RAPID PROTOTYPING: A GLOBAL VIEW

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ABSTRACT

Rapid prototyping technology is advancing at a tremendous rate. Much of this progress is due to research being conducted within academic institutions and industry throughout the world. The USA is leading the research community in this field but a significant contribution is coming from Europe, Japan and elsewhere. The primary aim of this paper is to give a worldwide overview of current research activity and initiatives. Hopefully, this will enable researchers to see where their own work fits into the global picture. If this leads to increased co-operation and a reduction in duplication of effort, then an even faster rate of advance should be attainable.

INTRODUCTION

Rapid prototyping (RP) is one of the fastest developing manufacturing technologies in the world today. In less than ten years it has grown from a single system sold by one company to a point where over a dozen different systems are sold commercially, research is being conducted in virtually every industrialised country and hundreds, if not thousands, of academics and industrialists are actively involved in developing RP technology. This exponential rate of growth makes it virtually impossible to remain informed about research in our own country, never mind the rest of the world.

The aim of this paper is to give a brief overview of what is happening in RP research outside of North America. (The author has assumed that information on North American research is readily available to most symposium attendees.) The majority of the research work discussed in this paper has been conducted in Europe. In Japan, the other major area of activity outside the USA, research is mainly undertaken by system vendors who do not readily publish their work. It cannot be claimed that this paper is an exhaustive review of the subject but it will hopefully cover enough developments to be both informative and useful. The paper begins by looking at various areas of RP research activity, goes on to list research initiatives and finishes with some conclusions that can be drawn from this overview.

RESEARCH ACTIVITIES

Much of the research in the field of RP is the area of applications, i.e. finding new products or industries to which the technologies can be applied. However, this type of research is often at a fairly low level and is considered outside the scope of this review. The research activities reported here are those aimed at advancing RP technology rather than using existing technology for a new purpose.

RP Data Preparation and Verification

This research addresses the "upstream" aspects of the RP process, i.e. preparation and verification of the data within the CAD system and the exchange of data to the RP system. At Helsinki University of Technology in Finland, researchers are developing software to verify and, if necessary correct, STL files that have been created for RP processes[1]. This software searches for incorrectly defined facets and uses topological algorithms to redefine them. This is one method of overcoming problems in what has become the RP industry exchange standard. A RP bureau in Belgium called Materialise have decided to follow a different strategy. They have developed a suite of software modules to work with the alternative exchange formats that use contours or profiles rather than triangulations[2]. These modules can convert data from one format to another, check for errors in contours (e.g. gaps, overlaps) and automatically correct them, allow manual error correction and automatically generate supports for a contour file.

A related area of research is prediction of RP build times. When presented with an exchange file, it would be useful for the RP machine operator to know how long it will take to build the part. At the Queensland University of Technology in Australia a software program called SLICER is being developed to do precisely this for an SLA 250 machine[3]. The program works by loading an STL file, slicing this file into layers and calculating the build time for each layer. The program takes account of laser scanning speed and pattern. The predicted times are currently well below actual build times. This has been attributed to the UV laser irradiance distribution not being truly Gaussian in nature. Work is continuing with the aim of modifying SLICER to take account of this factor.

Photo Polymerisation Process Development

Many research establishments have recognised the limitations of photo polymerisation in terms of part accuracy and distortion. Projects aimed at understanding and overcoming these problems are in progress both in Europe and Japan. The Fraunhofer Institut fur Produktionstechnologie (IPT) at Aachen in Germany has been conducting experiments over the last two years aimed at determining the influence of process parameters upon stereolithography part quality[4]. They have shown that part distortion can be reduced through optimised exposure techniques (e.g. using cells) and scanning strategies (e.g. checker-board scan). A similar investigation has been conducted into the accuracy of parts produced by the solid ground curing process at the SINTEF Institute Trondeim in Norway[5].

In Japan, much of this line of research is conducted by commercial system vendors who keep their results confidential. However, projects on stereolithography part accuracy have been undertaken in Tokyo and Hokkaido Universities. In Hokkaido, many aspects have been investigated including measurement and prediction of solidified unit shape, shape deformation analysis and analysis of laser optics with regard to spatial power distribution[6].

