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REVERSE ENGINEERING AND CAD INSPECTION OF KNEE IMPLANT USING THE NOOMEO OPTINUM 3D SCANNER

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Abstract: The paper presents an application of the Reverse Engineering (RE) technology using a 3D Scanner to read the shape of the knee implant manufactured via Rapid Prototyping (RP)technology and generate the geometry in a computer file that can be analysed by Computer Aided Inspection (CAI)software - GOM Inspect V8. Orthopaedic implants have always maintained close relationships with engineering disciplines, mostly relying on production engineering. Computer-aided technologies are being increasingly used for the solution of many problems associated with biomedical engineering. A significant number of these have proven to be especially useful in orthopedics. During the last decade, efforts have been concentrated towards advancement in modelling and manufacture of orthopaedicreplacements by introducing modern computer equipment and state-of-the-art materials and machining technologies.
Keywords: Reverse Engineering, 3D Scanner, knee implant, Rapid Prototyping, CAD Inspection

1. INTRODUCTION

Orthopaedic implants have always maintained close relationships with engineering disciplines, mostly relying on production engineering. Computer-aided technologies are being increasingly used for the solution of many problems associated with biomedical engineering. A significant number of these have proven to be especially useful in orthopedics. During the last decade, efforts have been concentrated towards advancement in modelling and manufacture of orthopaedicreplacements by introducing modern computer equipment and state-of-the-art materials and machining technologies. Amongst the modern engineering technologies which have found broad application in this area, the most widely used are 3-Dimensional (3D) digitization, Computer Aided Design (CAD), Reverse Engineering (RE), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM), Rapid Prototyping (RP), Computer Aided Inspection (CAI), etc. The development and implementation of such technologies and systems have paved the way towards significant advancement of conventional modelling, manufacture and inspection of orthopedic replacements,[1,2].

Non-contact optical three-dimensional measuring, scanning and digitising are increasingly present in quality assurance systems. Simple scanning procedures, high density of data acquired in a single scan, and the possibility of integrated Reverse Engineering and inspection, are all advantages of optical scanning compared to conventional measuring methods. Due to the three-dimensional acquisition of measuring data, an optical scanner is often considered to be an alternative possibility for coordinate measuring machines. However, the accuracy of the measured data acquired by optical scanning is still far below the level achieved by high-level coordinate measuring machines, [3, and 4]. This paper examines the possibilities of using a non-contact 3D scanner Noomeo Optinum for inspection of knee implant model manufactured by Rapid Prototyping technology.

Figure 1. The Noomeo Optinum 3D Scanner

2. THE DESCRIPTION OF THE 3D SCANNER

The Noomeo Optinum 3D Scanner, Figure 1, is a portable scanner that connects to the acquisition system via USB 2.0 with autonomy offered by the battery included in the configuration. This non-contact scanner was acquired by "EftimieMurgu" University of Resita, and itis intended to be used for 3D digitization purposein Centre for Numerical Simulation and Digital/Rapid Prototyping (http://www.csnp.roedu.ro/index_eng.htm). The scanner uses technology "Vision based self positioning", the point cloud acquisition is performed by successive multiple photographic images, through a CCD sensor with resolution 1024x768 pixels, which can take up to 500000 points/image. The scanner dimensions are 230 mm x 230 mm x 80 mm and the weight is less than 2 kg. The volume of the scanned objects fall in 10 $cm^3 \div 1m^3$, the minimum purchase size is 1 cm. Noomeo Optinum scanner technology combines structured light, which allows instant capture of the geometry through the deformation analysis of repetitive light projected onto the object, with 2D image processing, leading to the scanner position to the object concerned and capture its texture. Thus, by 2D image processing, the auto position is calculated, which eliminates the need for markers and the light flow provides additional information for taking geometry as a cloud of points.

Technical characteristics of the scanner are: accuracy ± 100 mm, spatial resolution 300 mm, the acquisition distance 400 mm, A4 FOV (field of view), 150 mm DOF (depth of field). The scanner system does not require preparation of items scanned, their installation in a reference system or reference markers, [5].The scanner comes with dedicated NumiSoft software, which conducts the whole process of acquisition and 3D model reconstruction of the cloud of points.

3. THE REVERSE ENGINEERING OF THE KNEE IMPLANT SLS MODEL

According with [6]:"Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. The process of duplicating an existing part, subassembly or product, without drawings, documentation, or a computer model is known as Reverse Engineering. Reverse Engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/digitizing existing parts/products."

