

Process Control System for a High Temperature Workstation performing the Selective Laser Sintering Process

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Abstract

This paper describes the design and implementation of a Computer Process Control System for a High Temperature Workstation performing Selective Laser Sintering of metal and ceramic powders. As compared to our previous machine [1], the increased complexity and sophistication of the new workstation [2] requires a variety of measurement and control devices which are interfaced to a process control computer. Among these are a gas analyzer, a data logger, a step motor controller and a CNC controller. This process control system incorporates a XView (a X Window System Toolkit) based Graphical User Interface which allows the user to set and change process parameters on-line as well as receive graphical feedback on the process.

Introduction

The Selective Laser Sintering (SLS) Process has made much progress since its first demonstration in 1986 [3]. With the objective of sintering metals and ceramics, the Solid Freeform Fabrication group at the University of Texas at Austin acquired a 1.1 kW CO₂ laser in September 1991. Design and Fabrication work on a High Temperature Workstation (HTW) to serve as the testbed for SLS of metals and ceramics was begun in June 1991 [2,4]. The construction of the first version of the HTW was completed in Fall 1991 and experimental tests on a variety of metal powders and ceramics were initiated in November 1991. This sintering chamber incorporated a powder delivery system and a work area for the laser scanning. A second chamber has been constructed to continue work towards the next stage of research (i.e. high temperature, high laser power sintering) . This chamber incorporates a powder heating and temperature control system and a strict environment control system [5]. This paper describes the Computer Process Control System that runs the SLS process on the HTW .

Design Objectives

Platform

In contrast with our previous SLS machine, called "Bambi", which uses an IBM PS-2 running MS-DOS as its process control computer, the SFF group decided to adopt the Unix Operating System for process control in the High Temperature Workstation. This choice is justified by several reasons. First, it provides us with multitasking capabilities, standard networking and file-transfer protocols and X as the Window system. This choice was also dictated by the desire to have two similar computing environments, one to be used for SLS software development and the other to be used purely to run the HTW.

Process Control

One of the design objectives at the start of the Selective Laser Sintering project was to design a fully automated machine which could be used for rapid part fabrication. The operation of this machine should require minimum human intervention and expertise. With

this goal in mind, the function of the Process Control System is to automate all aspects of the operation of the High Temperature Workstation, including geometry data processing, laser and scanning system, powder feed and leveling system, temperature data logging, monitoring sintering chamber environment composition and pressures, and safety procedures such as machine shutdown in the event of abnormal conditions.

Graphical User Interface

Another design objective of the Process Control System for the HTW was to present the user with a simple menu-driven graphical user interface to operate the machine. This user-interface should allow the user to enter process parameters such as part side drop and feed side rise, delay between successive scans and repetition of layers. The interface should also allow the user to interrupt the process, change process parameters and continue the process. The interface should include process monitoring features that provide the user with a graphical feedback on the status of the process. The graphical feedback should include a display of the current layer scanned on screen, reporting of various sintering chamber temperatures obtained from a datalogger and the composition of the chamber's environment obtained from a Residual Gas Analyser.

Design Features

Platform

A Sun Sparcstation IPC was chosen as the Process Control Computer. This choice provided binary compatibility as well as file sharing capability with the Sun Sparcstation 2GX being used for software development and testing purposes.

Process Control

The process control computer functions as a system integrator by handling all communication with the various control and measurement devices. This design centralizes the feedback from these devices and allows user control over them via a menu-driven interface. Figure 1 shows a schematic of the Process Control System in the High Temperature Workstation.

