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Computer Aided Process Planning for 3D Printing

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ABSTRACT

Computer aided process planning (CAPP) keeps an important role between the design and manufacturing engineering processes. A CAPP system is a digital link between a computer aided design (CAD) model and manufacturing instructions. CAPP have been researched and applied in manufacturing filed, however, one manufacturing area where CAPP has not been extensively researched is rapid prototyping (RP). RP is a technique for creating directly a three dimensional CAD data into a physical prototype. RP enables to build physical models automatically and to use to reduce the time for the product development cycle as well as to improve the final quality of the designed product. Three-dimensional (3D) printing is one kind of RP that creates three-dimensional objects from CAD models. The paper presents a computer aided process planning system for printing medical products. 3D printing has been used to solve complex medical problems such as surgical instruments, bioengineered products, medical implants, and surgical guides.

1. Introduction

Several traditional manufacturing methods can be replaced by 3D printing technologies where three dimensions are built by subsequent overprinting. 3D printing becomes one of the essential technologies that allow manufacturers to improve product quality as well as reduce time and cost of products. 3D allows transferring quickly the designs from concept to functional prototype that can cut product development schedule to weeks or months. In the medical field, 3D printing techniques and different materials for printing medical products have been proposed. 3D printing opens up the capabilities for customization in a wide variety of applications. Medical devices with bio-compatible and drug-contact materials can be produced. These devices are perfectly suited for a particular individual. Rapid prototyping through 3D printing technology is a suitable technique in production of bone tissue scaffolds and tissue scaffolds[1-6]. Classification of 3D printing for medical products is shown in Fig. 1.

However, despite having many applications, the 3D printing in medical applications faces challenges such as volatile prices of raw material and untrained professionals to use these devices[1,7].

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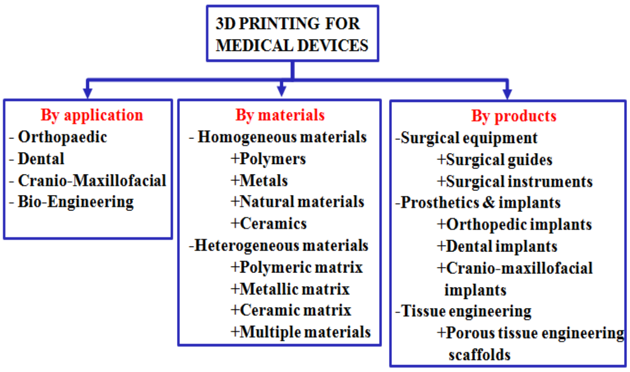

Fig. 1 Classification of 3D printing for medical products

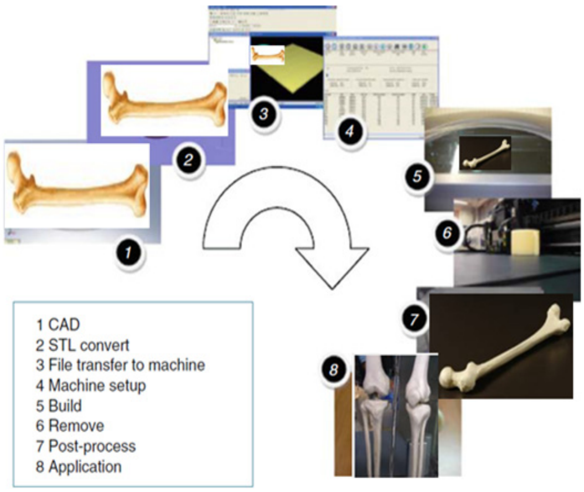

Fig. 2 Eight stages of the 3D printing process[7]

Fig. 2 shows stages of the printing process. All parts for 3D printing must start from a software model describing fully the external geometry. For this requirement, almost any professional CAD solid modelling software with the 3D solid or surface representation as output can be used. Then, the CAD model is converted into the stereolithugraphy (STL) file format. STL has become a defector standard which 3D printer machines accept this standard and nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices. The STL file describing the part must be transferred to the printer machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building[7].

The printing parameters such as the material constraints, energy source, layer thickness, timings, etc must be set up for the printer machine. The printing part is an automatic process and the machine can largely carry on without supervision. However, to avoid errors such as running out of material, power or software glitches, etc monitoring of the machine must have at this stage. In the next stage, the parts must be removed from the printer machine when the machine completed the build. In the post-processor stage, parts must be cleaned before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation. Parts may now be ready to be used. However, depending on applications, parts need more additional process before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish[7].

