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CAD/CAM and Rapid Prototyping in Product Development: A Review

Praneeth Jammula[1], Sampath Kumar Todeti[2]
[1]*Assistant Professor in Mechanical engineering Department, Anurag engineering College-Kodad*
[2]*Assistant Professor in Mechanical engineering Department, jyothishmathi engineering college-Kareem Nagar*

Abstract: Rapid Prototyping and manufacturing (RP&M) technique has shown a high potential to reduce the cycle and cost of product development. Integrating CAD/CAM RP&M systems have been developed and employed to implement remote parts and manufacturing for rapid prototyping and improve the capability of rapid product development for a large number of small and medium sized enterprises. This paper provides a comprehensive review of recent research on CAD/CAM RP&M systems. The key issues and enabling tools to implement the remote RP&M systems, involve (1) CAD/CAM/CAE, (2) Modeling and Optimization, (3) Algorithms, (4) Measurement of anisotropic strength, (5) STEP/XML, (6) Applying new technologies and concepts to Rapid prototyping systems, are described in detail. Finally, this review gives outlook on possible future development and research direction for CAD/CAM RP&M systems.
Keywords: CAD/CAM; Rapid prototyping; algorithms.

I. INTRODUCTION

Due to the pressure of international competition and market globalization in the 21st century, there continues to be strong driving forces in industry to compete effectively by reducing time to market and cost while assuring high quality product and service [5][3][4].RP is a new forming process which fabricates physical parts layer by layer under computer control directly from 3D CAD models in a very short time. In contrast to traditional machining methods, the majority of rapid prototyping systems tend to fabricate parts based on additive manufacturing process, rather than subtraction or removal of material. Therefore, this type of fabrication is unconstrained by the limitations attributed to conventional machining approaches [2][6].Additive processes, which generate parts in a layered way, have 15 years of history [1].It started in the late 80's with Stereo lithography. Since then, many new ideas have come up, many patents have been deposited, new processes were invented and commercialized, some of which have already disappeared. An overview is given in Table 1

Stereo lithography	SLA	1986-88
Solid Ground curing	SGC	1986-99
Laminated Object Manufacturing	LOM	1985-91
Fused Deposition Modeling	FDM	1988-91
Selective Laser Sintering	SLS	1987-99
3D Printing	3DP	1985-97

RP is newly evolving toward rapid tooling (RT). RT is a technique that transforms the RP patterns into functional parts, especially metal or plastic parts. It offers a fast and low cost method to produce moulds and functional parts. Furthermore, the integration of both RP and RT in development strategy promotes the implementation of concurrent engineering in companies. Numerous processes have been developed for producing molds from RP systems. The RT methods can generally be divided into direct and indirect tooling categories, and also soft (firm) and hard tooling subgroups. Indirect RT requires some kinds of master patterns, which can be made by conventional methods (e.g. High-speed Machining, HSM), or more commonly by an RP process such as SL or SLS. Direct RT, as the name suggests, involves manufacturing a tool cavity directly on the RP system, hence eliminating the intermediate step of generating a pattern [7]. Soft tooling can be obtained via replication from a positive pattern or master. Soft tooling is associated with low costs; used for low volume production and uses materials that have low hardness levels such as silicones, epoxies, low melting point alloys, etc. [53] RTV silicone rubber moulds, epoxy moulds, metal spraying moulds, etc., are some of these typical soft molds. Hard tooling is associated with higher volume of production, and the use of materials of greater hardness. Keltool process, Quick cast process, and the Express Tool process are some of these hard tooling's. Electrical discharge machining (EDM) seems to be an interesting area in which rapid tooling finds a potential application. Some methods of making EDM electrodes based on RP technique have developed such as abrading process, copper electroforming and net shape casting, etc. [37][38][39].

