# THE DEVELOPMENT OF AN INTEGRATED GRAPHICAL SLS PROCESS CONTROL INTERFACE

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## ABSTRACT

This paper presents the systematic development of a man/machine interface for Selective Laser Sintering. The interface developed integrates geometry design, process data/code generation, power control and communication in a graphical environment. The objective of this interface is to provide high flexibility and robustness to researchers to meet their special needs. For example, the user can generate laser power profiles of any shape, or control the laser power by PWM or an analog voltage. The control code for the machine is automatically generated with minimum human input. Currently the interface is limited to use on a single layer machine, but can be easily modified for multi-layer machines. LabVIEW™ is employed as the developing platform.

*Keywords*: Selective laser sintering, interface software, process control, LabVIEW

## INTRODUCTION

Selective Laser Sintering (SLS) is a process that employs a powdered material approach to rapid prototyping. The process begins with the deposition of a thin layer of powder, which is pre-heated to just below its melting point. A laser selectively traces the surface of the powder and sinters the material together. This process continues layer by layer until a complete part is fabricated [2].

Commercial SLS workstations are produced by 3D Systems. With these machines, the user can control the laser scanning parameters to finish basic SLS steps. The goal of the software system on these commercial workstations is to limit the amount of information required from the user, while producing consistent, repeatable part quality. However, researchers in the Laboratory for Freeform Fabrication (LFF) at UT Austin often build laboratory-sized SLS workstations, and must develop control software for each of these machines. The goal of this work reported here is to develop a unified control software system with a unified interface that can be ported to every laboratory workstation with minimum modification.

To support the research, the interface must be very flexible to accommodate the special requirements of different SLS experiments. For example, the power level as a function of time is a very important factor that will influence the quality of the final part and should be optimally designed for different materials and geometries. Secondly, the overall SLS process should be integrated into a single user-friendly environment to reduce the configuration time. Configuration of each SLS process, such as control code generation configuration, should be flexible and simple enough to minimize required human input. Thirdly, the interface should

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provide the option of simulating the SLS process before execution for cost and safety considerations.

To meet above requirements, a graphical user interface and necessary hardware interface to a General Scanning controller was developed using National Instruments' LabVIEW[TM] software. Although this interface is designed specially for use in a SFF research laboratory, it can be adapted for commercial use as well.

**SYSTEM OVERVIEW**

The interface was targeted for two different workstations in the LFF. Each workstation uses a General Scanning, Inc. (Watertown, MA) DE2000 scan controller and XY3037 scan head. One workstation has a Nd:YAG laser beam, while the other uses SYNRAD's 48 series $CO_2$ laser beam. The interface accommodates either configuration.

The structure of the interface system is shown in Figure 1. The major functions of the interface are to accept information from the operator, generate the control code and power profile, and communicate with the SLS machine controller. The hardware consists of a parallel port (for control code download) and a National Instruments AT-MIO-16E series DAQ board.
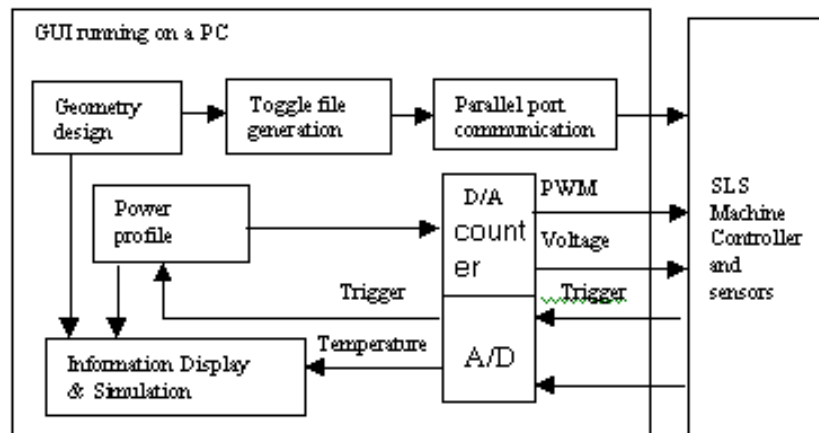


Figure 1.  System structure.

