A Review of Emerging Technologies for Rapid Prototyping

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ABSTRACT This paper reviews the prototyping of objects. Rapid prototyping is becoming increasingly important in mechanical and industrial design engineering. This study looks at how commercial CAD programming products can be used to model 3D objects for rapid composite prototype construction using the layer-by-layer method. Rapid prototyping (RP), commonly known as 3D printing or solid freeform fabrication (SFF), is a technology and apparatus that allows physical items to be made immediately from solid models developed in CAD utilizing additive layer manufacturing processes without the use of tooling or fixtures. Traditional CNC machining techniques, on the other hand, can be modified to do everything from high-precision metal cutting to fast milling of light materials, making them ideal for rapid prototyping and it assists in the development of projects and ideas prior to execution.

INTRODUCTION

Rapid prototyping is becoming increasingly important in mechanical and industrial design engineering. To aid the product development process, several ways for fabricating physical duplicates of CAD-defined models are used. The majority of these techniques are gradual and layer-based. Traditional CNC machining techniques, on the other hand, can be modified to do everything from high-precision metal cutting to fast milling of light materials, making them ideal for rapid prototyping. In a variety of situations, CNC milling is more cost-effective than incremental techniques. This is especially true when the prototypes are large (over 0.5 m) and the design emphasizes the product's surface, as in in-vehicle bodywork and consumer products [1].

The sculpturing robot (SR) system was created to test and adapt milling methods for rapid prototyping. A six-jointed industrial robot is utilized in conjunction with a rotational platform on which the first block of material is placed. This creates a broad, effective workspace, which is necessary when working with massive objects with complex geometries [2]. The competition in the industry has never been higher than it is now. To succeed, businesses must keep their product development cycles as short as possible. Reducing the time spent developing a product is a great way to shorten the time it takes to develop a product [3]. By reducing prototype time, the turnaround time for conceptual designs is significantly reduced. Furthermore, form, fit, and function tests can be performed much earlier in the design cycle with a physical prototype, reducing the need for costly engineering changes during the manufacturing stage. Manufacturing waste is also reduced, such as lost production time, retooling, rework, and scrap waste [4].

PRINCIPLES OF RAPID PROTOTYPING

The system has seven degrees of freedom and a workspace of 4m * 2m * 2m, allowing it to produce large-scale parts such as ship models. The technology of the rapid prototyping technique combines geometry, shape, structure, and material information from physical prototypes and parts with computer-aided design or reverse engineering to create a mathematical description of the prototype. To obtain the concept of the objective prototype, we can enter these details into a computer-controlled electromechanical integrated manufacturing system, which will form materials point by point and surface by surface to create a prototype that meets the design requirements in terms of appearance, strength, and performance. It can make a prototype or actual parts fast and accurately [5].

Rapid prototyping technology application

Researchers have been working on a range of rapid prototyping robotic systems over the past decade to reduce product development time and increase device functionality, environmental harmony, and product quality. Vergeest et al. proposed a sculpturing robot system. [6]. This device consisted of an industrial robot and a turntable that performed fully automated RP on foam stock milling. The system created an interference-free tool path using a six-grid voxel data format. The prototype measures 80*80*80cm, has a precision of 0.5mm2mm, and takes a few hours to make. Professor Chen of the University of Hong Kong created a robot system for prototyping large workpieces quickly [7]. The system has seven degrees of freedom and a workspace of 4m * 2m * 2m, allowing it to produce large-scale parts such as ship models. As shown in this Figure-

FIGURE 1- This diagram depicts the various phases of prototyping.

The system generated CAM tracks based on multi-axis machining features based on CAD models of parts in all previous research findings, whether it was material buildup or removal. They can also use self-developed data transformation software to convert CAM machining paths to robotic machining paths. To overcome the limitations of rapid prototyping systems, the focus is on how to build efficient tool paths and improve their accuracy [8].

Outline of the sculpturing system

Essentially, the system consists of a 6R industrial robot and a movable horizontal platform on which the first material block can be attached. The robot is a Siemens Manutec R15. Within the robot's end-effector is a milling machine. The Manutec, which is included with the robot, is used to control both the robot and the turntable. The controlling device sends movement (and other) commands to the robot and turntable. To prevent human injury and instrument damage, a PLC-based safety system governs room locking and system operation. [9]. Figure 3 depicts the outline of the SR system.