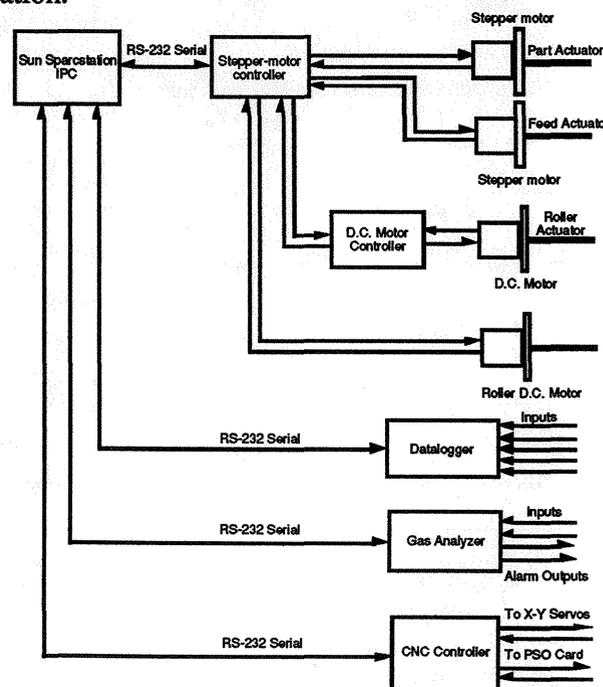


Fig. 1 A schematic of the HTW Process Control System

Laser Scan Control by CNC

The scanning system for the 1.1kW Everlase CO₂ laser on the HTW consists of a set mirrors mounted on a pair of X-Y linear motion tables. The motion of the X-Y tables is controlled by an Aerotech Unidex-21 CNC controller with a position accuracy of 0.001" over a travel of 12" in either direction. The motion tables are capable of scan speeds of upto 20 inches/sec. In order to perform raster scans, the CNC controller incorporates a Position Synchronous Output mechanism that ties the laser beam switching to the linear position encoders of the motion tables. The scan data is expressed in the form of a sequence of laser-off and laser-on distances (expressed in microns) for each scan-line. The scan data is sent from the process control computer to the CNC controller on a layer-by-layer basis. The CNC is interfaced to the process control computer via a serial RS-232 interface.

Powder Delivery and Leveling System

The powder delivery and leveling system consists of a pair of cylinders, a pair of pistons and a leveling roller (Figure 2). The pistons are actuated by a linear-actuator/stepper-motor combination. The roller is mounted on a linear-actuator that traverses the length of the powder bed. Rotational motion is delivered to the roller by a D.C. motor through a set of bevel gears and a flexible shaft. The leveling sequence consists of a sequence of motions of the piston actuators, the roller actuator and roller rotation, and is controlled by a stepper-motor controller and a set of relays. The stepper-motor controller receives commands from the process control computer via a serial RS-232 interface.

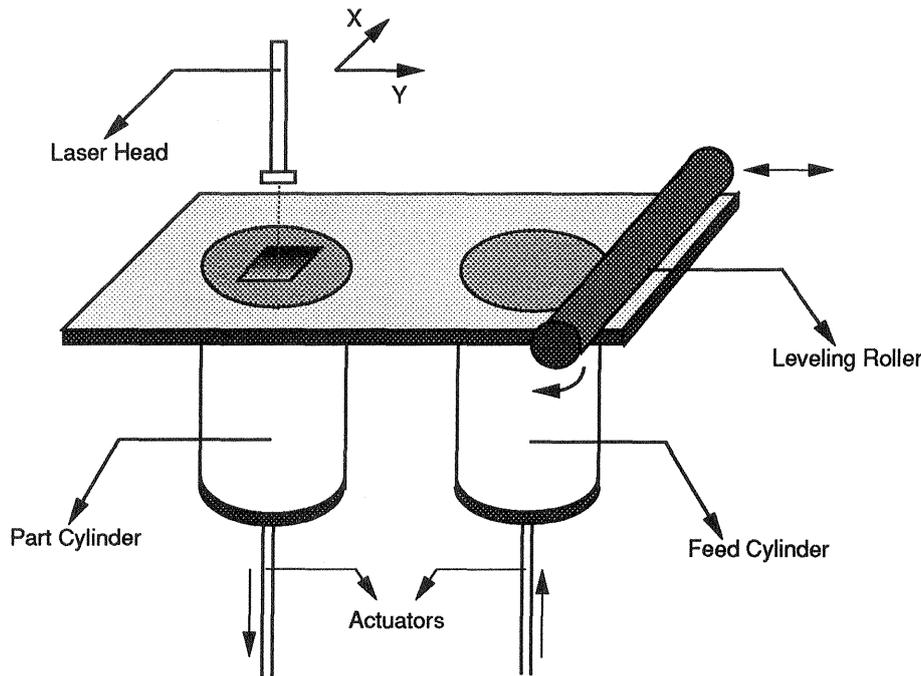


Fig 2. A schematic of the Powder Delivery and Leveling System

Gas Analyzer

Selective Laser Sintering of metals and ceramics requires monitoring the gaseous composition of the sintering chamber for two reasons. First, Oxygen content must be monitored for safety purposes, to prevent the possibility of explosive reactions. Second, the gaseous composition must be known during layer-wise gas-phase materials processing which is a future possibility. A Residual Gas Analyzer is employed for these purposes. The Gas Analyzer has an alarm output that goes high when a preset oxygen concentration is exceeded and sets on a relay which closes the shutter in the laser, thereby preventing the

