



*Review Article*

# ANALYSIS OF INTEGRATION OF REVERSE ENGINEERING AND GENERATIVE MANUFACTURING PROCESSES FOR MEDICAL SCIENCE – A REVIEW

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Bio-medical engineering is the emerging field; where lot of research is going on to combine engineering for medical problem solving. Bio-medical engineering has variety of applications. The different knowledge related to medical information, the various medical images and different materials used in medical science are very easy to achieve with the help of biomedical engineering. Reverse Engineering has been successfully used in engineering applications to recover drawings and details from existing components, for which knowledge base is not in existence. Recent developments in generative manufacturing processes have made it easy to create prototypes of complex objects with ease. The paper presents exclusive review of integration of these two techniques for the application of medical science.

Keywords: Reverse engineering, Rapid prototyping, Medical applications, Point data

## INTRODUCTION

Bio-medical engineering is a technological field with great potential for future advances. This field encompasses medical treatment engineering, tissue engineering, genetic technology, and medicine engineering. Building sets of medical information, medical images, and bio-medical materials and applying these sets of medical data assists in

the development of all aspects of biomedical engineering. In recent years, CAD has been increasingly applied in bio-medical design. The integration of CAD and medical technology is referred to as bio-CAD. Bio-CAD includes regenerative medicine engineering, computer-aided surgery, structural modeling of tissue and tissue informatics, design of orthopedic devices and

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implants, design of tissue scaffolds, Reverse Engineering (RE) and 3D reconstruction, heterogeneous tissue modeling, and solid freeform fabrication or bio-manufacturing. CT medical imaging is the key tool for viewing the internal structure of the human body, but is limited by its 2D image presentation, in that it does not allow doctors to quickly diagnose illnesses and explain symptoms and treatments to patients. Medical images in 3D solid models are therefore very important in the diagnosis and treatment process. All reconstructed 3D solid models can be converted to RP physical models and Virtual Reality Modeling Language (VRML) format for visualization. A number of open sources and commercial products for 3D biomechanical construction are available.

There is need for emergence of integration between RE and Generative Manufacturing processes to be applied for solving various medical cases. This will be easy for diagnosis and treatment.

## REVERSE ENGINEERING

Reverse Engineering (RE) techniques encompasses many engineering approaches in which an existing product is investigated either prior to or during the reconstruction process. The existence of geometric models provides enormous profits in improving the quality and efficiency of design, manufacture and analysis. In Reverse Engineering (RE), the shape of a three-dimensional (3D) physical object is scanned using 3D position scanners such as Coordinate Measuring Machines (CMMs), laser-based range finders, optic-based scanners, and so forth. Then the scanned data are turned into a description for

Computer-Aided Design (CAD) or transferred into computer-aided manufacturing (CAM) like Rapid Prototyping (RP) or NC milling to make the 3D replicas of the scanned objects. A number of RE applications have been widely investigated. In addition, it can also be applied into some recent emerging applications such as custom-made manufacture, design simulation, medical application, animation, sculpture, etc. RE procedure generally consists of three fundamental steps: data capture, data process, and model manufacture. Firstly, the data capture is to scan the surfaces of a target physical part in order to take a point cloud by appropriate 3D scanners. Secondly, the scanned point cloud must then be refined and edited with the point- or polygon-based technologies in the data processing step, such as sampling, triangulating, aligning merging, hole filling, smoothing, etc. Finally, the model manufacture is the process of creating CAD models or physical replicas from the refined polygonal data.

Xu *et al.*, presents color 3D reverse engineering. Their work presents a method of color 3D laser scanning measurement, based on the fundamental of monochrome 3D measurement study. A new color 3D measurement model was derived, and a rapid calibrating method to measure the system parameters was proposed titled the optical plane equation calibrating method. A calibrating drone was made. The work by authors also highlights advances an auto-merging method for multi-frame, i.e., several frames of measured color 3D digital images are merged quickly according to their curvature characteristics and RGB information, in order to accomplish the complete color 3D digital

model of the object. The system can be broadly used in the fields of product design, mold manufacture, multi-media, game development, animation, medical engineering, antique digitization, etc.