Physical prototyping Industries utilize both virtual and physical models to procure proper information, despite the fact that the applicable problem domains and the accuracy of virtual models are increasing. The trend in industry is to verify product quality and adjust design parameters through physical tests. The test/parameter tuning cycle is repeated until acceptable quality is obtained within allowed cost and time constraints. As this iterative quality improvement cycle is costly and time consuming, in many cases testing of scaled models is performed instead of direct product testing. In some cases, more expensive scaled-up models are prepared for functional tests

II. DEFINITION AND CLASSIFICATION OF RAPID MANUFACTURING

The major players in this field have already come to the conclusion that a breakthrough can only happen on the basis of manufacturing applying the RP technologies on a large scale. New terms were created or considered terms like mass customization (MC) by Siemens and Phonak [1] [8] [9], Production on Demand (POD) by Boeing, and recently Advanced Digital Manufacturing (AMD) by3D Systems. RM must guarantee long-term consistent component use for the entire product life cycle or for a defined minimal period for wearing parts. This calls for almost significant role of materials in the LM technologies. The indirect production via patterns and reproduction, by e.g. casting, are not considered as LM, even though generative processes have a significant ability and importance representing an important option in those process chains In contrast to the previous definition of Rapid Manufacturing (RM), Rapid Tooling (RT) aims only at long-term consistency tools, meaning a tool able to form several thousand or even millions of parts before final wearing-out. Referring to tooling, mainly plastic injection moulds are considered, as these are the most frequently used forming tools. Naturally we have to consider as well other needs with greater difficulty as in die casting, sheet metal forming and forging dies [10][11][12][13] [14]. Those applications increase substantially the requirements on thermal and mechanical load and wear. On the other hand we have also to consider tooling with lower load that is also of great interest: for example for thermoforming, fibre forming and similar processes [15][16].Fig. 2shows a flow chart of developing and manufacturing process for RT based on the integrated system[22]

A. Rapid prototypes for effective functional tests

Industries develop and apply rapid prototyping techniques for two reasons: (1) To improve design processes by providing timely information; and (2) To rapidly produce products or tools.

III.MODELLING AND OPTIMIZATION

The modeling module allows the designer to interact with the VR model to manipulate the viewing perspective and the part geometry. This allows the designer to view the model by navigating around it and changing the lighting, shading and rendering conditions.

A. Measurement of Anisotropic Compressive Strength

In order to make compression test specimens, an ABS material for FDM, azp102 (plaster powder) material for the 3D printer, and an acrylic-hydroxyapatite composite material for NCDS. The dimensions of the compression specimens are according to ASTM D695.In compression tests, build direction was the only examined process parameter. “axial” (horizontal) and “transverse”(vertical). The raster angles were setas (45◦/−45◦). Note that (45◦/−45◦) are the default raster angles defined in the Quick slice program. For the 3D printer process, the specimens were produced in three build directions—“axial,” “transverse” and “diagonal”. The diagonal specimen ‘slayers were assumed to be deposited at a 45◦ slope to the base.

IV. ALGORITHM

A slicing algorithm is to represent the boundary contour of each sliced layer as a closed NURBS curve to maintain the representation accuracy of an original model. A mixed tool-path algorithm is to generate contour and zigzag tool-paths to meet both the geometrical accuracy and build efficiency requirements. The contour tool- paths are used to fabricate the area along the boundary of each sliced layer to improve the geometrical quality of a product model. The zigzag tool-paths are used to fabricate the interior area of the model to improve the efficiency.

In Adaptive slicing the first layer obtained from one end with a sufficiently small thickness. Points in this layer are projected along the RP building direction onto a plane positioned at the component edge. This forms a 2D band of scattered points. An intuitive method is to use the width of this band as a measure for adaptive slicing. Adaptation of a thick layer in components with a large curvature variation along the building direction normally results to a thick scatter band width. It is assumed that a thick band width generally represents a large cusp height and

consequently a large shape-error. A band width tolerance is given to set the maximum allowable deviation between the generated model and the cloud data points. If the measured maximum band width is smaller than the prescribed band width tolerance, the layer thickness is adaptively increased. Since the actual shape-error can only be determined after a layer is constructed, the slicing procedure follows an iterative process. In this respect, construction-check-reconstruction procedure is performed until a suitable band width tolerance compatible with a satisfactory shape-error is achieved.