laser beam from reaching the powder bed. The gas analyzer receives commands from the process control computer and sends data back to the computer via a serial RS-232 interface.

Datalogger

High-temperature high laser-power selective laser sintering of metals and ceramics necessitates the monitoring of temperatures at various points in the chamber, on the powder bed and at the heater surface, to provide a uniform temperature distribution across the powder bed [5]. A datalogger is used for this purpose. This datalogger used for this purpose is capable of receiving sixteen analog inputs and four digital inputs as well sending 16 digital alarm outputs. The datalogger reports the various temperatures to the process control computer via a serial RS-232 interface. Along with the temperature, the data sent by the datalogger also indicates whether a preset temperature limit has been exceeded for each channel.

Graphical User Interface

On start-up, the process control software displays a base window with two pull down menus. The menu named "Process" has several submenus pertaining to process related items (Figure 3). The menu named "Simulation" has submenus that allow the user to view the geometry data associated with the part to be created without actually performing any sintering (Figure 4).

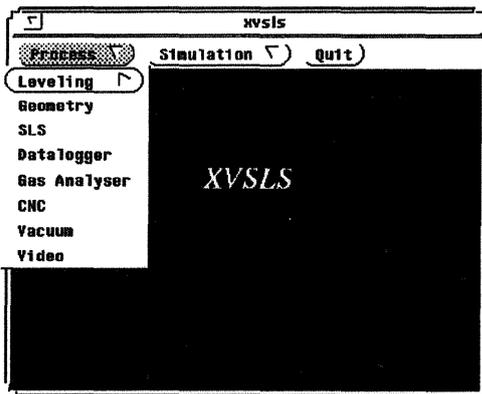


Fig 3. The Process Menu

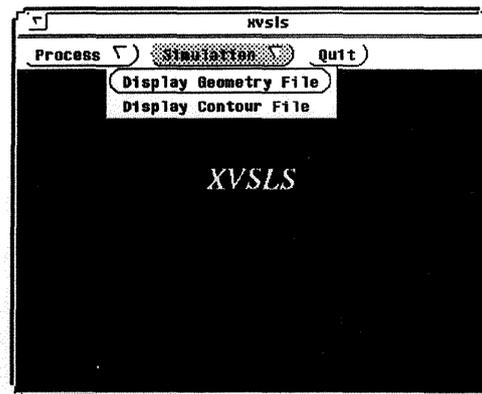


Fig 4. The Simulation Menu

Leveling Parameters

The leveling submenu has two subselections, "Leveling" and "Dummy Layers". Selecting "Leveling" raises a "Leveling Parameters" popup window (Figure 5). This window has a number of input text fields into which the user must enter his preferred parameters. Apart from supplying Part Side Drop and Feed Side Rise in mils, the user may also supply the value of following parameters:

- Inter Layer Delay: A time delay in seconds before scanning of the next layer is initiated.
- Scan Repeat Factor: Scan the same layer more than once without depositing fresh powder.
- Scan Delay: A time delay between successive scans when the value of the above variable is greater than one.

- Layer Repeat Factor: Each layer may be repeated. This is useful in scaling a part.
- Load Parameters from File: The user may load the above parameters from file into which these values were previously stored.
- Save Parameters to File: The user may save the entered parameters into a file for future retrieval.

Fig. 5 The Leveling Parameters popup Window

Selecting "Dummy Layers" raises a "Dummy Parameters" popup window (Figure 6). This window has input text fields into which the user enters part side drop, feed side rise and the number of dummy layers that are to be deposited (i.e. layers with no scanning). This feature is useful when one wishes to level the powder bed before starting the actual process of making a part.

