DESIGN OF 3D PRINTED LOW COST MULTI AXIS PROSTHETIC FOOT

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ABSTRACT

The low cost of manufacturing prosthetics is achieved by using 3D printing technology. In the 3D printing technology there are many methods of manufacturing but I have used fused deposition modeling. In this materials used are polylactic acid, thermoplastic polyurethane and aluminum for manufacturing the prosthetic foot. Polylactic acid and thermoplastic polyurethane materials do not required any preheating of the bed in manufacturing. As the cost of the prosthetic foot are higher and we want to reduce its cost and make available in the market as many people are not able to have an prosthetic foot due to its high cost. It may help common people to afford this foot and obtain nearly to the gait cycle standards. In this paper we will be knowing how to reduce the cost of the multi axis prosthetic foot without any compromise with gait cycle.

Key words: 3D printing, multi axis foot, prosthetic foot, poly lactic acid, fused deposition modeling, Thermoplastic polyurethane.

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1. INTRODUCTION

Prosthetics is a branch of medical sciences which deals with the replacement of damaged organs which lost due to trauma, congenital conditions, etc. In addition to the modern science and art of prosthetics and medicine, particular peoples with limb loss or lived without a limb or used primitive limb substitutes to perform everyday tasks. An example for such device is the peg leg prosthesis and probably one of the oldest. While the poor used simple wooden crutches, peg legs, and solid ankle cushioned heel foot, but other who are rich are using multi-axis foot, dynamic response foot and micro processing foot, which are very costly. Although the early prostheses improved in appearance, but restoring lost function has remained a challenge. In the last 100 years the most notable medical and technological advances has been occurred in prosthetic restoration and rehabilitation. The advances in prosthetics that are commonly available to individuals today are helpful to the veterans of war, particularly world war II, and

the individuals born with birth defects resulting from thalidomide. Titanium, carbon fiber, plastics laminates, and silicones has replaced to wood, leather, and metals which are the art of carving a socket and marking prostheses. Computer-aided design and computer-aided manufacturing made more efficient in fitting and fabrication [1].

There are different foot available in the market such as solid ankle cushioned heel(SACH), single axis, multi axis, dynamic response and microprocessor foot. The cost of prosthetic foot are ranging from INR6000-1,50,000. The foot which is available at INR6000 is solid ankle cushioned heel. It just act as a solid foot with no other motion. When we are going for higher range of cost it provide nearly the feeling of our original foot.

In additive manufacturing, 3D printing is a method used for making a three dimensional products using the design package models. The first 3D printed solid object was done by Hideo Kodama of Nayoga municipal industrial research institute from a digital design. But first 3D printer was invented in 1984 by Charles Hull. Stereolithography was the process used and the file format is STL(stereolithographic). It is most widely used 3D printing format across the world. In this we design initially an 3D object to be printed in computer aided design packages. Then it was been uploaded and converted to STL format using computer aided manufacturing packages. In the we can customize the aspects like layer thickness, temperature, outer finish, etc, and saved in format of STL file [2].

2. DESIGN ASPECTS

For the physical therapists and doctors gait analysis and research has provided kinetic and kinematic data which is required to treat the patients. The study of gait analysis has more famous since the 1960s, in clinics than in research labs. For patients with walking disorders gait measurements were found useful. Walking is like a general activity of humans. Locomotion of the human has been conducting for many decades which describe the relation between the motion and the muscle. The study of foot motion has been improved and complemented by a continuous research of technological advances over few decades. To understand a normal gait involves study of muscle activities at different stages of the gait cycle. During the 1940s and the 1950s advances in the study of muscle movement were made available. In the 1950s effects on hip, knee, and ankle joints were been calculated and free body diagram were been developed with respect to the ground reaction forces using the study of mechanical analysis of gait cycle were available as show in the Figure 1. This also indicates the motion of foot and the phases of motion. Mainly research studies have focused on the mathematical analysis to demonstrate the motion of the body parts and actions of different muscles has been done since 1960. Tremendous improvements has been take place from the 1970s and the 1980s in gait analysis methods. This has made to achieve accurate kinematic study with the help of electronics rather than images that took a long time to acquire information. To get reliable results in minutes we use force platforms and electromyography systems and obtain graphs as shown in the Figure 2. In this we can know the pressure acting on the foot in planter action. The colour code from blue to red indicates the pressure acting on the foot. Red colour indicates the maximum pressure and blue indicates low pressure [2].