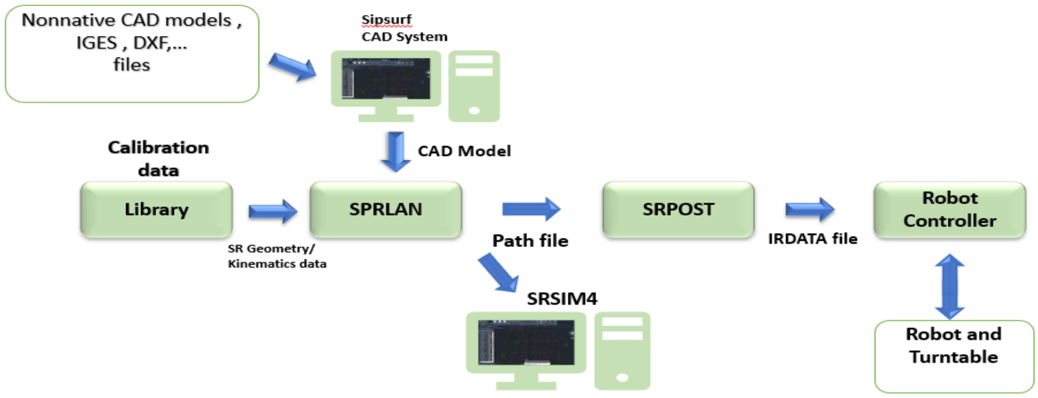

FIGURE 2 - A schematic diagram of the hardware and software components of the sculpturing robot system

A route file is used to depict the milling process in its entirety. This is a series of ASCII-encoded command lines, each of which causes the milling tool to proceed linearly through the work region, rotate the turntable, or start or stop the milling engine. The path file's syntax isn't robot-specific, and it's not designed to drive a robot. It can, however, be easily translated into robot-specific formats, such as the IRDATA format (for the SR system)[10]. The SRPOST software performs this translation and division of the path file (which may contain over 100,000 commands) into sections that are supplied into the robot controller [11]. The path file is generated by the SRPLAN software using the CAD geometry to be prototyped, the robot and work cell's kinematic/ geometric model, and user-defined parameters. [12].

The SRSIM program can be used to visualize the milling process on a graphics workstation[13]. Not only can the movements of the robot/turntable be seen, but the shape of the stock-in-progress can also be seen at any time. This simulation is designed to provide the designer with an idea of the expected prototype's quality. It is not used to prevent collisions; in normal operation, the SRPLAN software ensures that the entire milling process is collision-free for items up to a specified size limit.

Basic Steps involved in creating Rapid Prototype models

Although the sort of material used to build physical prototypes differs depending on the procedure, the initial steps in the process of making a rapid prototype model are the same for all of them. The initial stage, which is the same for all types of systems, is to define the part to be created as a surface or solid model in a CAD environment[14]. At IUPUI, this is accomplished by creating a solid model of the part using either AutoCAD or Pro-Engineer software. The bounding surfaces of the CAD model are then automatically discretized into a collection of triangular facets by the

CAD computer after the solid model is done. The faceted data is written to a disc file in the STL format. Some models require additional support structures (in the form of STL data) if they contain overhanging areas that might otherwise distort during the build process[15]. The Genisys software does this operation automatically in a later phase. The STL file is read by the rapid prototyping system's software, which then calculates "slice" data, which are lines of intersection of the STL facets with horizontal planes at consistent heights. The path that describes the outline of the portion to be built is the slice information. A laser or modeling head is driven down this path and in the interior, depending on the type of procedure utilized, until the model is built up one layer at a time[16].

ROBOTIC PROTOPYING SYSTEM

Instead of using standard CNC devices, a robotic prototyping system is used: According to the article, with the same size workspace, the robotic prototyping system saves 40% more floor space than traditional CNC equipment [17]. Tool access is more flexible thanks to the articulated robot configuration. The end-effector of an articulated ABB IR1400 robot arm is equipped with a precision spindle. After that, the robot arm is mounted on a track, allowing it to move around more freely and handle heavier objects. A solid model of the thing to be prototyped is created first in a computer-aided design system.

The user can then specify the cutter's type and diameter, as well as the desired accuracy for the prototype. The object's solid model will then be used to generate a path file automatically [18]. It's utilized to guide the robot arm while it mills the raw material into the final prototype. Figure 4 depicts the machining process' coordinate system. The milling tool axis is kept parallel to the z-axis throughout the milling process to make the algorithms easier to understand because the research is still in its early stages. In a zig-zag pattern, the stock is milled in two steps: rough cut and finish cut. Each stage contains one or more levels [19].