The main interface designed in LabVIEW 6.0 is shown in Figure 2. The menus from left to right follow the SLS operation sequence. When the user selects one of the menus, a detail window corresponding to this menu pops up. The menus are Geometry, Toggle File, Process, Power Design, Simulation, and Run. A new operator can just follow the menus left to right to complete a part. An experienced operator can select specific menus without following the left to right sequence. Communication between the SLS workstation and the control computer takes place through the parallel port and the NI DAQ board.

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[TM] LabVIEW is a product of National Instruments Corp., Austin, TX, USA.

**USER INTERFACE: GEOMETRY**

The SLS software uses an off-line preprocessor to convert an input STL file to a laser toggle point file that controls the SLS workstation. However, when conducting experiments, simple geometries such as circles or squares are always used first. Thus, the GUI provides a convenient method for designing simple geometries.



Figure 2. Geometry design module.

Figure 2 shows the geometry design interface. Currently, both open curves, such as lines, circles, and spots, and areas, such as squares and circles, are supported. Each geometry input is represented as an entity; entities can be combined to form more complex geometry. The advantage of this approach is that the user can adjust the number of scan lines to change the quality or properties of the part. For example, suppose a certain experiment requires a U-shaped area, with different densities for different sub-areas of the program. Commercial SLS workstations assume the desired density of the part is constant for a given build. With our research interface, this desired outcome is readily realized.

Although this module can only deal with simple geometries, it provides the "all-in-one" ability that allows researchers to design different experiments using a single software package. This module can be expanded to include a pre-processor module for STL files, if necessary.

**USER INTERFACE: TOGGLE FILE**

The toggle file generation module is one of the most important modules of the system. . The function of this module is to rasterize the geometry information into laser power toggle point information. The toggle point information is the coordinates where the scan lines intersect the contour of the geometry. The interface to this module is shown in Figure 3.

In this module, the user can choose the scanning pattern, which directly affects the quality of the part. The General Scanning DE2000 controller supports both unidirectional and bi-directional scanning. Thus, the toggle file module allows the user choose either a zigzag or

bi-directional rasterization.  The user can also choose either the horizontal or vertical direction as the major scanning axis.
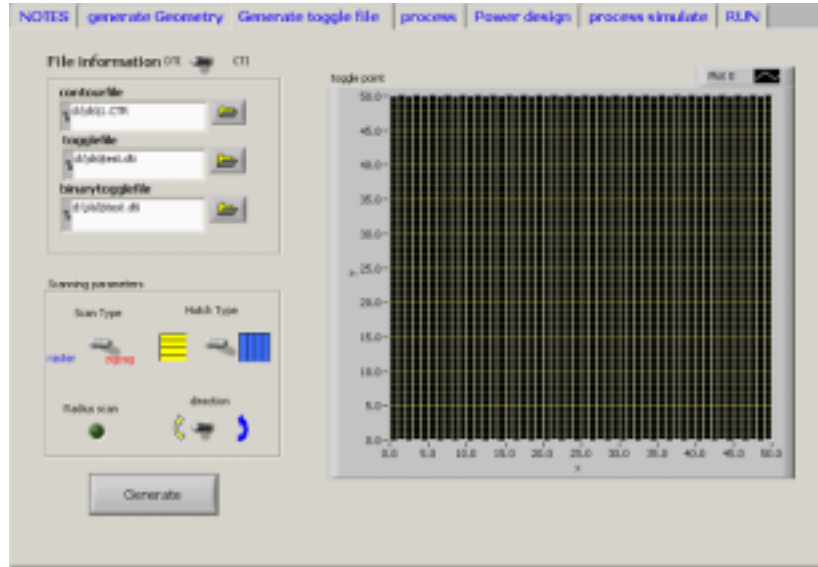


Figure 3.  Toggle file generation module.

## USER INTERFACE: PROCESS

The process module converts the toggle point information to DE2000 controller commands.  It requires four different types of information: file information, scanning mode information, part parameters, and laser scanning parameters.  All of this information is translated into the format required by the controller.  The interface helps the users set the parameters, and the controller code is generated automatically based on the toggle file and the user-provided parameters.  The interface is shown in Figure 4.