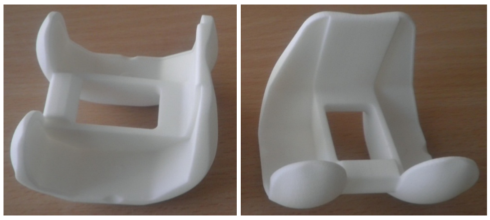

Figure 2. The SLS knee implant geometry

The knee implant model (Figure 2), were manufactured on the Formiga P100 machine in the laboratory "3D Impuls" at the Faculty of Mechanical Engineering and Construction in Kraljevo, Serbia (http://www.3dimpuls.com/en). The development of the model on this machine was based on the technology of Selective Laser Sintering (SLS). The material used in the job was Fine Polyamidepowder PA 2200 provided by the machine vendor. From a 3D scanning point of view, the difficulty of this part is given by its thin thickness and the complex surfaces.

This investigation presents analysis of the application of 3D digitization system of more general purposes in the field of orthopaedic prosthetics. The basis of this experiment is a method of CAD inspection that includes checking up geometric and dimensional deviations on the bases of CAD and 3D digitization model. Namely, a digitized representation of a physical model is checked for deviations against the nominal geometry defined by the CAD reference model. The investigation methodology is presented in Figure 3. The Reverse Engineering process consists of:

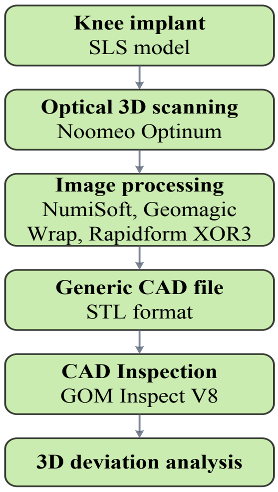

Figure 3. Investigation methodology workflow

- » **Scanning phase:** Generating the point cloud of the knee implant by non-contact 3D Scanner Noomeo Optinum and Numisoft software.
- » **Point processing phase**: this phase involves importing the point cloud data Geomagic Wrap software, reducing the noise in the data collected and reducing the number of points; the output of the point processing phase is a clean, merged, point cloud data set in the most convenient representation;
- » **Generate geometric model:** the goal of this phase is to generate CAD model from previous representation; mesh model processing and transfer into neutral CAD format in Rapidform XOR3 software, the generation of CAD models from point data is probably the most complex activity within Reverse Engineering because complex surface fitting algorithms are required to generate surfaces that accurately represent the three-dimensional information described within the point cloud data sets;

Scanning phase

In the first phase of the research the selected sample of the knee implant was scanned by the optical 3D scanner OptiNum and saved in ASCII format using NumiSoft software. NumiSoft software include the driver communicating with the hardware and algorithms for point cloud processing: alignment of 3D cloud of points, automatic 3D model reconstruction, cleaning capabilities of the points, sharp edges refining, optimization point, export cloud points and XYZ ASCII format, compared with STL-CAD geometry at points level, strategy alignment type for the geometry and/or texture, [5]. Figure 4 shows the Point Clouds scanned with Optinum scanner and edited in NumiSoft software.

Point processing phase

Geomagic Wrap software is a software tool for the cloud point transforming of the scan result into a 3D polygonal network (mesh), which can be used in the design, analysis and manufacturing. Geomagic Wrap can process large data sets, collected from different types of scanners, provides opportunities to optimize the scanned data (using remove outliers, reduce noise and other available tools), align and merge multiple scan data sets, create polygon mesh from point cloud data, automatically detect and correct errors in the polygon mesh, detect and create features in the model, repair and sharpen boundary edges, 3D model export in different formats: STL, OBJ, VRML1/2, DXF, PLY and 3DS, [7]. Figure 5 shows the implant mesh model created in Geomagic Wrap software.

