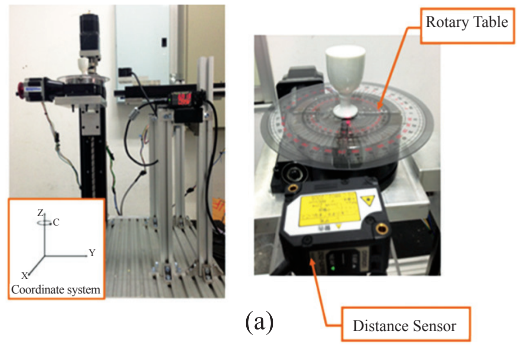
Illustrated in Figure 2(a) is the ASAS machine. The sample model, glossy-curve frog is used for demonstrating the ASAS as shown in Figure 2(b). The results present as the organized contour points which are directly used to generate 3D virtual model [Figure 2(c)].

5 Direct Interfacing between Slush Casting and Reverse Engineering Process

To enhance the acquisition process where the position and the reference of the feet part can be fixed and the acquired points can represent all features of the feet part, slush casting process has been applied as an assisting technology for transforming non-rigid part to be a solid one.

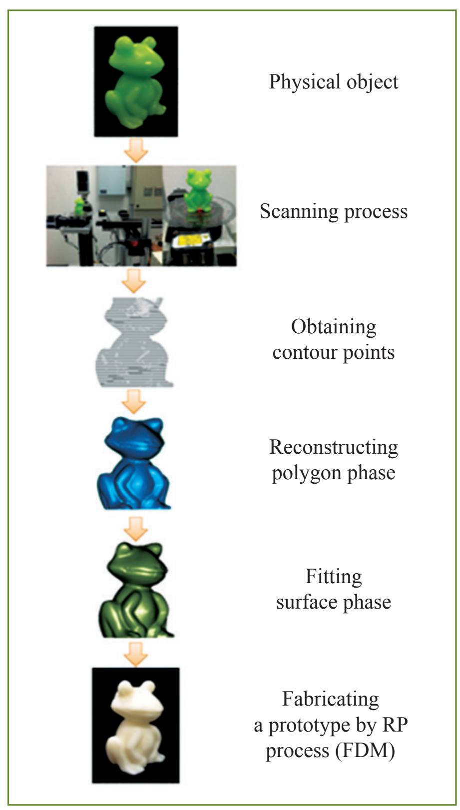
To obtain the organized points and quick surface reconstruction, the automated selective acquisition system has been applied instead of 3D laser scanning. The combination between slush casting and automated selective acquiring techniques can reduce times for eliminating noises and repositioning the object during scanning. Solidification time and shrinkage are the concerned parameters to select the appropriate materials for casting and moulding purposes.

Since, in this research, the object that is used for demonstrating the combination approach is the body part (i.e., foot); materials selected should provide non-skin irritation while preserving geometric details.



(a)

(b)



(c)

Figure 2: Automated Selective Acquisition System (ASAS): (a) Acquisition machine, (b) The sample model, glossy-curve frog, and (c) The steps required.