## USER INTERFACE: POWER DESIGN

Laser power is a major factor that influences SLS part quality. In commercial SLS workstations, the laser power remains fixed during the entire part build.  However, our research calls for more extensive control of laser power during a part build.  For instance, control of laser power is very important to eliminate balling in direct SLS metal processing [1].  For different geometries and materials, a specially designed power profile may improve the quality of the part. In many cases, determining these relationships is a trial and error process. Thus, the user interface provides much flexibility for the user to control the power profile of the SLS workstation as desired.

Figure 5 shows the interface for specifying the power profile.  The user has three options for generating the power profile: (1) create the profile from library functions (e.g., sine, triangle etc.); (2) sketch the profile; and (3) load the profile from an external file.  With this module, the user can quickly create practically any desired power profile.

411
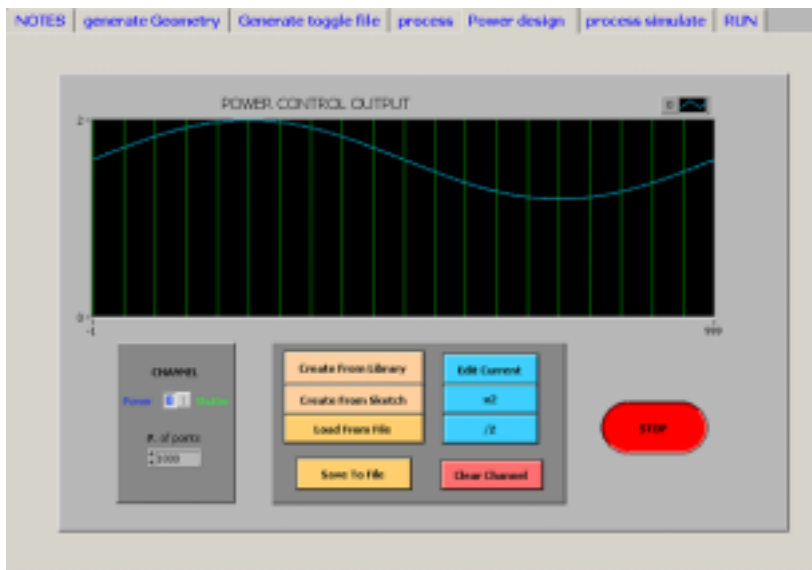
Figure 4.  Process module interface.



Figure 5.  Power profile design module.

As previously mentioned, two different laser systems are used in the LFF; therefore, two different control systems are employed.  The Nd:YAG laser uses an analog voltage to directly control the laser power.  Control of the SYNRAD 48 series $CO_2$ laser is achieved by pulse width modulation (PWM).  This mode can be used to control instantaneous power by adjusting the pulse width (PWM duty cycle) at a fixed modulation frequency.

In the voltage control mode, the laser power is directly proportional to a control voltage.  This conversion is accomplished by directly sending the power profile to the controller through the DAC port on the NI DAQ board.

Under PWM control mode, the power is controlled by a fixed frequency PWM signal. The 48 series laser beam requires a 1 µs "tickle" pulse delivered at a 5kHz clock frequency from the controller. The standard PWM frequency is 5kHz, which has a period of 200 µs, as shown in Figure 6 [3]. A counter in the NI board is used to generate the PWM pulse train and the tickle signal [4].
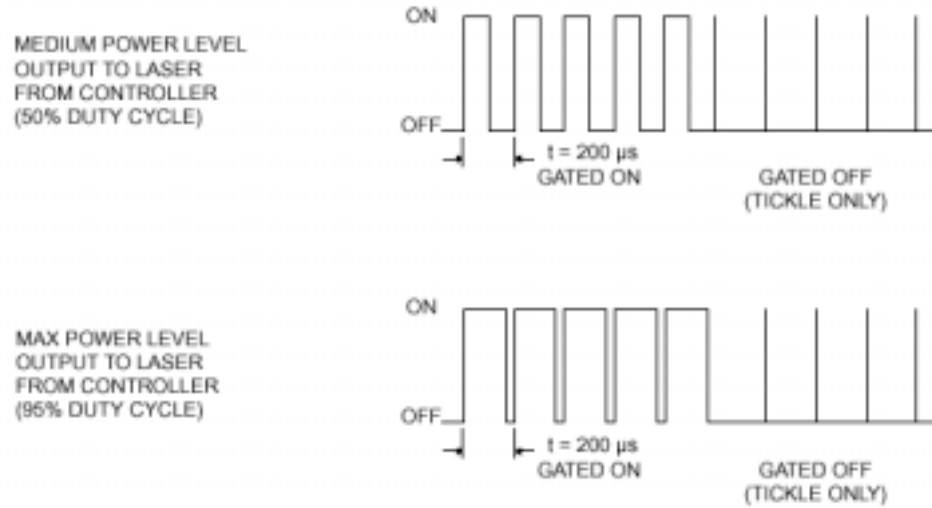