Figure 1 Gait cycle of human

Figure 2 2D plot of planter pressure distribution.

Locomotion and kinematics of the human foot is known by the study of common practice, investigating of rehabilitation and research. For better understanding in locomotion of the foot, various methods are been used such as a simplified representation. Mostly dynamic representations of the foot have been restricted to two-dimensional models. The recent models have been created in such a way that it can try to accurately represent the foot by dividing the foot into a three-dimensional segmented model. By this approach the segments are more accurately depict the motions of their counterpart [3].

The force from data of tests while walking was averaged between the three tests taken for both the left and right foot. In these tests time was not averaged between the three results while graphing because this would cause either the deletion or addition of forces at bounded times. Although the time was not averaged, the averaging for the three walking and jogging tests was indicative of an average walking and jogging test as shown in Figure 3. In this y-axis indicates force acting and x-axis indicates momentum of foot. In case of figure 3A it shows the graph of human while walking and figure 3B shows jogging. The peak forces were slightly shifted to the more average time while remaining very close to the peak forces measured. This includes the heel strike portion at the beginning of the test.

Figure 3 The forces acting on the foot while walking(A) and running(B)

In the design of this foot Dr. Sunder Babu a prosthetic doctor has given a valuable suggestions. Design consideration of foot taken such that it suites for a human weight maximum 70kgs as shown in the Figure 4. It is take in such a manner that the average human weight is ranging between 60-70kgs. The other consideration taken is the thickness of foot is about 10mm to ensure that PLA material can bear weight of 70kg. it consists of a total of 9 springs in which one can bear a load of 721N at base and other eight can bear the load of 320N surrounding at 90 degrees each. By using surrounding springs it can hold the rod firmly. By this we can achieve the momentum required.

Figure 4: Basic design of the foot

3. MATERIAL SELECTION

Material selection plays a vital role in any manufacturing process. In 3D printing process we can use materials including thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), high-impact polystyrene (HIPS), thermoplastic polyurethane (TPU) and aliphatic polyamides (nylon).

Acrylonitrile butadiene styrene made with the composition of polymerizing styrene and acrylonitrile in the existence of polybutadiene. This mixer of the compounds may vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene to form the product. As the big chains of polybutadiene will be combined with the nitrile groups which are adjacent chains and being polar which tends to attract each other and bound the chains together which make ABS stronger than pure polystyrene. The shying property is due to existence of styrene and improve the surface finish. The polybutadiene which as a property of rubbery substance and even gives toughness at least temperatures. In the maximum applications, ABS can work between -20 and $80\text{ }^{\circ}\text{C}$ (-4 and $176\text{ }^{\circ}\text{F}$). Its mechanical properties will diverge with temperature change. The

properties are diverge with respect to rubber toughening, which are prime particles of elastomer distributed to entire firm matrix [5].

Polylactic acid is a biodegradable thermoplastic. It is evolved from renewable resources which is extracted from crops like corn, cassava roots, and sugarcane in the different extraction processes across the world. In 2010, it is the second highest used bioplastic in concerns of volume in the world. It polymer range lies between amorphous glassy polymer to semi-crystalline and also highly crystalline polymer. It has a glass transition temperature of 60 °C. The melting point will occur at temperature of 130-180 °C. Its tensile modulus 2.7–16GPa. PLA can withstand up to the temperature of 110 °C. PLA mechanical properties lies between those of polystyrene and PET [6].