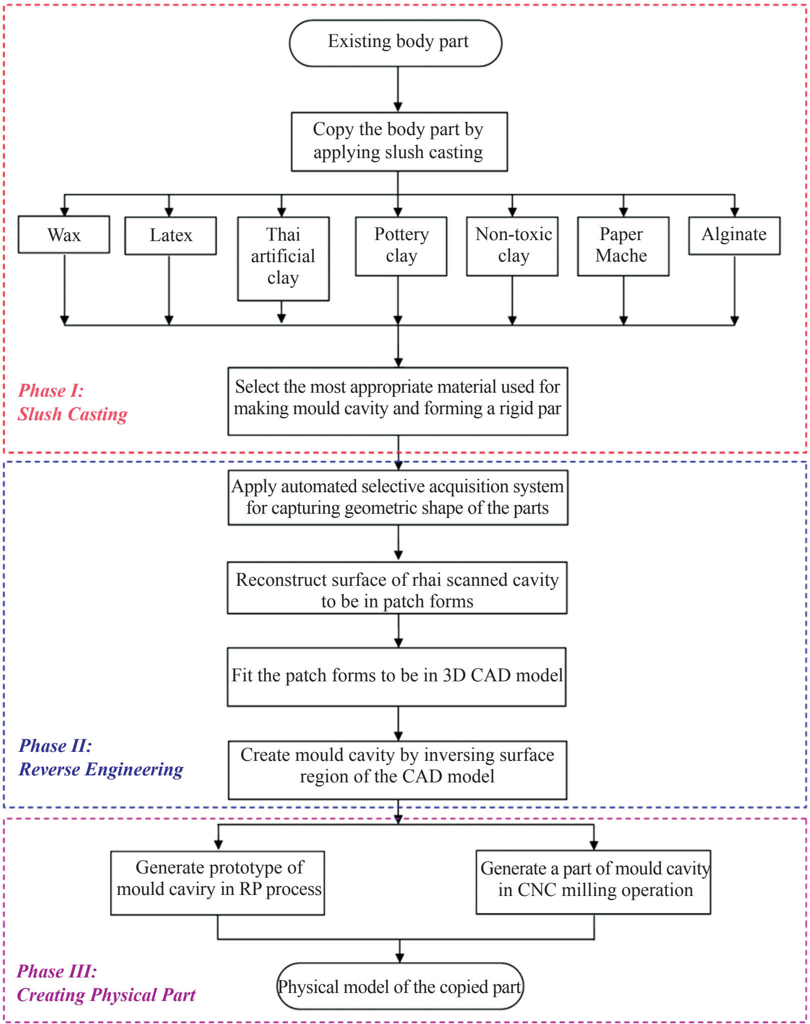


Figure 3: The overall process of the proposed approach.

Illustrated in Figure 3 is the overall process of this research. In order to accomplish the research objective where the complex shape of body part can be created quickly as 3D CAD model, and three main phases have been introduced. The contribution of this research is to generate mould cavity of the body part that contains curvature surface or specific surface shapes or characteristics.

5.1 *Phase I: Slush casting process*

Seven types of the materials which are wax, latex, Thai artificial clay, pottery clay, non-toxic clay, paper mache, and alginate are studied and analyzed. On each material type, the preparation steps required and results of solidification process will be discussed in the section 6.1, casting processes. The appropriate one that provides less sensitive to the body part, and can maintain the surface details will be selected. In slush casting process, the chosen material is changed its phase to be a liquid form which is easily poured all over the master part (i.e., foot shape) for creating and shaping a cavity. Then, the other material used for making a rigid form of the copied part is poured into the solidified cavity. Finally, the cast part is removed out from the mould.

5.2 *Phase II: Reverse engineering process*

After obtaining a rigid part, to generate 3D virtual model of the solidified part, reverse engineering process is applied where the Automated Selective Acquisition System (ASAS) is asked for capturing geometric shape of the rigid part by applying. The entire geometric shapes of the rigid object are scanned and converted into the organized contour points. Next, the stage of surface reconstruction is run where at least three points are used to generate a triangular facet (i.e., polygon phase) which represents one portion of the entire surface of the part. The obtained meshes can present as non-overlapped form which is easily fitted for creating 3D virtual model in the surface fitting process. Since the scanned points contain no noises, time used for generating and modifying surface is fast.

6 Applications of the Proposed Approach

Presented in this section are about forming a virtual foot model starting from selecting the appropriate casting type and material based on non-allergic processing concept. The second activity presents about the non-contact acquisition method to extract geometric shapes of the obtained cast part and transform them to be in a digital form. A series of organized contour points can be used for generating 3D surfaces directly without applying the redundant activities. Using this acquisition method can preserve some curvature surfaces of the feet.

