

The Development of Internet accessible Rapid Prototyping System

Ren C. Luo, Wei Zen Lee, Jyh Hwa Tzou, and Hou Tin Leong

Intelligent Automation Laboratory

Department of Electrical Engineering, National Chung Cheng University

160 Shang-Shing, Ming-Hsiung, Chia-Yi, Taiwan 621, R.O.C

Email: luo@ia.ee.ccu.edu.tw, wlee@ia.ee.ccu.edu.tw

<http://www.ia.ee.ccu.edu.tw>

Abstract

Automated tele-control of Rapid Prototyping Machine via Internet for the application of tele-manufacturing system is presented. The main features of this system are that users just need a general-purpose computer and a World Wide Web browser, for commanding the rapid prototyping machine in a remote location through Internet and Home Page. Hardware configuration of this architecture includes a thermal extrusion based layer-deposition rapid prototyping machine and several controllers, each of them is able to communicate with others via computer network. Software design includes the user interface, model slicing process, model support generation, and tool path generation. The system has extensive capabilities for teleoperation and other multimedia services. The system allows users to directly control our rapid prototyping machine via the Internet and access our Home Page through a friendly user interface. Also the remote user can receive real time images e.g. the completed rapid prototyping model parts captured by a CCD camera that is mounted on the rapid prototyping machine.

Introduction

Various remote control systems had been performed for manufacturing, underwater manipulation, space exploration, satellite repair [2-3], etc. The control commands and remote sensing measurements.

As mentioned previously, RP machine becomes a powerful tool for increased productivity, however, rapid prototyping machine is still too expensive to offer many companies. Therefore, it can be very useful and effective if we can let RP manufacturing to the universal access via Internet and make prototype production cheaper and easier. The key feature of this system is to make it transparent and simple enough to give users good results each time [4]. User can upload STL (stereolithography Interface) files of models they

have designed to our WWW server remotely. There are several pre-processes need to be performed before building up model, which include model slicing, support creating, and the working path generation for the rapid prototyping machine. After completing these pre-processes, user can send a model building command to the server and the server can then control the rapid prototyping machine to build up a physical model locally. When the RP model is completed, the remote user can examine the RP model through live image via Internet transmitted from the CCD camera mounted on the RP machine.

2. Hardware System Configuration

The hardware system configuration of this system, as shown in Figure 1, includes thermal extrusion based Rapid Prototyping machine developed in the Intelligent Automation Lab at National Chung Cheng University, the WWW server, CCD cameras and remote computer accesses, several computers.

The Rapid Prototyping machine uses ABS powder as object building material. The main features of this system are to build up a physical object model through the deposition of filling materials extruded from the thermal barrel and processed layer by layer.

A general-purpose computer is used as a server which receives client's request from remote world wide network. World Wide Web users can use IBM PC, Macintosh, workstation, etc to communicate with the server via Internet.

2.1 Brief Description of The Thermal Extrusion Based Rapid Prototyping Machine

The basic hardware configuration of the Rapid Prototyping machine structure are illustrated in Figure 2. It includes three independent axes working table, a thermal extrusion head, a temperature control system,

and a PC-based control system. XYZ Three axes are equipped with high precision ball screw and are driven through AC servomotor.

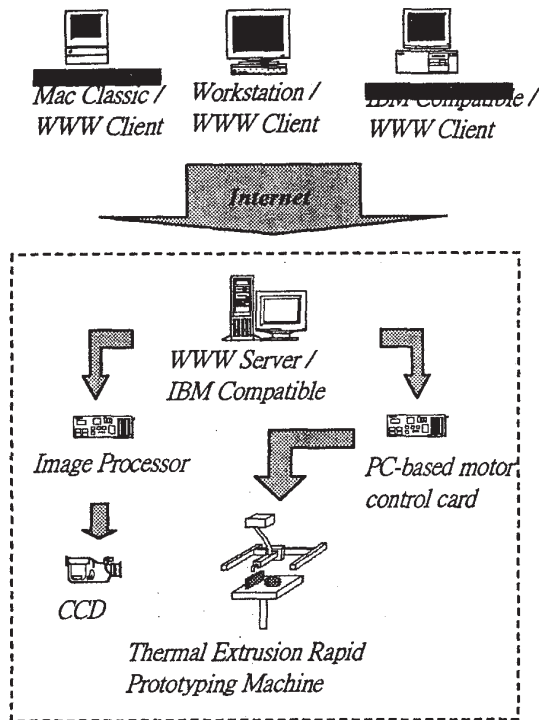


Figure 1. The Hardware Configuration of The Automated Tele-Manufacturing System.