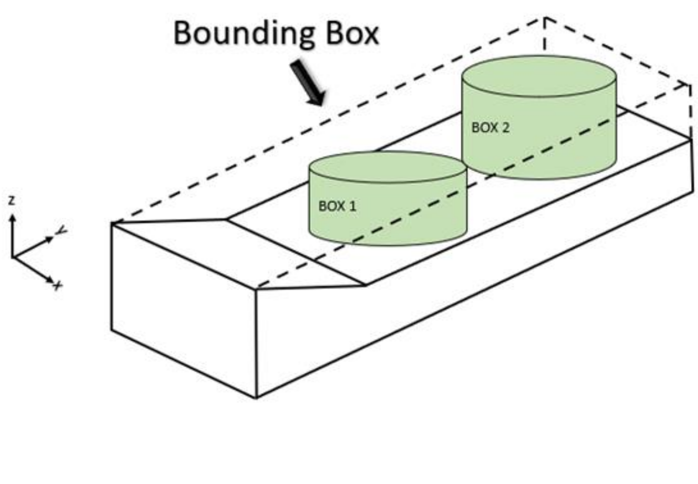

Fig. 4. This figure depicts how the model looks while creating its design

CAD TECHNOLOGY

For years, advanced 3D CAD systems have attempted to replace traditional 2D CAD systems [20]. It's critical to determine whether 3D modeling is required for a specific model. Many projects, such as simple blueprints, diagrams, and flow charts, do not require 3D modeling. However, because so much is created and built-in three dimensions, 3D modeling can be the most natural way to generate and document the design. However, 3D modeling can lengthen and complicate the design process. Understanding the benefits of 3D modeling and deciding whether it is worth the extra time and effort is critical[21]. Extruded things such as surfaces and other extruded entities could be used in architectural models, piping and machinery design, topographical models, and package designs, to mention a few. Solid modeling is required for precision in mechanical part design. Solids are mathematically accurate enough to significantly exceed the capabilities of NC machines, whereas surfaces are merely regarded approximations. What you see on the screen in 3D modeling is simply one of many possible views of the 3D models you've produced and saved in AutoCAD. It's critical to know the difference between a model and a model's view. For viewing them, AutoCAD 2008 and 2009 offer some built-in features[22].

RAPID PROTOTYPING TECHNOLOGY

There are a plethora of rival RP technologies on the market today. Because they're all based on additive fabrication, the key distinctions are in how layers are constructed to make parts. To create the layers, some rely on softening or melting the material, while others rely on layering liquid material thermosets that are cured with various technologies. Table 2.1 covers a handful of the most essential technologies as well as the materials that they employ as their foundation: [23]

TABLE 1- This table represents how rapid prototyping materials is different from the traditional materials

Rapid Protyping Technologies	Base Materials
3D printing	Various Materials
Laminated Object Manufacturing	Paper
Selective laser sintering	Thermoplastics ,Metals powder
Laser Engineered Net Shaping	Various materials
Stereolithography	Photopolymer
Fused Deposition Modelling(FDM)	Thermoplastics, Eutectic powder

3D PRINTING

In comparison to other additive fabrication methods, this is the most cost-effective and time-efficient way[24]. Powdered plaster and resins are the ingredients utilized in this technique. The material is selectively bonded by the printing head, which is commonly an inkjet print head, printing the adhesive onto the supporting platform. The CAD file that is entered into the system determines the model's cross-section. Color prototypes may be printed using 3D printing. There are a variety of 3D printing machines available as well. This is the most cost-effective and user-friendly version of RP technology. [26] Ex-RX-1 One's Rapid Prototyping Machine is a 3D printing device. Powdered Stainless Steel is the metal utilized in this procedure (S4). The print head deposits the binder on each layer as the item is built up. This generates a green part 15, which is then heat-treated to strengthen its strength through techniques such as curing and sintering [27].