Figure 6. PWM control duration

The relationship between the output power and the PWM pulse duty cycle is measured experimentally. As shown in Figure 7, when the duty cycle is less than 60%, the relationship between power and duty cycle is very linear, and becomes somewhat nonlinear when the duty cycle is higher than 60%. The duty cycle is generated based on required power from the data pictured in Figure 7.
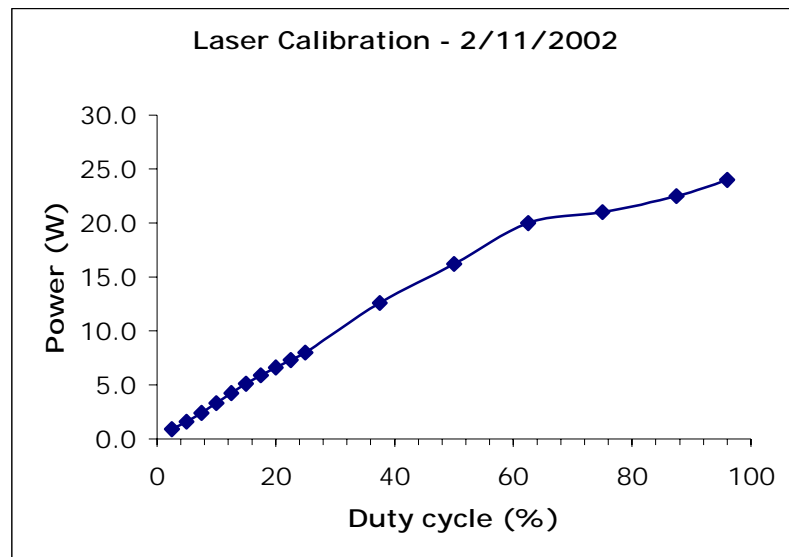


Figure 7. Calibration of laser power and duty cycle for PWM mode.

## USER INTERFACE: PROCESS SIMULATION

The process simulation module is still under development.  The initial design is shown in Figure 8.  In this module, the process information, including the layer profile, laser power and other process information is displayed in a single window.  The power versus time and laser position are displayed so the user can assess their effects before the real part is fabricated.
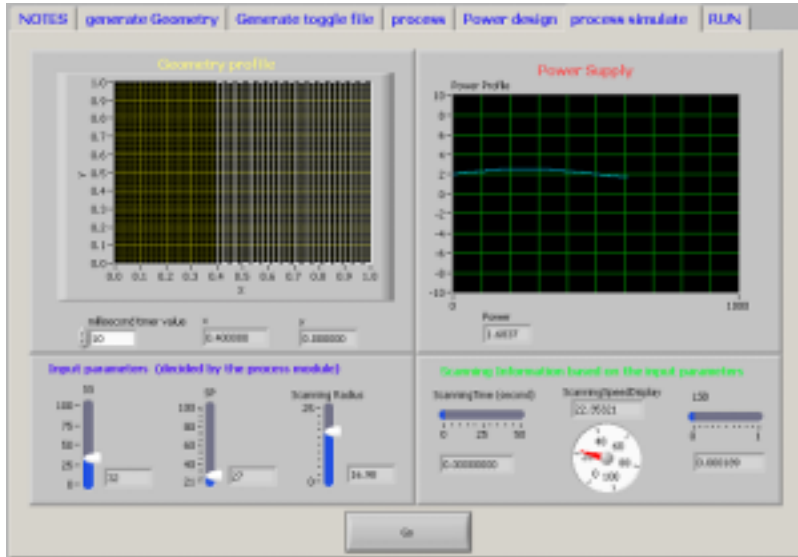


Figure 8.  Simulation module.