6.1 *Selection of materials and casting method for copying the foot model*

The slush casting process is applied in Phase I to create the rigid form of the body part while maintaining the surface accuracy where shifting in references and model positions can be eliminated. The key component of this project is mould making material used for slush casting process which will be selected according to well-formed shape, and low cost consideration. The experiment of materials has been trialed by starting from wax casting, latex, Thai artificial clay, pottery clay, non-toxic clay, paper mache and alginate, respectively.

6.1.1 Wax casting

In wax casting process, paraffin is asked for using as the material to make the prototype of the feet. Paraffin is introduced as an interesting wax since it has low melting point between 47–64°C [16], [17]. Master parts, feet, can be submerged in the liquid without any risks of blistering or scalding taking place. The paraffin wax casting process consists of three main steps: preparing surface of the feet, dipping the feet into warm paraffin wax for creating feet cavities (air sacs) with 2-mm thickness, and pouring melt paraffin wax into the feet sacs with a constant speed to form a solid pair of feet models.

From the results, this technique was fast and less time required; however, due to some properties of paraffin wax (e.g., easy to break, crack, and quite brittle, and soft), the wax pattern obtained was a near exact copy of the original pattern because the shrinkage which is occurred during solidification process, makes the size and shape of the wax pattern to deform and distort in all directions [17]. In order to diminish some missed features of the feet, some other materials which are harder than paraffin wax should be considered for creating mould cavity based on the concept of slush casting process. Illustrated in Figure 4 is the overall process of this technique.

6.1.2 Latex casting

The second alternative material used for making the copy of feet parts is latex rubber. Latex is extremely tough, durable and will last longer than other mould making choices [18]. In this research, to accomplish copying the feet, six main steps are required: clean and dry the feet which are going to be duplicated, brush on a thin layer of the liquid latex or dip feet into the latex liquid [Figure 5(a)], allow the mould to dry overnight or longer once, peel of the mould slowly, build a support stand for the mould, and the final process, casting parts using plaster of paris will be asked to perform.

After applying this latex casting method, the results were shown that it was easy and required less-skilled operators; however, it could not provide the near net shape of the feet mould since the shrinkage was presented as the main problem of this latex mould. The mould wall were stuck together even the proper

Figure 4: Cast part from wax casting.

(a) (b)

Figure 5: Latex mould, (a) Dipping feet into the latex liquid, (b) The cast latex mould sac/cavity.

support stand was provided after solidification process, as shown in Figure 5(b). Therefore, the plaster of paris could not be poured into these unshaped cavities. This casting was experimented on human organs, the feet skin was irritated by the latex rubber. Therefore, some other materials should be studied.

6.1.3 Thai artificial clay casting

To prevent any natural latex rubber allergies, Thai artificial clay casting was applied in the next trialed technique. Before using this clay, kneading process is required for letting the air distributes all around the clay surface. The kneaded clay is suitable for shaping the cavity of the feet since it is soft and easily deformed under varying in pressing conditions. Illustrated in Figure 6 are the mould cavities of the feet. The feet were asked to press on the kneaded clay which was spread on the one-centimeter-thick plate. The features could present clearly in details where the heels of feet were submerged into the kneaded clay around 4 mm. However, around the outer profile of the cavity, the shrinkage was occurred where the size of the cavities was smaller than the master one. The wall thickness of the cavity was reduced by 1.5 mm (from 4 to 2.5 mm).

To obtain more details of the feet cavities with precise dimensions, the material that contains less

Figure 6: Thai artificial casting.

shrinkage after solidification and less sensitive to the environment (e.g., hot/cold room, or humidity) should be considered.

6.1.4 Pottery clay casting

The other trialed material used for making feet cavities is pottery clay or natural clay. This type of material is very cheap compared to the aforementioned materials where no chemicals or expensive components are mixed. Using natural clay for copying the master-feet can eliminate some skin allergy reactions. In the process of making cavity through compression technique, the clay is soaked in the water for about 15 minutes and then it is dried for 5 minutes where the outer most layer of the clay surface is similar to a thick-hard cream [19], as shown in Figure 7.