Other interesting photo polymerisation developments include the use of stereolithography for microfabrication. The Kyushu Institute of Technology in Japan have been using an ultraviolet lamp with a spot size of 5µm and positional accuracy of 1µm. They have been able to produce components in polymer and metal (using investment casting) with feature sizes of around 50µm[7].

At Osaka Sangyo University a high power CO_2 laser with a spot size of 50 to 60µm is being used to cure an epoxy-cationic resin loaded with carbon powder[8]. Using this configuration it is possible to obtain a deep and narrow solidified unit shape. This has the potential of delivering a faster and more accurate system than those currently available.

Beam interference or biphotonic polymerisation is a development of standard photo polymerisation. Instead of a single laser beam scanning in 2d to create solidified layers, two laser light sources are directed to interfere with each other anywhere in 3d space within a vat of resin. Thus a 3d object can be built in situ without the need for incrementing a platform between layers. A joint project between the Institut Polytechnique de Sevenans and the Laboratoire Apolo in France aims to develop such a system[9]. The approach they are pursuing is to use a mercury lamp to provide a "layer" of horizontal light and a He-Ne laser to provide a focused vertical beam. The resin used will only polymerise when both light sources are present.

Laser Fusion Process Development

Much of the process development research for laser sintering is aimed at producing metal components. At IPT in Germany a 300W Nd:YAG laser has been used to sinter both high and low melting point metal powders (stainless steel and bronze nickel)[10]. They have also been working with laser generation (see below) and have been drawing comparisons between the two processes. Important differences identified are in surface roughness and internal crystalline structure. To underline the imminent arrival of a commercial metal sintering process, the German company EOS have been using their EOSINT machine to sinter a low melting point alloy powder without polymer coating or pre-heating[11].

Laser generation or laser cladding involves directing a high power laser onto the part being built and, simultaneously, feeding a cladding material in the form of powder or wire directly into the laser spot on the surface of the part. By moving the laser and feed with respect to the part it is possible to lay down tracks and create a 3d shape. IPT have been applying this technique since 1993 and have created a range of fairly simple parts. Using a 700W CO_2 laser with a cobalt-based alloy, accuracies of +/- 0.1mm and surface finishes of 50µm have been achieved[12]. Research into laser fusion is also being conducted at Stuttgart University in Germany. The Institute for Polymer Testing and Polymer Science have developed a process called laser aided powder solidification (LAPS)[13]. There are two versions of this process, one uses a powder jet and the other a powder bed. The second version is very similar to laser sintering.

Bead Deposition Process Development

Research into use of metals for bead deposition is also in progress. At Nottingham University in England a 3d welding process is being used to create steel and aluminium parts[14]. A MIG welder has been attached to a programmable robotic arm which builds the part one layer at a time. At present, the process creates a poor surface finish but a major EU funded programme commenced in 1993 with the aim of optimising system parameters to resolve this problem.

A joint project between the Fraunhofer Institute for Applied Materials Research (IFAM), Bremen and the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart in Germany has developed a bead deposition process known as Multiphase Jet Solidification[15]. This process uses a heated extrusion head (70 to 220^{o}C) which can create metal or ceramic parts. For low melting point metals such as tin-bismuth alloys, the material is deposited directly. For high melting point metals and ceramics, a mixture of powder and binder is used. This creates a "green" part which subsequently has the binder removed and is then sintered resulting in around 30% shrinkage. The advantages claimed for the system are the wide variety of possible materials and the simplicity of the apparatus.

Sheet Lamination Process Development

For this technique, once again research into the use of metals is in progress. At Dundee University in Scotland a 1000W CO_2 laser is being used to profile cut sheet steel of 1 or 2mm thickness[16]. Currently, the profiles are manually stacked and bonded using solder or adhesive. Advantages claimed for this process over other proposed metal RP systems are low cost of material and the ability to produce overhangs without supports.

RESEARCH INITIATIVES

There are a number of national, continental and global RP research initiatives that are being funded by governments and/or industry. The general aim of these is to promote collaboration between academic and industrial partners to enable advances in RP technology. Several of these initiatives are outlined below.