Most 3D printing technologies operate by depositing 2 1/2 D “layers” of material derived from the cross-sections of the part. The 3D printing systems have two strict criteria[8-10]:

- They must be able to make various arbitrary geometries using the same system hardware;
- Parts must be created with little input from the user before or during the process.

2. Literature Review

In the manufacturing filed, before applying CAPP, the process planning was carried out by a manufacturing engineer, based on engineering knowledge and work experience. With the high volume manufacturing industries, the CAPP has many benefits, so the CAPP systems was applied early in the mid 1970s[8,9]. The hardware systems involved in the process, the personnel operating these hardware systems, and data stored about current and past production are main parts of a CAPP system. Together with developing a CAPP, the manufacturing method must be determined, then the CAPP system is used is used and revised throughout the life of the production system. With the CAPP, the manufacturing process can be generated automatically by making real-time decisions based on the model of the part, sensors, and resources on the shop floor. Together, the CAPP system’s components will determine how to efficiently manufacture the product.

In assembly system, to improve part flow, reduce assembly errors, and increase the general efficiency of operations, the

CAPP systems have been used. Together with the development of CAD and computer aided manufacturing (CAM) systems, the CAPP systems keep an important role in the machining system. However, a standard CAPP system for CAD/CAM applications has not emerged, mainly due to differences in CAD/CAM computer languages and specifically, the CAD 3D model format[8]. NC programming has not changed much during this time, and most of the work in CAPP for CAD/CAM has been in feature recognition, albeit with limited success[8,9].

Early the CAPP systems improved the manufacturing efficiency for new parts that had slight variations in their design from previous or similar current models by using the group technology theory. With this technology, the parts with similar designs will have similar process plans. The system only considers the variations in the parts and then modifies manufacturing instructions based on these variations[8,10]. The process planning is created based on previous manufacturing methods for the product, and outputs one simple, similar instruction set for the manufacturing hardware.

In contrast, with the generative method, new process plans are generated for each new part based on the manufacturing hardware, product details, and sources on the shop floor. The process plan contains function variables that change for every part[8,9]. The system inserts values into its guiding functions to generate the process plan. This functional process plan incorporates the machine hardware and software. These CAPP systems are able to adapt and reconfigure to changing manufacturing needs, making them more flexible.

Rapid prototyping (RP) is one kind of manufacturing method where the CAPP technologies have not been extensively researched. It is a challenge to develop a CAPP system for RP in consideration of economic benefits due to low production quantities. This manufacturing method often requires not more than one part to create. Some researchers propose the layered manufacturing method to allow a direct and simple interface with CAD to CAM. This method almost completely eliminates the need for process planning[8]. Some RP processes use completely subtractive rapid prototyping (SRP) methods for creating the part. The final part created by these SRP systems not only conveys the form of the design, but enables testing of the part's function[8].

3. Process Planning for Printing Medical Products

A generic 3D printing process is shown in Fig. 3. Data for the CAD solid model can get from scanned image of a physical object, 2D surface data, or 3D CAD data. The digital imaging technology has changed the way systems communicate with others using image data from simple digital pictures to complex medical images. In medical community, many images have been taken to diagnose patients in hospitals since late 1970's[8]. Such images may include computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine, and ultrasound.

Digital imaging and communications in medicine (DICOM) data format is the most common standard for receiving scanned images from medical equipments. DICOM is becoming a global information standard that is being used by virtually every medical application. DICOM images play a key role for developing prototypes[12].

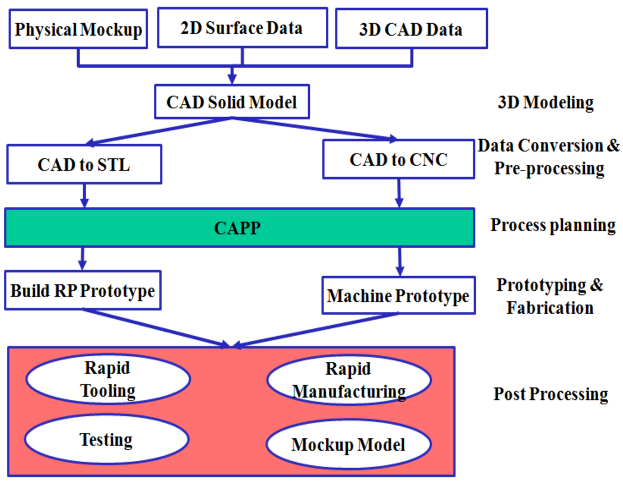

Fig. 3 Generic 3D printing process[11]