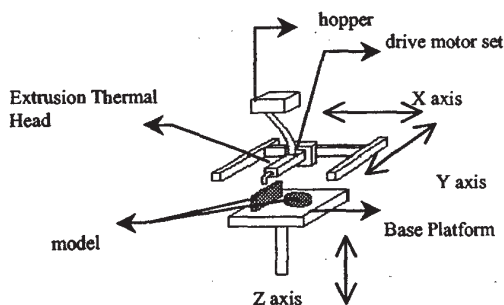


Figure 2. The Configuration of the Thermal Extrusion Based Rapid Prototyping System.

In order to mechanically build-up each successive layer, three AC servo motors are provided to selectively move the base platform and the thermal extrusion head relative to each other in a predetermined pattern along "X" and "Y" axes while the model building material is

being thermally extruded. Relative vertical movement along "Z" axis is carried out after the completion of each layer to achieve desired layer shape and thickness.

2.2 Motion Control System

We have used a PC-based motion control card to control the 3-axes motion of the working table of the RP machine. It consists of an intelligent motherboard populated with four intelligent plug-in function modules. There are on-board linear interpolation, circular contouring, and continuous path motion functions and dual-ported memory for high-speed communications.

2.3 Vision System

The vision hardware consists of an onboard image processor and a single camera mounted in Rapid Prototyping machine. The image processor is a 50MHz TMS320C44 DSP and it has a PCI supporting bus master mode for fast data transfers to the host PC. It allows us to perform all the computation of vision program on board. As a result, the vision algorithm will not occupy the time of main processor system.

3. Software Design

Based on the hardware configuration, software design of the system consists of the assignment of the server, communication between WWW Server and Rapid Prototyping Machine, and the user interface.

User just need to upload STL file of CAD model from remote site to our server. The STL file which is a standard format for transferring the CAD data to rapid prototyping machines uses a faceted description of the computer model. The STL file is a list of triangular facets representing the surfaces of the object to be built together with a unit normal vector associated with the outer surface of each triangle.

Our Rapid Prototyping machine requires that physical model be stabilized during layer fabrication to prevent the distortion of unsupported areas. Therefore, the fabrication processes require that a separate support structure be designed, added to the model geometry file, and then fabricated as a part of the physical model concurrently.

To start the model building process the three dimensional representation of the object

are converted into a series of thin cross sectional layers by intersecting a series of planes with the STL file representation in a process called "Slicing". Each two dimensional cross section is a set of closed areas that must be filled with a solid material. A physical model is formed by sequentially building and stacking the thin two dimensional layers to form a complete three dimensional object.

The motion control consists of Applications Programming Interface (API) which provides a high level function call interface to PC-based motion control card. The API can be programmed in C or C++.

3.1 Assignment of the WWW Server

The WWW server is responsible for the commands sent from remote user and call the CGI (Common Gateway Interface) programs correspond to the receiving command. The CGI programs is then executed to transmit the related commands to the RP softwares, such as slicing, support creating, path generation program, and motion control of rapid prototyping machine. During the model building process and after the completion of the physical RP model, the sever can transmit the image data through Internet to the remote Web browser.

3.2 User Interface

The user interface is shown is Figure 3 captured from a Web Browser of Microsoft Internet Explorer when we perform remote control via a LAN (Local Area Network). There are four major parts in the interface, which include Homepage Title, Model STL file or Slicing Illustration, Process Control Window, and Estimate Building Time of Physical Model. There are six hyperlinks which include Upload .STL File, Support Creating, Slicing .STL File, Generate Machine Working Path, Build up Physical Model, and Show Image of the Physical Model in the Process Control Window. The Flow Diagram of the remote control system is illustrated in Figure 4.

First, user clicks the hyperlink of Upload STL File and it links to a program, which will ask user to upload a STL file format and save it in the hard disk of the server. Then the STL file will be illustrated in left window of the interface. User can orient the STL file with moving, rotation or scaling commands and the illustration of STL file will be refreshed by the orienting.