Vidosav Majstorovic *et al.*, presents Reverse Engineering of human bones by using method of analytical features. The research presents a new Method of Anatomical Features (MAF) for the creation of 3D geometrical models of human bones (polygonal, surface and solid) and parametric point models (predictive bone models) is presented. The main benefit of the MAF application comes from its capability to create a complete geometrical model even if a part of bone is missing or only a single X-ray image is available. The testing of MAF for twenty femur samples and ten tibia samples have shown that the created bone and bone region models are characterized by a good level of anatomical and morphometric accuracy, that is, they are within the required limits defined by orthopedic surgeons.

Gokhan Altintas presents effect of micro-CT slice intensity on natural vibration behavior of cancellous bone models based on Reverse Engineering techniques. It presents an idea about identification of natural vibration properties of bone structure in macro and micro levels is important because of increasingly vibration inclusion of current methods in recognition and treatment of bone diseases. In this scope, results which are obtained from non-destructive reverse engineering approaches are crucial especially in living tissue studies. The results may differ from each other because of the multi-staged methods and differences in

constituted models due to the redundancy of options. Effect of differences due to the slice intensity on natural vibration analysis results by using constant resolution Micro-Computational tomography (Micro-CT) data of L3 vertebrae in voxel based finite element models are investigated. In addition to this investigation, another approach which is different from classic approach where non-cubic voxel based finite elements can be generated and only about the effect of slice thickness and cubic voxels is improved. The results obtained from the study show that solutions of proposed model are more conservative than the results of voxel based finite element (V-FEM) and these results are purified from the effects of element aspect ratio.

## RAPID PROTOTYPING

Prototyping or model making is one of the important steps to finalize the product design. It helps in conceptualization of a design. Before the start of full production a prototype is usually fabricated and tested. Manual prototyping by a skilled craftsman has been an age old practice for many centuries. Second phase of prototyping started around mid-1970s, when a soft prototype modelled by 3D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties. Third and the latest trend of prototyping, i.e., Rapid Prototyping (RP) by layer-by-layer material deposition, started during early 1980s with the enormous growth in Computer Aided Design and Manufacturing (CAD/CAM) technologies when almost unambiguous solid models with knitted information of edges and surfaces could define a product and also manufacture it by CNC machining.

RP process belong to the generative (or additive) production processes unlike subtractive or forming processes such as lathing, milling, grinding or coining etc. in which form is shaped by material removal or plastic deformation. In all commercial RP processes, the part is fabricated by deposition of layers contoured in a (x-y) plane two dimensionally. The third dimension (z) results from single layers being stacked up on top of each other, but not as a continuous z-coordinate. Therefore, the prototypes are very exact on the x-y plane but have stair-stepping effect in z-direction. If model is deposited with very fine layers, i.e., smaller z-stepping, model looks like original. RP can be classified into two fundamental process steps namely generation of mathematical layer information and generation of physical layer model. Process starts with 3D modelling of the product and then STL file is exported by tessellating the geometric 3D model. In tessellation various surfaces of a CAD model are piecewise approximated by a series of triangles and coordinate of vertices of triangles and their surface normal's are listed. The number and size of triangles are decided by facet deviation or choral error. These STL files are checked for defects like flip triangles, missing facets, overlapping facets, dangling edges or faces etc. and are repaired if found faulty. Defect free STL files are used as an input to various slicing software's. At this stage choice of part deposition orientation is the most important factor as part building time, surface quality, amount of support structures, cost etc. are influenced. Once part deposition orientation is decided and slice thickness is selected, tessellated model is sliced and the generated data in standard data formats like SLC (stereo

lithography contour) or CLI (common layer interface) is stored. This information is used to move to second step, i.e., generation of physical model. The software that operates RP systems generates laser-scanning paths (in processes like Stereo lithography, Selective Laser Sintering, etc.), or material deposition paths (in processes like Fused Deposition Modelling). This step is different for different processes and depends on the basic deposition principle used in RP machine. Information computed here is used to deposit the part layer-by-layer on RP system platform. The final step in the process chain is the post-processing task. At this stage, generally some manual operations are necessary therefore skilled operator is required. In cleaning, excess elements adhered with the part or support structures are removed. Sometimes the surface of the model is finished by sanding, polishing or painting for better surface finish or aesthetic appearance. Prototype is then tested or verified and suggested engineering changes are once again incorporated during the solid modelling stage. There are various generative manufacturing processes available working on different principles as listed below.