A brief on 3D printers

LOM (laminated object manufacturing) is a 3D printing technique. Helisys Inc. (now Cubic Technologies) in California was the first to design this rapid prototyping technology. During the LOM process, layers of plastic or paper are fused using heat and pressure, then cut into the required shape with a computer-controlled laser or knife [28]. After the pieces have been printed, they are further modified by machining or drilling. The typical layer resolution for this process is determined by the material feedstock, which typically ranges in thickness from one to a few sheets of copy paper. While LOM isn't the most popular 3D printing technique today, it is still one of the most flexible and quick ways to create 3D prototypes [29]. All 3D-printed items, including models created with a LOM system, begin as CAD files. A model's CAD file must be converted to a 3D printer-friendly format, such as STL or 3DS before it can be printed. A set of feed rollers in LOM equipment pulls a continuous sheet of material, such as plastic, paper, or (less commonly) metal, over a build platform [30]. Plastic and paper construction components adhere together with an adhesive. A heated roller is used to melt the glue on a sheet of material on the build platform and press it onto the platform to form an object. A computer-controlled laser or blade is then used to slice the material into the required design. The laser also slices up any excess material in a crosshatch pattern, making it easier to remove once the object is finished. After one layer of the object is built, the build platform is lowered by about one-sixteenth of an inch — the normal thickness of one layer. After that, new material is pulled across the platform, and the hot roller is used to bind the new layer to the one beneath it. This procedure is repeated until the object is finished [31]. When an object has completed "printing," it is removed from the construction platform, and any excess material is discarded. Printed-on-paper objects have the appearance of wood and can be sanded or finished as desired. To keep moisture out, paper things are frequently coated with paint or lacquer.

Advantages:

- resources that are very inexpensive and accessible (adhesive and paper)
- a slim thickness
- Paper models are similar to wooden models in that they can be manipulated and finished in the same way.
- No chemical reaction is required, very big pieces can be produced.
- Creating scaled models and conceptual prototypes that can be tested for form and design is the most common application.
- Most “green” technology of 3D printing

Disadvantages:

- Materials selection is limited.
- Produced parts have a poor strength
- Not suitable for the creation of complicated geometries
- Unable to make hollow objects
- Low precision isn't appropriate for working prototypes[32].

The application to the prototype molds

This composite was machined into a mold at high speeds to determine the feasibility of the application. A prototype fan was injected into the mold. First, using the composite manufacturing procedure described above, two pieces measuring 200 mm x 200 mm x 50 mm were created. Figure 8 depicts the machining of the upper (left) and lower (right) molds under Table 5 conditions. Under the above conditions, the upper mold took 100 minutes and the lower mold took 90 minutes [33]. Alloy steel and aluminium alloy were frequently used to make moulds. The Machinability Data Center's machining conditions and the material removal rate (MRR) equation can be used to estimate their machined time [34]. As can be seen, the created composite outperformed both alloy steel and aluminium alloy in terms of time. Furthermore, compared to alloy steel and aluminium alloy, this material was less expensive. As a result, a composite was found to be suitable for high-speed machining of the prototype. To test the applicability to the simple prototype mould, a fan was injected using RIM (reaction injection moulding) equipment that was basic at the low injection pressure (about 1 MPa).For a total of 6.58 hours, mould design, NC data generation, machining, and injection took 2, 1, 3, and 0.58 hours, respectively. As a result, the prototype fan was built quickly, and the composite was discovered to be ideal for prototype production. [35].

POSSIBLE EXTENSIONS AND IMPROVEMENTS

The fabrication technique is currently being improved. A mechanism will be installed to continuously clear the milling tool's dust. Path planning software SRPLAN2 is the result of many changes to the algorithms and data structures[36]. The tool will no longer approach from five specified directions, but rather from directions. Directions that are appropriate for the prototype at hand. This will allow for the creation of more complex shapes. Another enhancement to the software is the explicit avoidance of robot linkages colliding with other objects [37]. This, together with increased efficiency and computer hardware enhancements, will result in a prototyping facility that can quickly manufacture larger models (up to 1 cubic meter) with higher precision (0.5mm or less) (less than five hours). The software does not have access to robot-specific data (such as geometric/kinematic models). As a result, the software may be used not just with other 6R robots, but also with work cells of varying sizes.[38]

CONCLUSION

Prototyping becomes an important step to the design and development of any component or project. The purpose of including a fast-prototyping technology into the curriculum was to supplement many CAD-related courses. It helps to do the modifications as per requirements. we briefly discussed one of the most exciting and advanced technologies for product Design - Rapid prototyping (RP) or 3D printing. This technique or technology has the potential to improve not only product development turnaround times, but also functional prototype and small-scale production, personal 3D printing, and medical applications, and many more. It is considerably easier for the general public to appreciate a CAD model if they can hold a tangible prototype while watching a picture on a CRT during events like these

TABLE 1- This table represents the comparison of Rapid prototyping and traditional method compared on different parameters

Parameters	Rapid Prototyping with Auto-CAD	Traditional Fabrication
Tools	No tools required	Tooling is always required
Design	Automated Design	Physical validation
Cost and time`	Less physical . Less time .Reduced Cost	More work, More time, More cost
Geometries	Able to create one-place part geometrics	Part is made in assembles
Shapes	Difficult shapes can be made	Useful for making simple shapes

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