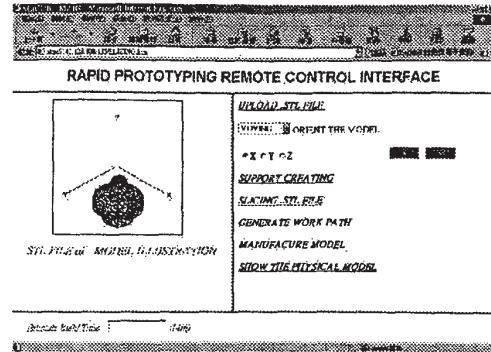


Figure 3. The User Interface for Remote Control of Rapid Prototyping System.

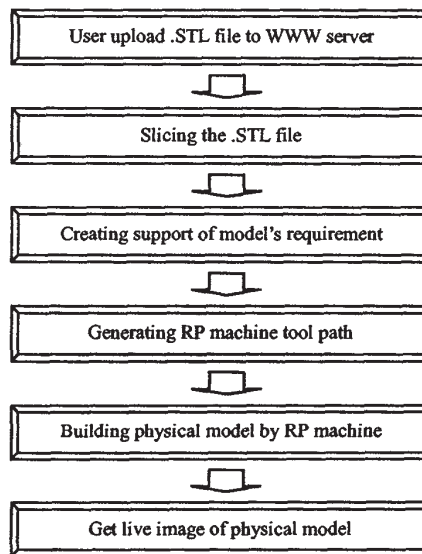


Figure 4. The Flow Diagram of the Remote Control for the Rapid prototyping System Flow Diagram.

When user click the hyperlink of Slicing .STL File, it links to a program which will analyze the STL file part which defines the model to be fabricated and slices the model into layer cross-sections. Each slice consists of one or more curves that follow the shape of the part at the particular height. The description of the slicing algorithm is briefly described in Section 4. The illustration of the STL file slicing illustration will be displayed in the left window of the interface.

User clicks the hyperlink of Create Support of Model and it links to a program, which can generate support required to build the physical model.

After performing Support Generation, user clicks the hyperlink of Generate Machine Tool Path and it links to a program, which makes up extrusion head's tool path which can fill the cross-section boundaries. The working path data and extrusion of the thermal extrusion head will be saved as a file. The program will also estimate building time of the physical model. Building time will be displayed in the bottom window of the Interface.

When user click the hyperlink of Build up Physical Model and it links to a program, which includes the motion control API for the motion control card. It will read the working path file and control the motion of the rapid prototyping machine.

User can click the hyperlink "Show Image of the Physical Model" and it will link to a CGI program. This program can show live images captured by the CCD in our rapid prototyping machine. And the image can be displayed in a new web browser. User can examine the physical model through the image display remotely.

4. Slicing Algorithm

The cross section boundaries required for the rapid prototyping process are generated from intersecting a plane with the STL file object. This is generally referred to as the slicing process. From a geometric modeling perspective, the intersection process should result in the formation of a boundary representing the wall of the object at that layer.

The slicing algorithm works as follows. The layers are defined as the geometric intersections of planes horizontal to the platform of rapid prototyping machine with object. As the plane moves up from the base of the object, successive layers are defined and the thermal extrusion head traces out a contour defining the cross section on each layer. Basic analytical geometry is used to determine the intersections, which are then stored in a dynamic array. Each facet that intersects the plane will form a directed line segment on the planar slice. These intersection lines will define the contour. The intersections are not found in any particular order, so the vectors must now be sorted in head-to-tail fashion in order to derive a closed contour on that slice.

5. Tool Path Generation

The generation of the tool path is the final

stage before fabricating the part. The first step in the process of generating the final tool path is to define a general path pattern; there are three types of tool path patterns: Linear, Zig-Zag and Spiral (Figure 5)