- Selective Laser Sintering
- Stereo lithography
- Fused Deposition Modelling
- Laminated Object Manufacturing

Chung-Shing Wang presents STL rapid prototyping bio-CAD model for CT medical image segmentation. He presents a simple process to construct 3D rapid prototyping physical models CT medical images segmentation. The use of stereo lithography (STL) triangular meshes as a basis for RP

construction facilitates the simplification of the process of converting CT images to an RP model. This is achieved by constructing the STL triangular meshes directly from data points without having to draw the curve model first. The grey prediction algorithm is used to sort contour point data in each layer of the medical image. The contour difference detection operation is used to sequence the points for each layer. The 3D STL meshes are then constructed by this proposed layer by layer sequence meshes algorithm to build the STL file. Once this STL file is saved, a 3D physical model of the medical image can be fabricated by RP manufacturing, and its virtual reality model can also be presented for visualisation. CT images of human skull and femur bone were used as the case studies for the construction of the 3D solid model with medical images. The STL models generated using these new methodologies were compared to commercial CAD models. The results of this comparative analysis show that this new methodology is statistically comparable to that of the CAD software. The results of this research are therefore clinically reliable in reconstructing 3D bio-CAD models for CT medical images.

Bahattin Koc and Yuan-Shin Lee presents research on Adaptive Ruled Layers Approximation of STL models and Multi axis Machining Applications for Rapid Prototyping. It is new method of generating adaptive ruled layers for rapid prototyping processing of complex parts. To increase the accuracy and reduce the build time, an adaptive ruled layers approximation of STL models and multi axis machining applications for rapid prototyping are proposed. New method proposed is of

constructing ruled layers from slicing STL points to approximate the STL models with better surface accuracy. A technique of surface error analysis is presented to find the maximum errors at different layers of RP parts. By finding the RP surface errors, adaptive ruled layers are generated for the RP process of the STL CAD models. Using the constructed ruled layers of the STL models, the multi axis material removal process is integrated with traditional RP processes to achieve better surface accuracy and to reduce the total RP build time.

Van Der Smissen *et al.*, presents the work on modelling the left ventricle using rapid prototyping techniques. Biomechanical research of left ventricular function involves the assessment and understanding of ventricular wall mechanisms, deformation and intra ventricular flow patterns, as well as how they interact. Experimental research using hydraulic bench models should therefore aim for an as realistic as possible simulation of both. In previous experimental investigations, wall deformation was studied by means of thin walled passive experimental models, consisting of a silicone membrane in a closed box, which is squeezed passively by an externally connected piston pump. Although the pump function of these models has already been well established, the membrane deformation remains unpredictable and the effect of muscle contraction and hence natural wall deformation cannot be simulated. Authors build this model by combination of rapid prototyping techniques and tested it to demonstrate its wall deformation and pump function. Their experiments show that circumferential and longitudinal contraction

can be attained and that this model can generate fairly normal values of pressure and flow.

## INTEGRATION OF REVERSE ENGINEERING AND RAPID PROTOTYPING

Reverse engineering refers to the process of creating engineering design data from existing parts. It recreates or clones an existing part by acquiring the surface data of an existing part using a scanning or measurement device. It is useful in recreating the CAD model of an existing part when the engineering design is lost or when the model has gone through many design changes. It enables us to capture the surfaces of design models that are otherwise impossible to determine. It also saves us from performing tedious manual dimensioning and tracing work. When a designer creates a new design using a mock-up, it is necessary to construct the CAD model of the mock-up for further use of the design data in analysis and manufacturing. The manual operation involved in RE requires a great amount of time and operator skills and is also subject to error. Coordinate measuring machines have been used to extract surface data but their data capturing operation is very slow for parts having complex free-form surfaces. In recent years, the laser scanning technology has improved significantly, and it has become a powerful tool in capturing the geometry of complicated design models. Surface modeling in the RE process, however, is a challenging task. It takes a significant amount of time and skill to generate an accurate surface model from the point cloud data. This step is usually not automated and involves frequent manual interaction with the user even with a well-