Fig. 6 The Dummy Layers Parameters popup Window

Geometry Parameters

Selecting the Geometry submenu raises a "Geometry Parameters" popup window (Figure 7). This popup allows the user to enter the name of the geometry data file

associated with the part to be made. The geometry data file contains the scan information for all layers of the object . Upon entering the file name and clicking on the "Open" button, the process control software counts the number of layers in the geometry file and reports it to the user. The user can now enter the starting layer (default is 1) and the number of layers to be processed (default is All). Clicking on the "Apply" button saves these parameters into geometry parameters file which is used by the process control software. Clicking on "Close" closes the currently open geometry file allowing the user to open another geometry file.

Fig. 7 The Geometry Parameters popup Window

SLS Parameters

Selecting the SLS submenu raises the "SLS Parameters" window (Figure 8). This window has text input fields for the CNC program that is to be run and the desired scale factor on the part. There are two checkbox choices also; one allows the user to by-pass the leveling action and the other allows the user to invoke a display of layer scans on screen. This display is synchronized with the actual scanning of the laser as the part is being built. The "Start" button initiates the execution of the SLS process. Three other buttons "Interrupt", "Continue" and "Stop" allow the user to interrupt an ongoing scan for any reason, to continue the process after an interrupt and to stop the process respectively.

Fig. 8 The SLS Parameters popup Window

Datalogger

Selecting the Datalogger submenu raises the "Datalogger" popup window (Figure 9). This window has 20 text output fields that display the value of each channel of the datalogger. A slider is provided to adjust the frequency with which the data is reported. Pressing the "Connect" button establishes a connection with the datalogger. Pressing

"Start" initiates the reading data from the datalogger. A checkbox choice provides the user with the option of saving the received data to a file.

The screenshot shows a window titled "Datalogger" with a standard Windows icon in the top-left corner. The window contains the following elements:

- 20 input fields labeled "DL Channel 0:" through "DL Channel 19:". The first field has a mouse cursor pointing to it.
- An "Interval between Reads (secs)" field with a value of "5" and a slider control. The number "300" is displayed to the right of the slider.
- A "Save Data to File" checkbox with "Yes" selected (checked) and "No" unselected.
- A "Save to File:" text field.
- Four buttons: "Connect", "Start", "Stop", and "Disconnect", each enclosed in a rounded rectangular frame.

Fig. 9 The Datalogger popup Window

Gas Analyzer

Selecting the Gas Analyzer submenu raises the "Gas Analyzer" popup window (Figure 10). This window has a text field that displays a preset Oxygen concentration threshold in terms of partial pressure (Torr) . There are six text output fields that display the peak values of the each of the six channels of the Residual Gas Analyser. Pressing "Connect" establishes a connection between the process control computer and the Gas Analyzer. Pressing "Start" initiates reading the peak partial pressures from the Gas Analyzer. A slider allows the user to set the frequency at which the Gas Analyzer output is sampled. A checkbox choice provides the user with the option of saving the pressure data to a file. The gases currently being monitored are Oxygen, Nitrogen and water vapor.