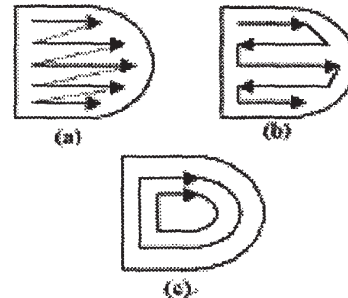


Figure 5. Three Types of Tool Path. (a)Linear; (b)Zig-Zag; (c)Spiral

[Tool Path Algorithm] Generation of Zig-Zag tool path

- (1) For each layer, put its contour edges in a single list.
- (2) For all contours in one layer, we define x_{min} as left boundary and x_{max} as right boundary. Make a set of successive infinite parallel lines in the region of $[x_{min}, x_{max}]$. The distance of the parallel lines is equal to the diameter of the deposited material(d).
infinite parallel lines: $x = x_{min} + d \cdot i$
where
 $x_{min} \leq x \leq x_{max}$
 $i \in \text{integer}$
- (3) Generate intersection points by intersecting the contours with the infinite lines. The used_flags of all intersection points are set to be "False".
- (4) After read in the intersecting points of intersecting zone #i, we define the intersecting points as $P_{i1}, P_{i2}, \dots, P_{in}$ by its value of y coordinate.
- (5) From the result of observation, we find $\overline{P_{i1}P_{i2}}, \overline{P_{i3}P_{i4}}, \dots$ are working segments and $\overline{P_{i2}P_{i3}}, \overline{P_{i4}P_{i5}}$ are not working segments. So we get the following result:
The working segments :
 $\overline{P_{i(2k+1)}P_{i(2k+2)}}, k=0,1,2, \dots$
- (6) From the left boundary of working segments, we first connect $\overline{P_{11}P_{12}}$ in intersecting zone #1. If there is a point P_{22} (in intersecting zone #2) on the same contour with point P_{12} , connect $\overline{P_{12}P_{22}}$ and then $\overline{P_{22}P_{21}}$. Following this procedure, we can

connect the intersecting points in the same working area with Zig-Zag tool path. Until there is no adjacent point on the same contour, working area 1 is discovered. [see Figure 6(a)]

- (7) If not all the intersecting-zones are processed, point to the next intersecting-zone and find Zig-Zag tool path of the next working area as step 6. Otherwise, carry out the next step.
- (8) Set the used_flag of the connected points as "True". If not even one single working area is found, terminate the procedure. Otherwise, read in the intersecting-zones from the very beginning and start a new working area.

The final results of working areas are shown in Figure 6(b).

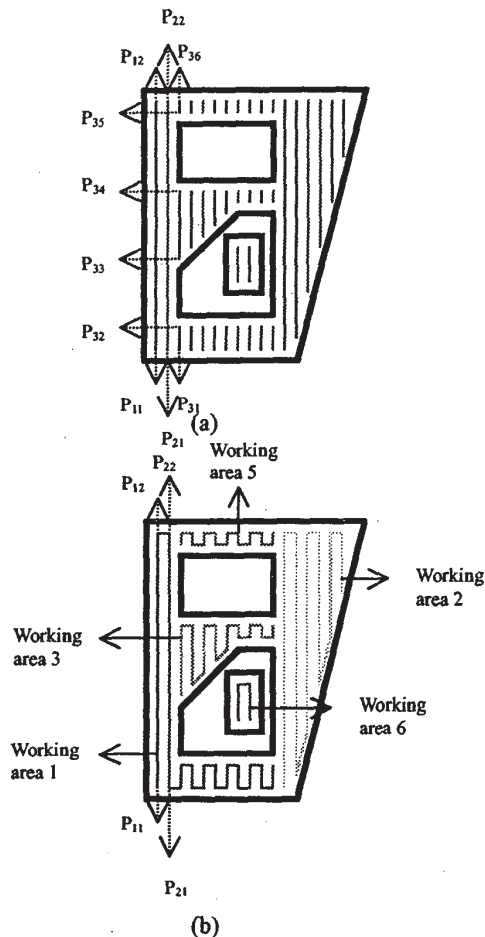


Figure 6. Tool Path Generation Process

6. Experimental Implementation:

To demonstrate the concept, we have created a 3D model with a CAD software-

PRO/ENGINEER, and exported it as a STL file. It is shown in Figure 7.

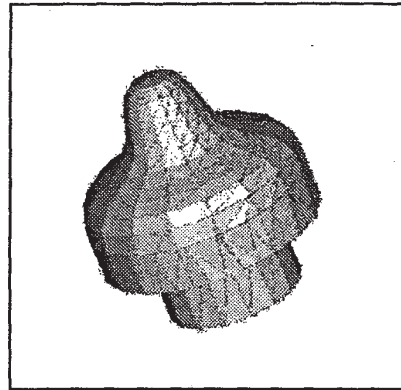


Figure 7. A Model of STL Format .

Then we upload the file to WWW server of remote control interface. It is shown in Figure 3. The model of STL file is shown in left window of the interface. Slicing Process can analyze the model part that defines the model to be fabricated and slices the model into layer by layer cross-sections. Since the model needs support to avoid model structural fail or collapse, support creating process can generate support during model building process. The cross sections are shown in left window of the interface as shown Figure 8.