developed surface modeling software package. The CAD model developed by an RE process can be converted to the physical prototype using an RP technique. Generally, in RP, physical parts are fabricated layer by layer. It uses additive manufacturing processes, which do not require any tools or set-ups compared to the subtractive techniques used in the traditional machining operation. It allows us to fabricate features that are difficult or impossible to fabricate by machining operation. Different fabrication methods exist for RP, but nearly all use the same geometry input format, called STL (Stereo Lithography), which consists of a list of triangular facet data. The STL format has advantages due to its simple structure and ease of use, but it also has serious drawbacks. It requires a large amount of memory as the accuracy of a part increases and also takes a significant amount of repair time when it has was such as gaps, overlaps, and mixed normal vectors.

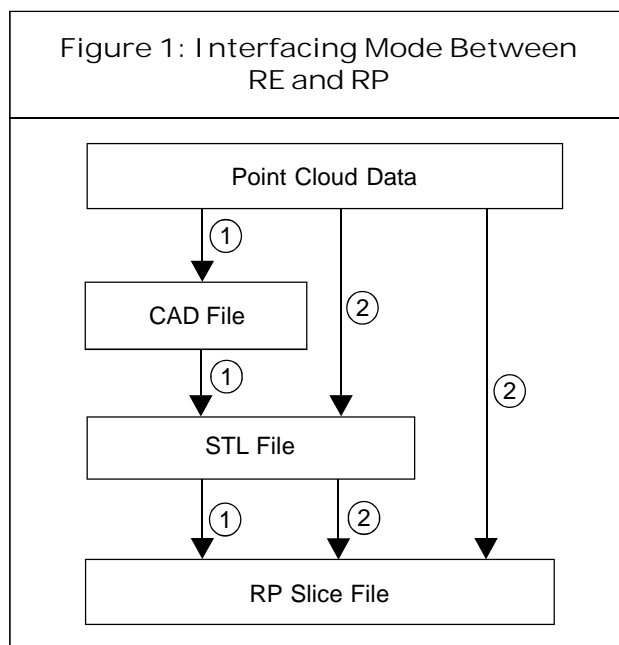
In order to bridge RP and RE technologies, ancient point cloud handling methods have to be developed first. Second, an accurate geometry input format for RP machines needs to be prepared.

Kwan and Woo presents work on direct integration of reverse engineering and rapid prototyping. New method that creates a direct link between these two technologies is proposed. In RE, an enormous amount of point data is gathered during data acquisition. This leads to huge file size that requires a large execution time. Surface modeling using these point's data is time consuming and requires expert modeling skills. Some researchers suggested crating an STL file directly from the

point cloud data to avoid surface modeling tasks. In this research, algorithms that greatly reduce point cloud data are developed and thereby the data file sizes are decreased considerably. The efficiency of the algorithms is demonstrated by comparing them with existing ones.

## INTERFACING MODES BETWEEN RE AND RP

RE data can be linked to RP in three different ways. In the first path, a 3D surface model is created from point clouds and then converted to an STL file. The STL file is then sliced to generate a series of layers for RP fabrication. This path is generally followed by RE practitioners since most RE software packages concentrate on creating a surface model from point clouds. Once the surface model is created, CAD packages are used to convert it into the STL file.



Some researchers have investigated the possibility of creating the STL file of a model directly from point clouds. This link bypasses

the creation of surface models, which involves tedious manual operation. The third path goes directly from point clouds to an RP slice file. In this path, the initial scan data is reorganized and reduced to make the contour data. This contour data can be categorized as an RP slice file since the layers of an RP part can be directly fabricated using these contour data. This link eliminates both the surface modeling task and the STL file generation task.

## CONCLUSION

This paper presents review of research work on integration of reverse engineering and additive manufacturing processes like rapid prototyping. Reverse engineering consists of 3D scanning of physical object. It is concluded from the review that lot of research work is going on integration of RE and RP. Still there is scope for developments of new algorithms, new techniques and new methodologies to combine these technologies for medical field. It is also observed that the study is limited with concern to few number of human body parts. There is wide scope for exploring remaining parts. 🌀

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