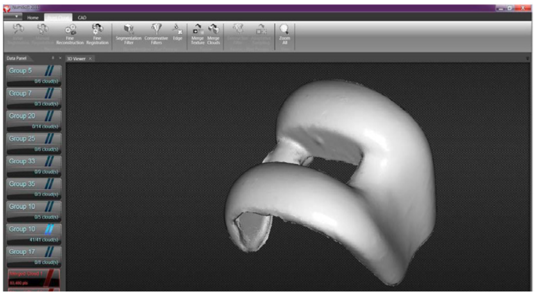

Figure 4. Point Clouds scanned with Noomeo Optinum scanner

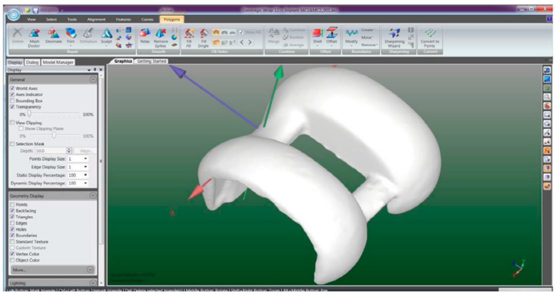

Figure 5. Knee implant mesh model created in Geomagic Wrap software

Generate geometric model

Rapidform XOR3 software (nowadays Geomagic Design X) is a "Reverse Engineering" application that combines CAD with 3D scan data processing, to create parametric, editable solid models of virtually anything scan data sets. Because Rapidform XOR3 is based on Parasolid kernel, it can generate history-based CAD models with feature trees and export the geometry into the SolidWorks, Pro/E, AutoCAD, CATIA and others native format, [8]. The steps to generate geometric model in Rapidform XOR3 software are [5], Figure 6:

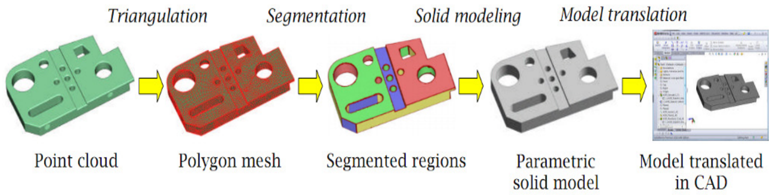

Figure 6. The steps to generate geometric model in Rapidform XOR3 software

The Rapidform XOR3 software can operate in the followings workflows [9]:

- **Scan-to-Mesh**- for archiving, animation, measurement, 3D printing and other polygon-based applications, Rapidform XOR3 includes a full suite of mesh processing tools. With the Mesh Build-up Wizard™, it is possible to go through the entire scan alignment merging and mesh optimization processes. Steps: Mesh Optimization, Mesh Modelling, Export.
- **Scan-to-Surfaces** - Rapidform XOR3 also supports NURBS surface fitting, which is useful for creating an identical copy of scan data that does not need editing. Steps: Mesh Optimization, NURBS Surfacing, Export.
- **Scan-to-CAD** - to make a CAD model suitable for manufacturing, Rapidform XOR3 employs a straightforward workflow that parallels today's well-known solid modelling processes. Instead of modelling from scratch, Rapidform XOR's feature wizards and other automated tools help to build the features directly from 3D scan data. Steps: Mesh Optimization, Solid Modelling, Export.

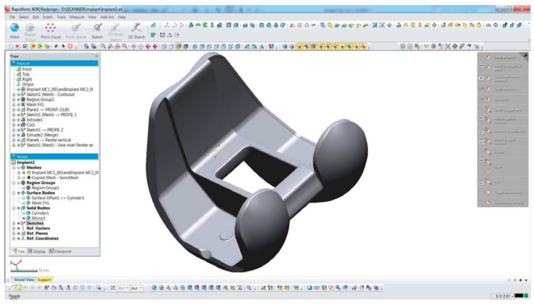

Figure 7. Knee implant geometry recreated in Rapidform XOR3 software

Figure 7 shows the knee implant geometry recreated in RapidForm XOR3 software.

4. CAD INSPECTION OF KNEE IMPLANTDIGITIZED GEOMETRY

3D digitization represents a measurement method which can utilize various working principles. Basic indicators of quality of 3D digitization are accuracy and precision. Accuracy represents the degree of closeness of measurements of a quantity to that quantity's true value, while the precision (also known as reproducibility or repeatability) is the degree to which repeated measurements under unchanged conditions show the same results, [2].

Measurements and analyses of deviations were performed using GOM Inspect V8 software.

GOMInspect software is a "free" application for inspection and processing of the 3D polygonal mesh, analysis of dimensional data sets of cloud-point type. Capabilities of the application: import of CAD models (IGES, STEP, etc.) and points cloud scanned data (STL, ASCII), alignment (automatic, 3-2-1, best-fit), mesh processing (mesh generation, filling holes, mesh refinement, extraction curve, export STL, ASCII), CAD comparisons (surfaces, section, points), CAD primitives generation (lines, planes, circles, cylinders, cones, etc.), 3D and 2D analysis inspection tools (dimensions, angles, diameters), report (tables, images, PDF) and export data, [10].