Thermoplastic polyurethane (TPU) is made from of a class of polyurethane compounds which consists properties such as elasticity, transparency, and resistance to oil, grease and abrasion. TPU material is used in manufacturing parts such as automotive instrument panels, caster wheels, power tools, sporting goods, medical devices, drive belts, footwear, inflatable rafts, and a variety of extruded film, sheet and profile applications. TPU is widely used material for manufacturing outer cases of mobile phones and also used to produce keyboard protectors for laptops [7].

In these materials had chosen polylactic acid and thermoplastic polyurethane for manufacturing the multi-axis prosthetic foot. It is because polylactic acid is having a good strength to withstand the load and it also biodegradable so there will be no harm done to the environment if we want to dispose of the product. Thermoplastic polyurethane is used to build supports for the foot in place of springs. It is used because it used in make footwear and has high abrasion resistance and elasticity. This both can be 3D printed using fused deposition modeling.

4. DESIGN ANALYSIS

Analysis of design is done by applying the total force of 70kg on whole springs and on the foot in solid works software. The result states that the multi axis foot is achieving one degree of freedom. As we applied on each spring it shows little damage on the side springs as it can only bear a load of 33kg. But the whole weight of 70kgs will not be applied on the side springs as the force acting on foot so there is no much problem occurs to the springs and the material. We have tested on different materials and selected polylactic acid to be manufactured. Here acrylonitrile butadiene styrene and polylactic acid got same results. But we have selected polylactic acid because it is biodegradable and bioplastic. This product can bear the maximum weight of 70kgs. It had achieved factor of safety 1 as shown in the Figure 5. The springs are been loaded more to know the withstand ability of the foot. So the springs are turned into lite blue color.

Figure 5 Stress analysis of foot at 730N

5. MANUFACTURING PROCESS

3D printing is most emerging process in manufacturing field. It has different manufacturing process 1. Stereolithography 2. Selective laser sintering 3. Direct laser sintering 4. Fused deposition modeling(FDM).

Fused filament fabrication (FFF), also known term as fused deposition modelling (FDM). It is a 3D printing process which uses a continuous filament of a thermoplastic material to print products. Filament will be fed from a large coil through a moving, heated printer extruder head, and is deposited on the bed layer by layer. The print head is moved under computer control to define the printed object shape. Usually the head moves in two dimensions for deposition on horizontal plane, or layer, at a time and the print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head can also be controlled to stop and start deposition. It also can control form an interrupted plane without stringing or dribbling between sections.

The temperature is regulated by heat input from electrical coil heaters. The system continuously adjusts the power supplied to the coils according to the temperature difference between the desired value and the value detected by the thermocouple, forming a negative feedback loop. This is similar to heat flow rate in cylindrical pipe.

FDM technic is used to manufacture the foot. In this material is drawn by the feeder and heats it to melting point. After that first a platform is setup to print the product. This process is done by printing the material layer by layer. It form a raft to give support to the hanging parts.

In this process we initially have to upload the drawing into the software. Then it will give the estimated time of printing. After that it will demonstrate the printing format, if any flaws we have to rectify and redo the process until no flaws detected. After this it has to be transferred to memory card and has to be connected to the 3D printer input device. Then the printer start printing a raft to build the prototype as shown in the Figure 6. This is how the printer starts raft operation. After raft operation the component is printed on it. It also builds a supports to withstand and is removed after printing is completed. This product has two parts which took nearly 20hrs of printing time.

Figure 6. Printer performing raft operation

6. CONCLUSIONS

The traditional process of manufacturing prosthetic is costly and involve lot of time. But using 3D printing technology we can reduce manufacturing cost and time of production of a prosthetic foot. By this method we can reduce the cost of the multi-axis foot which is ranging from INR 25000-65000 to INR 7800. This is due to the lower manufacturing and material cost. In this process the time involved is less than a day. Further research can much more reduce the cost of the product.

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