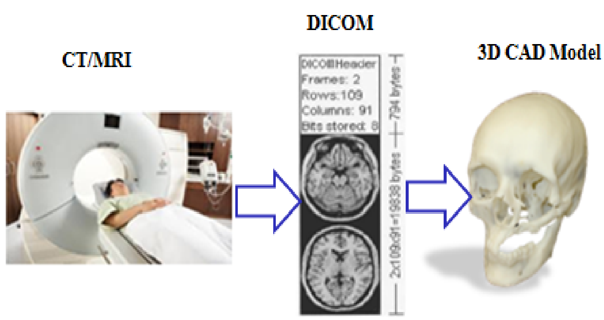

Fig. 4 DICOM data format for modeling 3D solid

Most RP machines use stereolithugraphy (STL) file as input. So, CAD data is interpreted into the STL data format. By using STL, the surface of the solid is approximated using triangular facets with a normal vector pointing away from the surface in the solid[11].

From CAD data, before the application of RP, prototypes were created by using computer numerically controlled (CNC) machines as shown in Fig. 5. With these machines, the final shape of the part is achieved by removing work-piece material. In contrast, with RP machines, models are built by adding material layers after layers until the whole part is constructed[11,13].

Process planning for RP involves optimal selection for orientation of model with a support structure, printing method, the best machine, and the optimal printing parameters. The CAPP model involves modules as shown in Fig. 6. A systematic procedure for realizing a CAPP system for generating process planning is shown in Fig. 7.

3.1 Engineering model for selecting an appropriate 3D printing method

In RP process, many methods have been proposed to transform different materials such as liquid, solid and powdered into physical parts. In which, stereolithography (SLA), fused deposition modelling (FDM), selective laser sintering (SLS), electron beam melting (EBM), laser beam melting (LBM), photopolymerization, droplet deposition manufacturing (DDM), and hot melt extrusion (HME) have been widely used by many industries.

3D printer machine with SLA technology uses liquid as input. The material vat is part of the machine. In SLA process, the ultraviolet laser beams were used to solidify the liquid polymer at each layer. The part and the support are created simultaneously. Then, the part is removed manually and cleaned.

FDM is a solid-based process. An extrusion head on the printer machine is used to melt material. The temperature is adjusted based on the type of the material used to keep the state of material as semi-liquid. Then, this material is extruded and deposited layer by-layer. The finished part is then manually removed and cleaned.

SLS is a powder-based process. A CO_2 laser is raster scanned across the surface of the powder, melting and bonding the power together. In this process the part is built inside the powered material which can then be brushed off

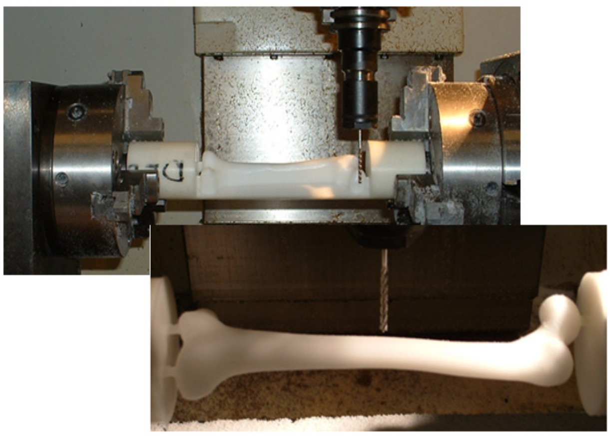

Fig. 5 CNC machining for creating a bone prototype[13]