In DSP algorithms designed using MATLAB (version 6) Simulink DSP block sets implemented in real-time through RTW.RTW generates C code from the graphical block sets through the Target Language Compiler (TLC) [14]. Together with other supporting files, the codes are compiled, assembled and linked automatically using TI TMS320C6000 code generation tools and GMAKE utility. The executable code is then downloaded to the TMS320C6701-EVM for real-time signal processing. The rapid prototyping process can be summarized into three processes:

A. Code generation process;
B. Executable code building process; and
C. Executable code downloading process.

D. Step/Xml

The key function in the structure of this layer is the data storage and retrieval based on STEP based data model standard. STEP standard has data protocols on which the structure of product data-form its design information and data related to its production process data is organized. The structure that has been used for implementing this standard was based on the integrity of product data [40]. The STEP data model is composed of substructures called Application Protocols (APs). These APs include definitions not only of typical geometry and drafting elements, but also of data types and processes for specific industries such as automotive, aerospace, shipbuilding, electronics, plant construction, and maintenance [13][41]. Considering the INFELT STEP platform to support CAD/CAPP/CAM processes and CNC machining efforts, the following Application protocols are used in Integration layer:[34-39]1. Configuration controlled design2. Functional data and schematic representation for process plans3. Core data for automotive mechanical designprocesses4. Mechanical product definition for processplanning5. Material information for products
6. integrated CNC machining

E. Applying new technologies and concepts to Rapid prototyping systems

3D printer builds parts in layers. From the model data of STL, and slicing algorithm generated with detailed information for every layer. First, a layer of powder is spread over the machine bed. The component slice is then formed by ink jets which selectively inject a binder into the material to forma green part. A piston lowers the part, the next powder layer is spread and the binder is printed again. This layer-by-layer process repeats until the part is completed. Following a post process, unbound powder is removed, leaving the fabricated part. The Nano composite deposition system (NCDS)uses polymer resins as matrix and various nano particles to form composite materials, and consists of deposition mechanism and material removal process of "mechanical micromachining" .The nano composite deposited into 10–100_m thin layers to form a near-net-shape. By repeating the deposition and machining for each layer, final three-dimensional part will obtain.

V. CONCLUSIONS

CAD/CAM and Rapid prototyping have the potential to further improve the traditional manufacturing and service; moreover, they will become more and more important for current manufacturing industry. CAD-based RP&M systems have been developed and employed to implement remote products and manufacturing for rapid prototyping, enhance the availability of RP&M facilities and improve the capability of rapid product development for a large number of small and medium sized enterprises. This paper reviews the state-of-the-art in CAD-based RP&M systems. The future improvement tasks for the systems should further focus on the following aspects: In a collaborative environment, the integration and interoperability can enhance the competitive advantages of RP service. Therefore, the integration and inter operability in CAD-based RP&M systems is an important issue. CAD services represent a step forward in enabling collaborations between various entities on the design and in overcoming the scaling problems that may appear. CAD services technique may provide a solution for this issue. Some new technologies and concepts such as, STEP, XML; provide effective enabling tools for software-based application systems. Future research and development on CAD-based RP&M systems should be based on these new technologies and concepts, in particular 3Dprinting, NCDS. Further research will be focused on concurrent process for RP and RT, optimizing external manufacturing resources. CAD-based design and manufacturing system is a new product mode in term of mission, structure, infrastructure, capabilities, and design process. The significant contribution of this paper is to present a comprehensive review of recent advances in CAD-based RP&M systems, and discuss the future research directions. That may provide a reference and direction for the development of CAD based RP&M systems. Although CAD-based technologies have been applied to collaborative product design and manufacturing for many years, real industrial applications have not been in place yet. As one of the most typical cases for CAD-based collaborative product design and manufacturing system, CAD-based RP&M system has shown a promising prospect for manufacturing. However, there is still a long way for really commercial application of the CAD-based RP&M systems.