In order to prepare the clay for making feet cavities, the kneading process is firstly required to be softened and leveled the clay surface [Figure 7(a)]. Similar to the Thai artificial casting technique, the feet were firstly cleaned and then they were pressed onto the flat natural clay [Figure 7(b)] which was spread onto the plate (2 cm in height). Then, the copied cavities had been dried for 10 hours. After solidification process where the cavities can be formed the shape as the foot print with 3 mm-wall-thickness, unfortunately, some small cracks and wrinkles were occurred around the rims [Figure 7(c)] which has the direct effects on preserving in shape and size of the cavities. To protect the outer most layer of the clay skin surface from moisture loss, plastic-wrap coating is applied all over the clay before and after forming process.

Figure 7: Pottery clay casting: (a) The kneaded pottery clay, (b) The initial stage of pottery clay-mould, and (c) The obtained feet cavities of pottery clay with cracks at outer rim.

6.1.5 Non-toxic clay casting

The problem with the natural clay is that the feature cavity made from this clay type cannot be formed its shape and dimension because of the cracks. Adding some non-toxic oil into natural clay may reduce the moisture loss for eliminating crack and shrinkage problems. This has led to another clay type that has the similar physical properties with natural clay but contains more moisture; plasticine is introduced Figure 8(a).

In the experiment, the white plasticine was pressed into a box where the layer thickness was about 2 cm [as shown in Figure 8(b)]. The plasticine was suitable for easily forming process; however, hot blower was asked for warming the plasticine surface to be ready for forming the feet cavities. The warm plasticine surface was pressed easily by feet to make cavities without any cracks, shrinkages or deformations after the pressing process was completely done. This technique could reduce time spent for casting process (copying the feet) where the feet details could be shown through the cavities with 1 cm-wall-thickness. Containing oil inside plasticine, non-toxic clay, preserved the pressing shapes of feet cavities where the cracks or shrinkages did not present around the rims and the outer profile of the cavities. However, it was quite soft and sensitive to the hot environment where the temperature was over than 35°C. Since the thickness of the feet cavities obtained from this process was about 1.5 cm which was quite difficult to be captured by laser scanner in the subsequence process. To enhance the surface accuracy, capturing geometric shapes of the entire feet might be the choice. This has led to the next casting technique that applies the basic concept of paper mache to form the entire shape of the feet.

(a) (b)

Figure 8: Non-toxic clay casting: (a) Package of non-toxic clay (plasticine), (b) Feet cavities from pressing onto the non-toxic clay.

6.1.6 Paper mache casting

Paper mache is a construction material made from a paper product (e.g., pulp, torn paper and a glue, flour and water, or resin) [20]. In the experiment, the tissue papers were torn into strips which were dipped gently into diluted flour glue. The tissue paper strips was stuck over the foot and smoothen down by finger. After completely covering the feet with a layer of the saturated tissue paper strips, the air blower was asked for drying where the moisture was evaporated from the paper. The total number of layers was ten. As the results, the formed tissue papers which were coagulated as the distorted feet cavities were removed out from the feet. The air blower was still applied for drying the cavity of each foot mould. The shrinkage was the main problem of this technique where the shape, size, and foot details could not be preserved, as shown in Figure 9(a) and 9(b).

(a) (b)

Figure 9: Foot mould from paper mache technique: (a) The paper mache mould in top view, (b) The paper mache mould in side view.

In order to enhance the process that is used for extracting geometric shapes of the feet without the problem of the size deformations, the technique that provides accurate and good surface finish where operation time is short is introduced in the next section.