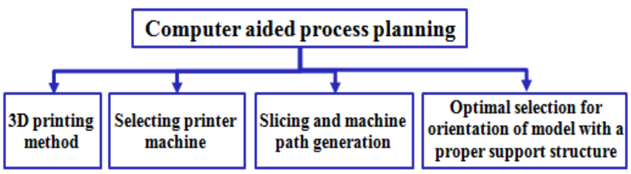

Fig. 6 CAPP model for generating 3D printing process

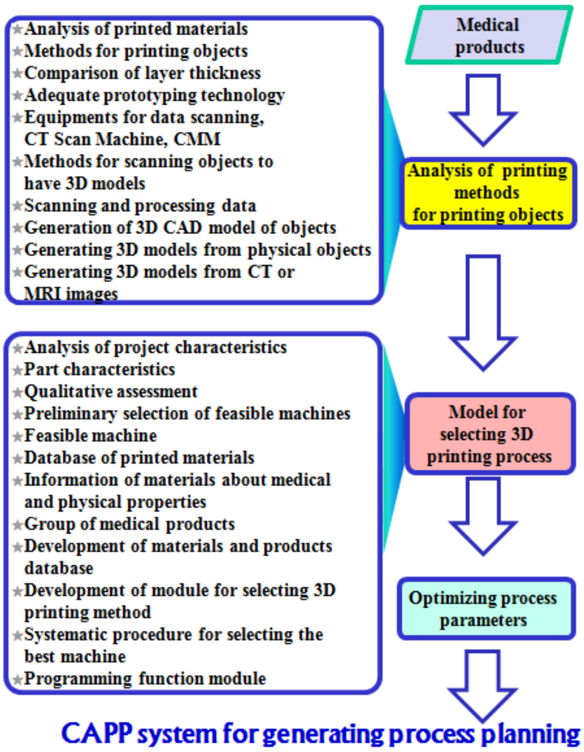

Fig. 7 Systematic procedure for realizing a CAPP system

and reused[11].

The technologies such as EBM, LBM, photopolymerization and DDM are applied in 3D printing for medical application. Many medical structures such as surgical guides, medical implants, surgical instruments and bioengineering have been manufactured by applying these technologies. In which, LBM and photopolymerization have proven to be more accurate and efficient for manufacturing various bio-models using raw materials such as metal and polymers. These technologies also are used to manufacture medical implants such as dental, orthopedic and craniomaxillofacial implants[1].

HME has been used for pharmaceutical applications during the last decades. HME can be used to produce solid dosage forms that are then usually developed into traditional capsule or tablet formulations conventionally. This technology is also used for production of implantable devices. When 3D printing polymers; the printer heats the thermoplastic polymer until it can be extruded from the printer nozzle. In the printer machine with HME technology, material is extruded from the nozzle in layers onto the printing surface, and the position is controlled with a x, y, z axis positioning system[2].

An appropriate printing method is selected depending on the material characteristics and the requirement of the final quality of a prototype. The choice, therefore, depends on the purpose of the prototype[14].

3.2 Engineering model for selecting the best machine

Fig. 8 illustrates strategy for selecting the best machine. A database of machine types and capabilities is read, which represents the set of machines that the software will consider. The software supports a qualitative assessment of the suitability for the application, and then enables the user to explore the performance of various printer machines. Build time and cost estimates are provided, which enable the user to make a selection decision.

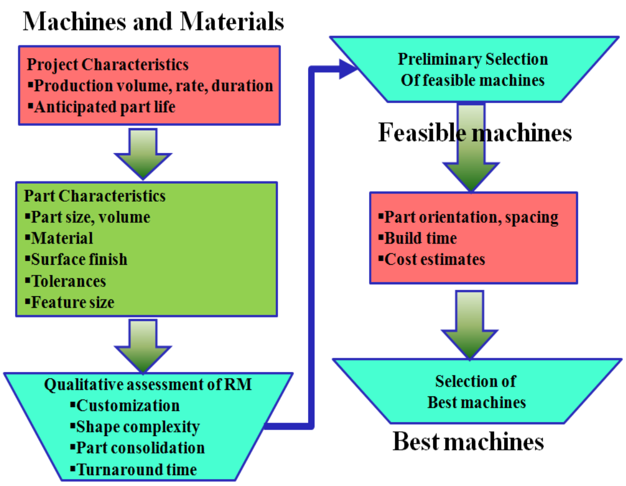

Fig. 8 Selecting the best machine for printing[7]

3.3 Slicing and machine path generation

There is no standard machine path code for Rapid Prototyping (RP) because of the differences in the nature of rapid prototyping processes. Each RP process, based on its characteristics and requirements, uses the standard CAD file format to extract the required data for the process. The CAPP system needs a specialized machine path generator to create an appropriate machine path file. Machine path such as boundary path and hatch path should produce the printing pattern that enables the machine user to easily remove the fabricated part from the surrounding material. The machine path generator provides the ability to process CAD models of any size and complexity, the ability for machine path verification before sending the file to the machine, and the ability to fix the possible STL files disconnection errors.

The CAPP system uses STL files with the ASCII format as input and works in two steps (Fig. 9). The first step generates slices at each increment of Z by intersecting the XY plane with the facets within the part. The second step uses all individual unsorted intersection lines in each Z increment to form the contour. This step includes sorting the intersection lines, recognizing the closed loops and disconnections (STL file error), and generating the machine path such as boundary path and hatch path, and simulation files.