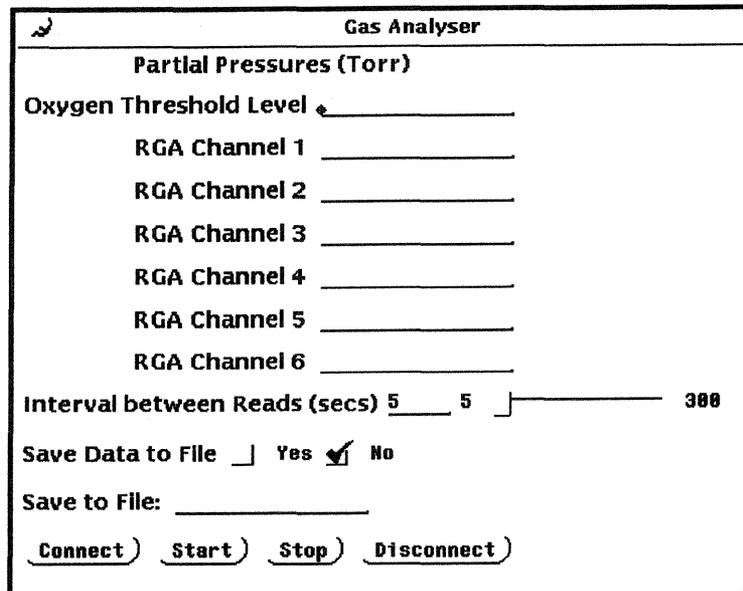


Fig. 10 The Gas Analyzer popup Window

Geometry File Display

Selecting the "Display Geometry File" submenu under the "Simulation" menu raises a "Geometry File" popup window (Figure 11). This window has three buttons labeled "Draw", "Clear" and "Quit" respectively and a viewport (canvas) in which the graphics are displayed. Pressing "Draw" raises a popup (Figure 12) which has a textfield for the name of the geometry file to be displayed. Upon entering the file name and pressing "Open", the software counts the total number of layers in the file and reports it to the user. The user can now select the starting layer, ending layers and a time delay between the display of successive layers. Selecting "Start" initiates the display. The user may interrupt the display at any time by pressing "Interrupt", continue the display after an interrupt by selecting "Continue" or stop the display altogether by selecting "Stop".

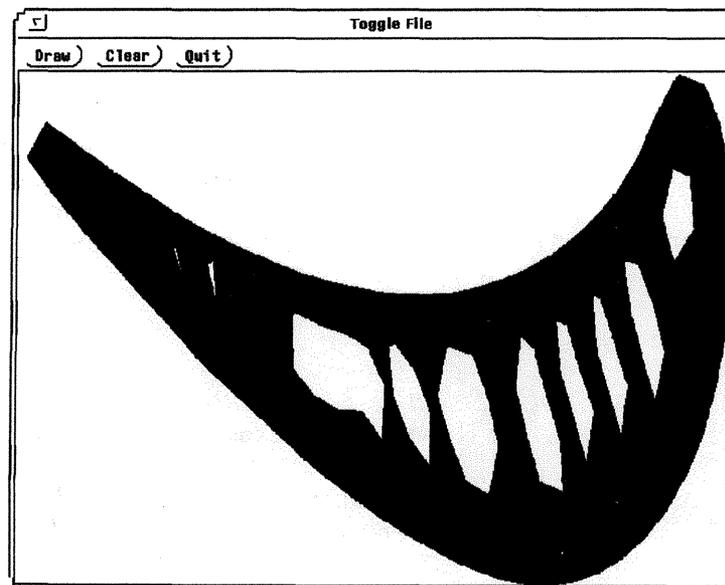


Fig. 11 The Geometry File Display

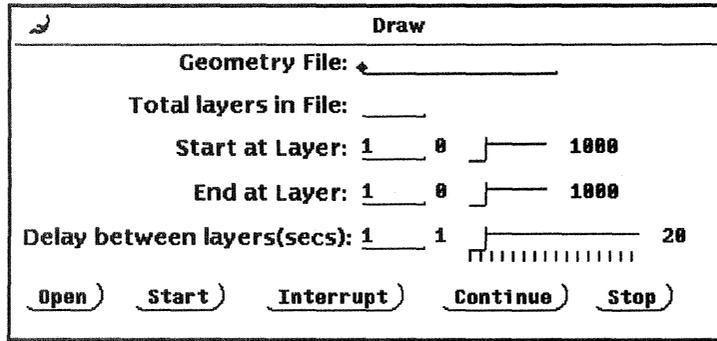


Fig. 12 The Draw popup window

Future Work

Features to be incorporated in future versions of this Process Control Software are:

1. A time history plot of various temperatures logged from the datalogger.
2. A time history plot of the partial pressures read in from the gas analyzer.
3. An interface to the temperature controller for the heater.
4. Real time control of laser power through software.
5. Tracing of part boundaries prior to raster scanning, which may improve part quality and surface finish. A polygonal contour representing the boundary of a layer may be used to approximate the actual boundary by several cubic splines joined together.
6. A display of contour files used in 5 above.
7. A Video popup window that shows the actual process captured through a video camera positioned above the part cylinder.

Conclusion

The first version of process control software for the High Temperature Workstation has been tested and used successfully to make test parts [6]. This design successfully meets the objectives established for implementing an integrated process control environment for the Selective Laser Sintering Process. This design is modular and provides room for enhancements, improvements and changes as the requirements of the ongoing research on the High Temperature Workstation become more stringent.

References

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