6.1.7 Alginate casting

Alginate is one of the most frequently used for dental materials where it is simple, cost-effective, vital part of dental particle [21]. In general, alginate is supplied in powder phase which is mixed with water. This powder consists of alginate salts (i.e. calcium sulphate), and trisodium phosphate [22].

On mixing the powder with the water, a solution is formed, a chemical reaction takes place and a gel is formed. The second reaction occurs in preference to the first reaction until the trisodium phosphate is used up, then the alginate will set a gel. There is a well-defined working time during which there is no viscosity change.

In the experiment, the alginate had been mixed with water (mixing formula: 1 *lb* or 453 g of an alginate powder per 950 *ml* of water) and stirred for 35–40 seconds before pouring onto the feet which were located in the box, as shown in Figure 10(a). Currently, there are various brands of alginate powder available in the market, the mixing formula can be slightly changed or modified according to the instruction of the brand used.

Since the fast-solidification alginate was selected to apply in this study instead of slow-solidification one (30 minutes was required for forming the shape), pouring activity was done within 45 seconds. The solidification time was required around 5–8 minutes for forming and setting the feet cavities where the pouring level of the alginate was around the ankle.

(a) (b) (c)

Figure 10: Alginate casting: (a) Mould making, (b) Pouring plaster powder into the alginate mould, (c) Removing cast part from the mould.

(a) (b)

Figure 11: The complete parts from alginate mould: (a) The cast part from plaster powder (top view), (b) The cast part from plaster powder (bottom view).

Then, the feet were removed out from the alginate mould slowly for getting the cavities.

In order to create feet prototype models from the alginate cavities, a plaster powder was mixed with proper amount of water. Then it was poured into the cavities [Figure 10(b)]. The solidification time of casting plaster part was around 30 minutes, and then part made from plaster powder was obtained, as shown in Figure 10(c). After obtaining both left and right feet with top and bottom views [Figure 11(a) and 11(b)], the cast parts were checked the feature details where the surface finishing were asked for cleaning unsmooth sections.

Since the prototype models were made from plaster powder which was easily broken and sensitive to the environment (e.g., hot and cold weather, low and high moisture, and humidity), the other material called dental stone was introduced. Comparing with the plaster powder, the dental stone provides more strength and accuracy where low expansion, and less chipping and breakage are obtained. The stone powder had been mixed with water where the stirring time was about 2 minutes. After that the mixed stone powder was poured into the alginate cavities with constant pouring speed for preventing any bubbles. The cast part made from the stone powder is shown in Figure 12.

Figure 12: The cast part from dental stone.

Alginate materials process and provide the quality of good surface details and faster reaction at higher temperatures. They are elastic enough to be drawn over the undercuts but tear over deep under cuts and are not dimensionally stable on storing due to evaporation [21]–[25]. After applying the non-toxic ingredients, the respiratory allergies and skin problems could be eliminated. However the problems about poor dimensional stability, incompatibility with some stones, facing with fungi were presented. This alginate mould could be used only one time for casting process, when the cast parts had been removed for 30 minutes, the shape and size of the alginate cavities were slightly deformed and reduced. In order to enhance the performance of this casting technique, some parameters (e.g., percentage of alginate components, or moisture) should be taken into considerations.

6.2 *Application of the Automated Selective Acquisition System (ASAS) on the foot part*

Based on the reverse engineering technique in which three main steps are required: data acquisition, surface reconstruction, and surface fitting, the Automated Selective Acquisition System (ASAS) has been applied for quickly acquiring geometric shape of the entire part where data reduction process is not required. The obtained points can be used directly to create 3D virtual model. In data acquisition step, ASAS was asked for acquiring the geometric shapes of the stone foot (i.e., copied parts) contour by contour where data reduction process was not required to remove some noises and outliers after scanning process. The process of surface reconstruction was started to create polygon model (triangular facets) where some holes, gaps, or overlapped areas can be fixed by applying the applications available in Geomagic Studio application. Illustrated in Figure 13 are the activities required for ASAS on the stone foot.