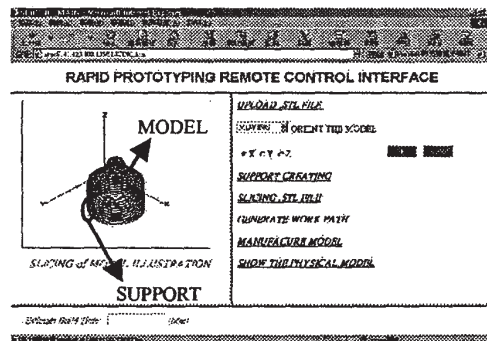


Figure 8. Illustration of Model Slicing.

Then the Generate Machine Tool Path Process generates the Tool path and extrusion of the thermal extrusion head. Those data will be saved as a file. When the re-process finished, the server sends command to control the rapid prototyping machine to build up physical model. We can get a live image of physical model in

rapid prototyping machine by CCD as shown in Figure 9.

When the model is completed, we can remove the support part and get the physical model as shown in Figure 10.

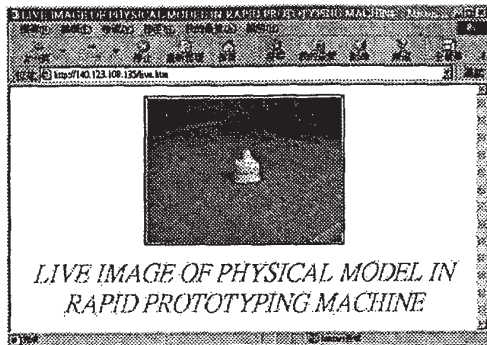


Figure 9. A Live Image of Physical Model in Rapid Prototyping Machine.

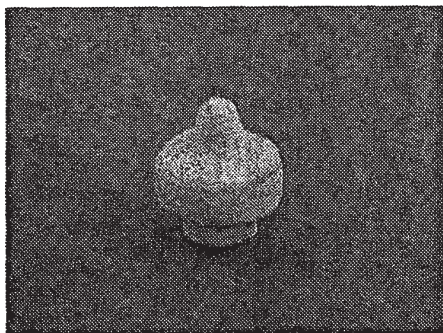


Figure 10. Completed Physical Model.

6. Conclusions

Rapid prototyping system has been used for a variety of applications extensively. The remote control system has proven itself as a feasible and useful tool to share our rapid prototyping machine with others via Internet. Through the World Wide Web browser one can directly build a physical model with rapid prototyping machine, and receives the live images of the physical model in the rapid prototyping machine.

The main features of the system can be described as follows:

1. A Rapid Prototyping machine can be shared and accessed through Internet to

reduce the capital investment on expensive RP machine.

2. No restrictions of computer platform on remote user site.
3. The client will need only 3D CAD software and WWW browser on the client site to create a 3D model as STL file, no special software is required.

Reference

- [1] Chua Chee Kai, "Three-dimensional rapid prototyping technologies and key development areas", IEE Computing & Control Engineering Journal, pp. 200 ~ 206, August 1994.
- [2] Hagen Schempf, "Neptune: Above-Ground Storage Tank Inspection Robot System", Proceedings 1994 IEEE International Conference on Robotics and Automation, vol.2, pp. 1403~1408.
- [3] Lynn Conway, Richard A. Volz, and Michael W. Walker, "Teleautonomous System: Projection and Coordinating Intelligent Action at a Distance", IEEE Transaction on Robotic and Automation, Vol. 6, No. 2, pp. 146~158, April 1990.
- [4] Michael J. Bailey, "Tele-Manufacturing: Rapid Prototyping on the Internet", IEEE Computer Graphics and Applications Journal, pp.20~26, November 1995.
- [5] Ya Wei Ma, "Representation and Slicing of Freeform 3-D Geometric Models for Desktop Prototyping and Manufacturing", A dissertation submitted to the Graduate Faculty of North California State University, 1995.
- [6] Jerome L. Johnson, *Principles of Computer Automated Fabrication*, Palatino Press Inc, 1994.
- [7] Y. Koren, C. C. Lo and M. Shpitalni, "CNC interpolators: Algorithms and Analysis", Manufacturing Science and Engineering, PED-VOL. 64, ASME, 1993