Australian Initiative

In 1991, the Queensland Government Department of Business Industry and Regional Development identified RP as a technology that was vital to local industry[17]. As a result, it has set up a network within six educational establishments to encourage research into RP and dissemination of knowledge to local companies. Each institution has been provided with a CAD/CAM workstation and access to an SLA 250 machine. This facility can be used for the education of undergraduate engineers, for research projects or as a low-cost bureau service for industry. This approach has proved so successful that the network has been able to provide support to industries across the whole of Australia and beyond.

Japanese Initiative

In Japan most research is undertaken by the RP companies and government support has not been extensive. However, this year the Japanese government is expected to begin funding a four year research project concentrating on the areas of data transfer, fundamentals of resin solidification and applications of stereolithography[18]. The total funding for the project will be in the order of 800m YEN. Once again, most of the research will be conducted within industry rather than academia.

European Initiatives

A project entitled the European Action on Rapid Prototyping (EARP) has been initiated by the Danish Technological Institute using funding from the EU Brite EuRam programme. Its partners are drawn from both industrial and academic establishments researching in the field of RP. Amongst the project objectives are the provision of a forum for information exchange, the encouragement of co-operation and the identification of new areas for research and development. EARP has five work areas:-

- Creative Design and Product Development
- Model and Prototyping
- Tooling
- CAD and Software
- Medical Applications

The project commenced in early 1993 and will run for three or four years.

Several other European RP research projects are being funded through the Brite EuRam programme[19]. These include leadtime reduction, spray-forming tooling, RP for the automotive industry, RP models from medical images, RP for short-run injection moulds, development of laser sintering and RP of metal components. Each project involves a consortium of academic and industrial partners with one partner undertaking the role of co-ordinator.

Another EU funded initiative is the SPRINT programme aimed at evaluating the current Europe-wide capability for producing tooling using RP techniques. It takes the form of a survey of all RP facilities in Europe and the result will be a public report detailing the technologies that are available, the organisations using these and the feasibility of creating RP parts in the correct production material.

Nordisk Industrifond has given a grant to a consortium of companies and institutes from Norway, Sweden, Finland and Denmark for a project entitled "Layer Manufacturing as a Tool for Reduction of Product lead Time"[20]. The 2 year project has just started and will concentrate mainly on the impact that RP can have on casting technologies.

Global Initiative

The Intelligent Manufacturing Systems (IMS) programme was established with the aim of conducting international pre-competitive R&D in advanced manufacturing[21]. Six regions are participating in IMS namely Australia, Canada, European Union, European Free Trade Association, Japan and the USA. A test case on Rapid Product Development was initiated during 1993 along with five others to ascertain the feasibility of co-operation on this world-wide scale. Part of the test case was a capability assessment of commercial RP technologies using two test parts. The fact that RP was chosen as one of the key areas to be addressed by this major international programme indicates the high profile it has already gained within manufacturing industry around the world.

Rapid Prototyping Associations

Throughout the world, users of RP technology are recognising the benefits of co-operation and dissemination of knowledge. This has resulted in the formation of RP user associations. Although these associations cannot be classified as research initiatives, they do share some of the same aims. They promote collaboration between academic and industrial partners and provide a forum for sharing information on RP technology and applications. In recent years, several national RP associations have been formed. These include the Japanese Rapid Prototyping Industrial Association, The UK Rapid Prototyping and Manufacturing Association and the Association Francais de Prototypage Rapide. There are also plans to establish an Australian Rapid Product Development Consortium[22] to help co-ordinate RP research activities in that country.

CONCLUSIONS

The activities reviewed in this paper show that researchers outside of North America are making a significant contribution to the advance of RP technology. Centres of excellence are emerging such as the Fraunhofer institutes in Germany. A major theme of research in Europe is the development of RP systems for metal components. In Japan, most work is directed at improving the photo polymerisation technique. The use of lasers figures highly in much of the research, with high power lasers playing an increasingly important role. Governments are recognising the strategic implications of RP technology and are supporting research through various initiatives. This is especially true in Europe where a number of different funding programmes have been established. Finally, world-wide co-operation on RP research has only just begun with the IMS Rapid Product Development test case. The opportunities for developing symbiotic links are there and must be taken if RP technology is to advance at its maximum potential rate.

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