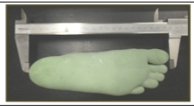
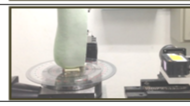
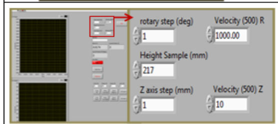
	**1st Step**: Height of foot sample is 217 mm.
	**2nd Step**: The foot sample is located on the rotary table in vertical direction
	**3rd Step**: Degree of rotary table: 1 Degree (360° / rev) Velocity of rotary table: 1000 pulses/rev Velocity of z-axis: 10 pulses/rev Height sample: 217 mm Layer thickness: 1 mm
	**4th Step**: The bottommost contour is firstly scanned.
	**5th Step**: Total number of scanned contours is 217 contours. The results present the organized points where data reduction process is not required.
	**6th Step**: Polygon phase is constructed directly from the scanned contours.
	**7th Step**: 3D virtual model is created and sent to fabricate prototype in RP process.
	**8th Step**: Physical prototype of the remote is generated by fused deposition modeling (FDM) technique.

Figure 13: The activities required for ASAS to generate 3D CAD model and physical part of the flat foot.

Both feet are copied and cast by Alginate casting process. For urgent case where immediate action is required, two fast-track activities are performed: quickly casting foot's cavity on only left or right foot, and scanning an obtained cast foot. Casting the right foot was used to demonstrate the overall concept of the proposed approach, after accomplishing the polygon phase of this right foot, the mirror application was performed to generate a left foot. Then, the cavities of the cast feet were created by applying the inverse

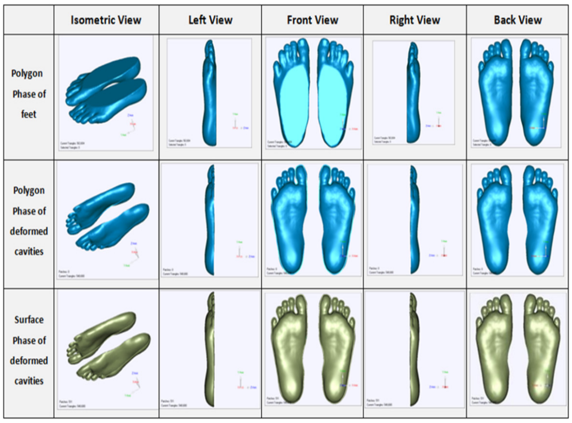


Figure 14: Generating the cavities of the feet in surface reconstruction and surface fitting.

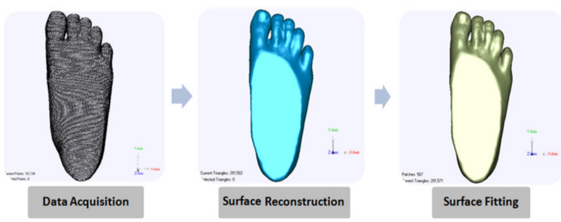


Figure 15: Three main steps of RE process.

function of surface fitting as shown in Figure 14. However, using this fast-track platform is sensitive to the huge difference between curvature surfaces of left and right foot. Mirroring process is not recommended to create the duplicate part.

6.3 *Rapid prototyping*

Rapid Prototyping technique (RP) is applied to create the prototype of the foot mould layer by layer from the obtained virtual model (in surface fitting process) (Figure 15). In general, RP process can be classified into 3 main types (according to material that is being used for creating layers): solid, powder, and liquid [26]. In this research, the prototypes of the feet and the mould cavities were fabricated by Fused Deposition Modeling (FDM) technique which is the solid-based RP process as shown in Figure 16(a) and 16(b). The fabricated prototypes present the clear geometric shapes of the feet and the mould cavities where the curvatures around the fingers and the heel can be well preserved.

(a)

(b)

Figure 16: The fabricated parts from FDM-RP process: (a) the feet, and (b) the prototype of the mould cavities.

