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Additive Manufacturing Fixture Box for Bone Measurement

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Abstract

Bone is unsymmetrical, porous and complex structure as well. Therefore, it is very challenging to measure its dimensions by both contact and noncontact methods using Co-ordinate Measuring Machine (CMM). Especially, in recent years, bone measurement data is highly needed for various medical applications (anatomical study, fabrication of implant, surgery, etc.). Total Knee Replacement (TKR) is nowadays becoming popular in bringing back of injured person to normal life. TKR needs exact three-dimensional (3D) data for making functionally-satisfactory implant which in turn almost eradicating post-surgical management. In order to acquire 3D bone data it obviously needs an aiding device (precise holding and rotating device for bone measurement). In this, a site-specific rotating box with gears was indigenously designed, developed and manufactured using Poly Lactic Acid (PLA) as material through 3D printing. The additively-manufactured fixture box was used to hold and rotate (0.2^{o} resolution) the bone precisely to obtain the three dimensional data and further imported it to Computer Aided Design (CAD) system for generating 3D model of knee joint. For verification and validation purpose; measurement done by fixture box aided CMM was compared with results measured by Vernier calliper. It showed reasonably close in agreement which pave the way in furthering this research.

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Keywords: Bone; Knee joint; Co-ordinate Measuring Machine; 3D printing; Implant

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1. Introduction

Our day to day life is based on physical movements of the human body which can be done with the help of different types of joints made with bone. Bone is a light weight porous material having greater strength. It gives protection to delicate internal organs in the body. It is an active connective tissue made up of minerals and collagen (a protein) and supplied with blood. It acts as a reservoir for calcium and phosphorous minerals. Long bones like femur and tibia have greater length than width. Hollow space inside the bone is called bone marrow cavity. Yellow marrow stores fat and red marrow produces blood cells. If any damage occurs, it can repair itself.

Nowadays, bone measurement data is needed for various applications like anatomical study of various intricate features in complex shaped bones, patient specific implant modeling and bone repair surgeries like Total Knee Replacement (TKR) and Total Hip Replacement (THR) etc. There are three types of arthritis: osteoarthritis, rheumatoid arthritis, and post-traumatic arthritis. The osteoarthritis will affect hip and knee joint severely. TKR and THR surgeries are increasing in number nowadays. Revision surgeries after primary surgeries are increasing currently because of the unsuitable implants erection and wrong-site surgeries. These problems are happening due to improper preplanning. Recent statistics of revision surgeries in the USA show that the primary and revision of TKR have increased drastically in a decade [1]. Therefore, an error -free system is necessary for orthopaedic surgical applications.

Bone measurement data is used to identify geometric variations of bone with respect to different regions around the world to model patient-specific implants with better accuracy. Several femoral parameters like femoral head offset, femoral head center, femoral head diameter, femoral neck length are identified from bone measurement data for effective design of implants [2]. Bone repair surgeries like TKR and THR need bone reference data of a patient for preplanning and execution. Different types of scans like X-ray, Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) are done before the bone surgery.

TKR needs perfect 3D data of a bone for modeling the implants. For modeling entire knee joint, dimensions of femur, tibia and patella have to be known. But, femur and tibia are the long bones in the human body and having complex structure. It is very difficult to measure the femur and tibia using Co-ordinate Measuring Machine (CMM). Therefore, an aiding device is needed to measure the bone using CMM. Hence, a rotating fixture box could be used to hold bone. The Additive Manufacturing (AM) technique is believed to be the most appropriate one for fabricating the rotating fixture.

American Standard for Testing Materials (ASTM) defines the additive manufacturing as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.” Various synonyms of AM are: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication. AM machine can be divided into three broad areas: solid-based, liquid based and powder bed systems [3]. AM technique can be used to convert digital 3D model into a final product.

Major AM processes include Fused Deposition Modeling (FDM), Ink Jet Printing (IJP), Laminated Object Manufacturing (LOM), Laser Engineered Net Shaping (LENS), Stereo lithography (SLA), Selective Laser Sintering (SLS), Three-Dimensional Printing (3DP). Three steps in AM process are the conversion of digital 3D model into a standard AM file format, transfer of file from computer system to AM machine where the part model can varied to suit the printing process, building of part as layer by layer [4].

3D printing is a process of rapid prototyping of a 3D CAD models created by CAD software. 3D printing is a technique that will print the molten material as layer by layer to form the entire 3D structure of a physical part. The CAD program created by CAD software will be converted into .STL format. The .STL format was developed by Hull at 3D systems and it is being used as standard across globally for the data transfer between CAD software and the 3D printer [5].

Medical applications of 3D printing includes printing of customized implants and prosthesis like titanium mandibular prosthesis, PolyEtherKetoneKetone (PEKK) skull implant, orthopedic implants, maxillofacial, spinal, hearing aids, invisalign braces, neuroanatomical models and dental implants. 3D bio-printing is a current trending research in medical field. Many researchers have tried to print knee meniscus, heart valve, spinal disk, cartilage tissues, bone, artificial ear and liver and bio-resorbable tracheal splint [6].

The main usage of CMM is to obtain 3D data for constructing a parametric model of the object and for inspecting the surface profiles of machined materials for error analysis. While retrieving the dimensions of the sample for 3D