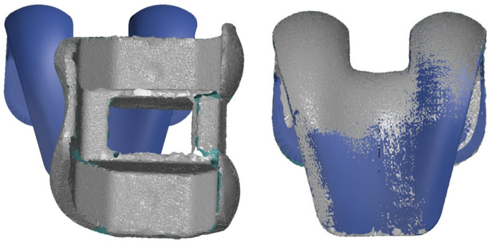

Figure 8. Combining nominal model of the 3DCAD with measure knee implant

Application program GOM Inspection V8 allows the subsequent analysis of the accuracy of the measured performance of the element with respect to the nominal model. The possibility of analyzing the whole item - described thousands or even millions of

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points - it gives a complete picture of the accuracy of its execution. In addition, optical measurement coordinate system gives the possibility to use different systems of measurement to match the CAD model: the geometric elements, best-fit or RPS (Reference Point System). Figure 8 shows phases of combining nominal model of the 3DCAD with measure knee implant.

Performed investigation procedure, as already shown in Figure 3, involved 3D deviation analysis which included two different kinds of results. Figure 9 presents the result in a form of map of regions, where the different colours indicate respective deviations. From the histogram in Figure 9, it is clear that the majority of deviations are in positive direction, ranging from –0.5 to 1mm, and with the most concentrated deviations around 0.25 mm.

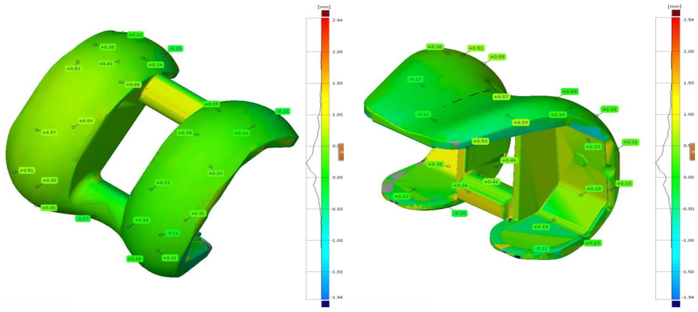

Figure 9. Resulting deviations in a map of regions form

Another type of 3D results is presented in Figure 10, where the coloured regions present deviation areas within 0÷75 %, 75÷100 % and over 100 % of defined tolerance, in both directions – positive and negative. The mentioned regions are represented on the accompanying scale by the terms Pass, Warn and Fall, respectively. This type of result includes numerical values of areas in mm^{2}from the analysed CAD model. Figure 10 shows results obtained for four different tolerance levels: 0.25 mm, 0.5 mm, 0.75 mm, 0.9 mm.

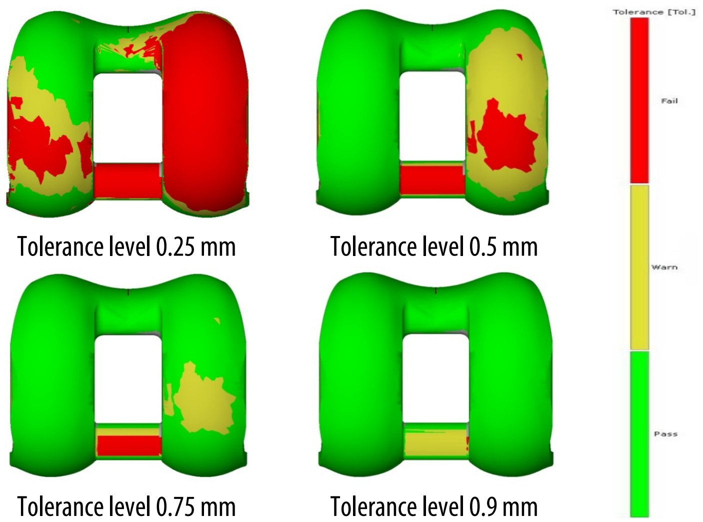

Figure 10. Resulting deviations in a form of areas classified according to level of tolerance

5. CONCLUSION

The Reverse Engineering technology was used to recreate the knee implant SLS model geometry using the NoomeoOptinum 3D Scanner and RE software's: NumiSoft, Geomagic Wrap and Rapidform XOR3. Some general considerations about the RE process and commercial software that is able to generate geometric models from scan data are presented, with an accent on the Rapidform XOR3 software.

Obtained results of an accuracy analysis of high-end 3D digitization system of more general purposes (NoomeoOptinum) confirm previous findings and indicate the effective application of this system in the field of orthopaedicprosthetics. The accuracy of obtained measurement results via GOM Inspect V8 software confirms that theapplication of this system contributes to the quality of orthopaedic implants in terms of geometry. In the result's analysis some obvious limitations should be considered. Theseprimarily include difficulties in models' orientation and fitting as well as the problem of differences in algorithms of STL file format generation. Future research will be aimed at overcoming identified obstacles and problems as well as at the confirmation of assumptions related to dependency of the analysed systemaccuracy of the model's geometry and position.

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