7 Discussions and Conclusions

According to the concept of the proposed approach that describes about the integration between slush casting and reverse engineering process, a non-rigid part (i.e., body part) is formed to be a rigid one that is easily scanned geometric shape by acquisition device. Since the synthetic silicone rubber or resin material consists of toxic reagents, in order to apply slush casting process to make the mould of the body part, non-toxic materials such as alginate, and dental stone materials that provide stabilized hypoallergenic formula are selected to prevent any skin allergies.

The economical alginate-based impression material and dental stone has been applied in this research for quickly transforming a non-rigid part to be in a hard structure which is easily to be scanned by ASAS method. In order to maintain the surface quality and geometries of the copied part, the relevant parameters of alginate casting are taken into considerations. The overall processes of the proposed approach can be separated into three main phases: casting, RE, and fabricating prototype or generating (Figure 17).

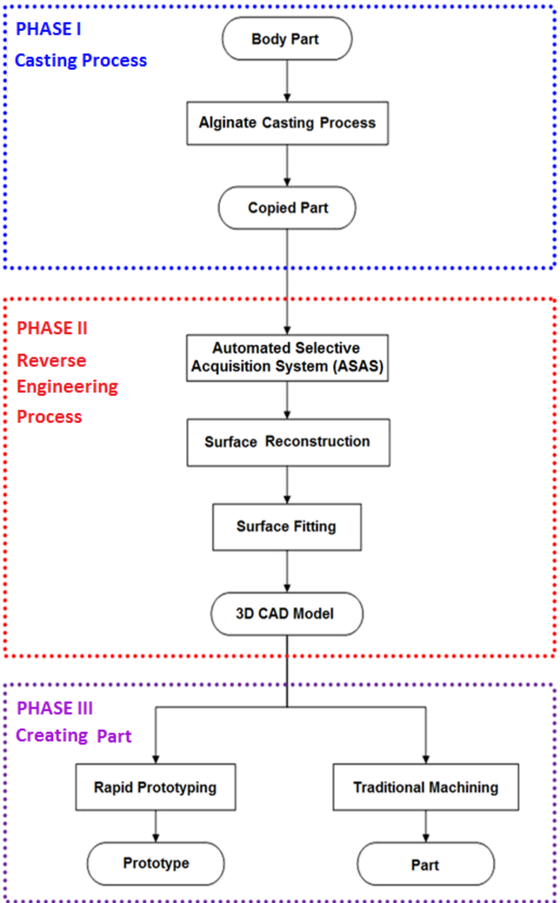


Figure 17: Overall process of the proposed approach.

In Phase I, the alginate casting process is applied to create the rigid form of the body part while maintaining the surface accuracy where shifting in references and model positions can be eliminated. The key component of this casting process is mould-making material which will be selected according to well-formed shape, and low cost consideration. In casting process for both feet, the proper ingredients of the materials are mixed: 1 lb (453 grams) of an Alginate powder per 950 ml of water. Then, the mixed material is poured on over the master parts for forming the mould cavities. For the entire process ranging from mixing the Alginate power with water until forming feet cavities, time spent was around 3 minutes.

Once the mould material is cured and the parts are removed, as the results; the cavities of the feet can maintain the feature details of the master parts. Dental stone material used for casting the copied parts is poured into the mould cavity slowly. After 2 minutes, dental stone material is perfectly cured in which the copied parts are generated and removed out from the mould.

In Phase II of the project, after slush casting process, the copied part is used as an existing model for scanning geometric shape in reverse engineering process where ASAS technique is applied. Using this technique can eliminate some errors which are related to the movement of the soft-part while scanning surface data with 3D laser scanner (handheld type). After obtaining the contour points, times used for surface reconstruction and surface fitting can be reduced. The obtained virtual model can be used as the input for generating the prototype in rapid prototyping process or creating the product by manufacturing process as shown in Phase III.

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