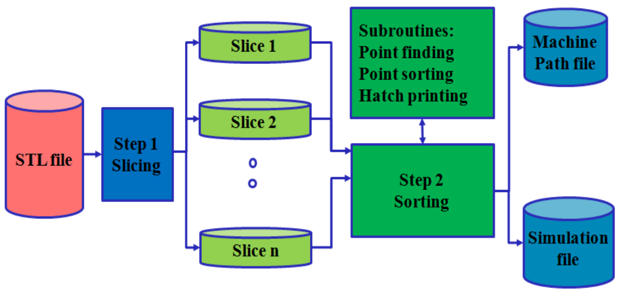

Fig. 9 Steps of slicing and machine path generation[15]

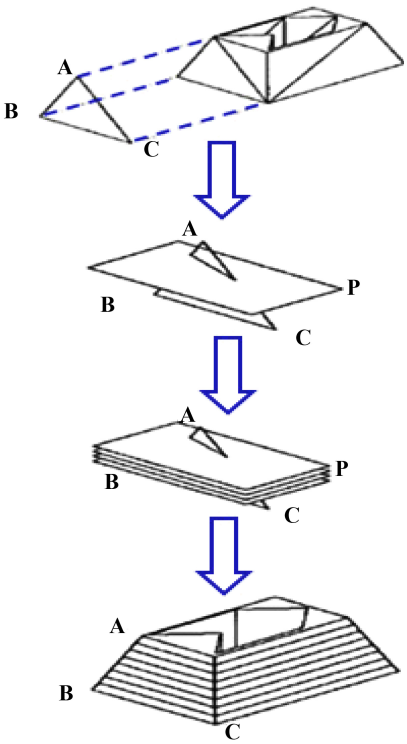

Fig. 10 Slicing algorithm[15]

In the first step the STL file is read as input. Slice files are then generated by executing the slicing algorithm. Only the intersection of those facets that intersect current Z=z are calculated and saved. In this step, one facet is read at a time from the STL file. Then the intersection lines of this facet with all XY planes are calculated. The intersection lines are stored in the specified file for the associated z increment. This results in one intersection line on each XY plane. By repeating this process for all facets, a set of slices is generated.

The example shown in Fig. 10 illustrates the slicing algorithm. After the completion of the slicing process, a set of vectors becomes available in each z increment. These vectors are not connected and are not in sequence.

In the machine path generation process as shown in Fig. 11, the software starts from one vector and tries to find the next connected vector to this vector. Then it does the same for the newly found vector until it reaches the start point of the first vector (in the closed loop cases) or finds a vector with no leading attachment (in faulty STL files containing disconnections). To sort the vectors, the algorithm reads one vector at a time from a slice file and writes it to another file. This file is either path file, when vector is connected to previous vector, or temp file, when the vector is not connected to the previous

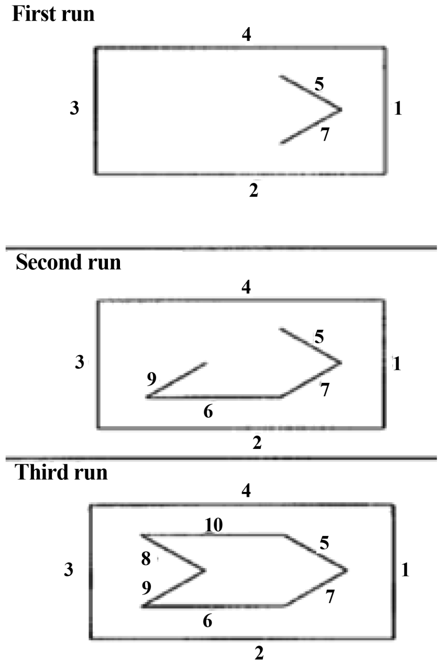

Fig. 11 Machine path generation[15]

vector. Therefore, the sorting process does not need a large amount of memory to sort the data, and there is no limitation on the number of vectors in a slice and on input file size. This algorithm can generate a machine path even with disconnection errors in the STL file[15]. At disconnection instances the system sends a message to a log file and turns the printer off and starts from a new vector. In either case the printer is turned off and the system starts printing from another start point.

4. Conclusion

Computer Aided Process Planning (CAPP) has been applied for manufacturing area for a long time. However, CAPP technologies have not been extensively researched in Rapid Prototyping (RP) manufacturing. Currently, RP in medical engineering is attracting great interest. Medical images can be used from any CT or MRI scanner, and format recognition for most scanner formats is available for processing the data. Precise medical models deliver visual and tactile information for diagnostic, therapeutic, and didactic purposes. This research proposes to develop a CAPP system for printing medical products, in which the concepts of the CAPP system as well as the modules of the CAPP system were presented. The implementation and applying the system to practice are the future work of this research.

Acknowledgement

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