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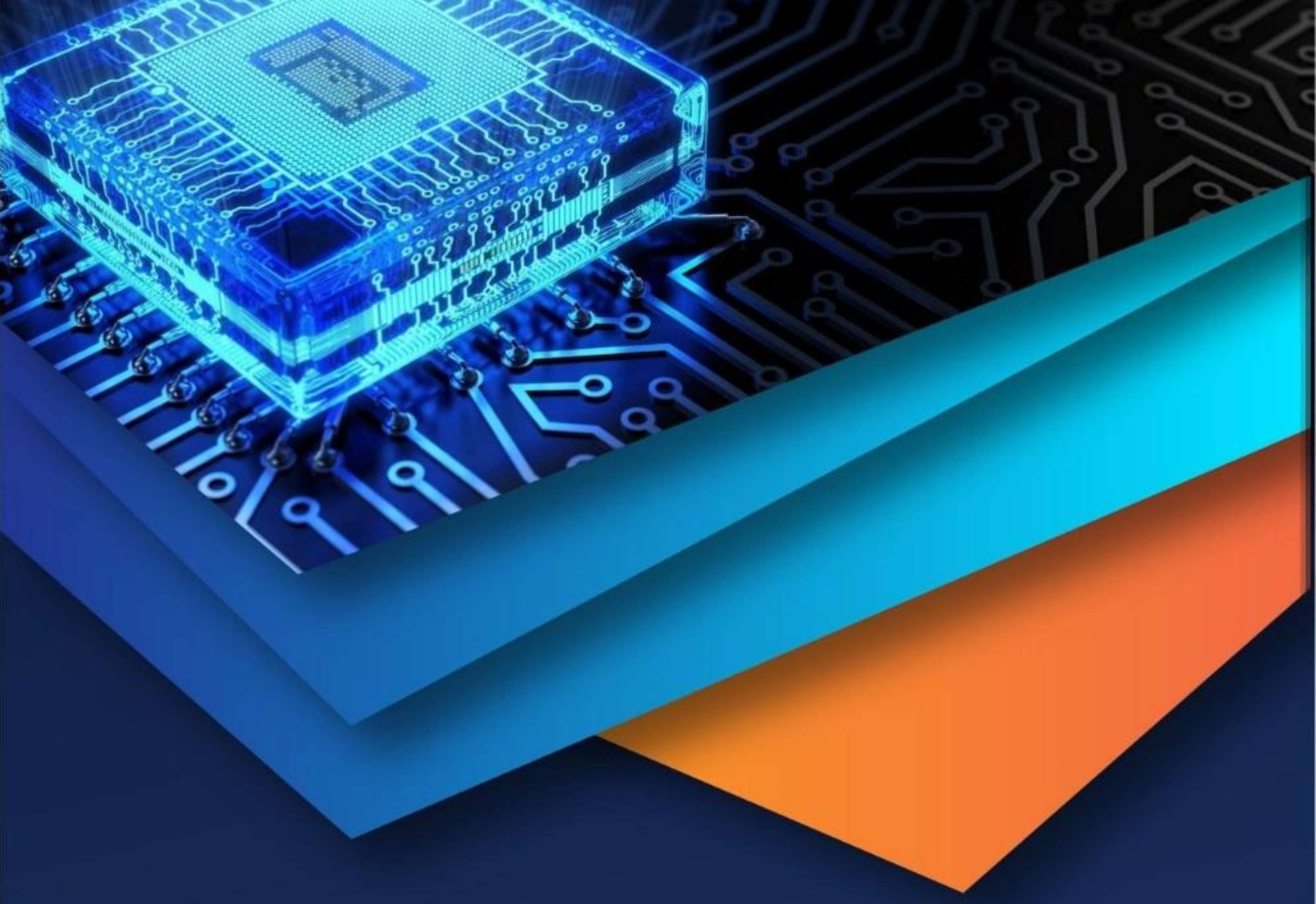

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