## USER INTERFACE: RUN

As shown in Figure 9, all information generated in previous modules is integrated in the run module.  The geometry, power profile, power control, and other information are displayed.  The power control mode is set in this module.  The working sequence of this module is shown in Figure 10.
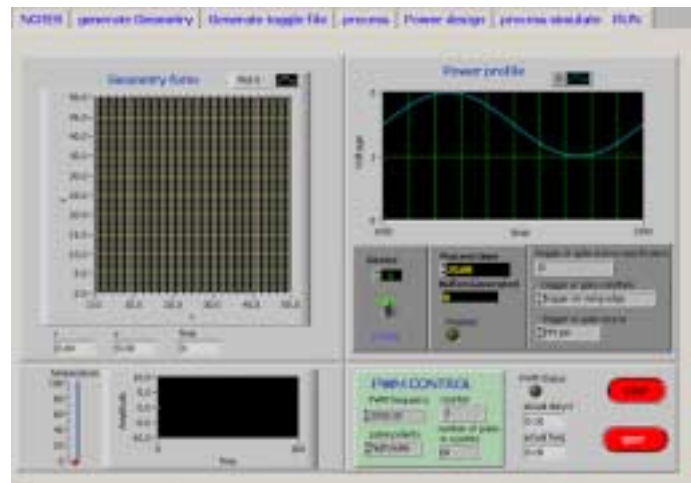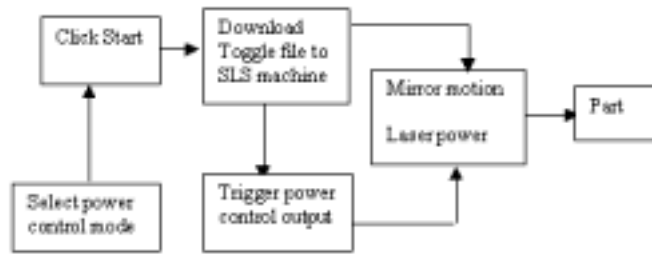


Figure 9.  Run module.

414

Figure-10.  Operation sequence of run module.

The user selects power control mode and then click on the START button.  The toggle point file is then downloaded to the SLS Controller.  Once the download is complete, the SLS Controller sends a trigger signal back to the GUI and starts to execute the file.  The trigger signal activates the output of the power control signal.  Thus the motion of the laser deflection mirrors is synchronized with the power profile.  The temperature monitoring function is still under construction.

**CONCLUSION AND FURTHER DEVELOPMENT**

This paper describes a man/machine interface for controlling a research SLS workstation.  The interface integrates geometry design, process data/code generation, power control, and communication with the workstation in a graphical environment.  The main objectives of this interface are to provide high flexibility and integrated information display to meet the special needs of the researchers who will use the SLS workstation for a variety of experiments.

Further improvements to the GUI are underway.  More extensive geometric design capability is being added, including a STL file interface.  Real-time monitoring of the process temperature, which will give researchers the opportunity to study the relationship between temperature and laser power, part quality, etc., is also being developed.  In current SLS workstations, only open-loop control is employed, and the laser power cannot be adjusted during the part build.  Employing closed loop control of laser power based on the operating temperature is an important goal of future development.

**REFERENCES**

1.  Das, Suman "Direct Selective Laser Sintering of High Performance Metals – Machine Design, Process Development and Process Control", Dissertation, University of Texas at Austin, 1998.
2.  Beaman, J. J., Barlow, J. W., Bourell, D. L., Crawford, R. H., Marcus, H. L., and McAlea, K. P., *Solid Freeform Fabrication: A New Direction in Manufacturing*, Kluwer Academic Publishers, 1997.
3.  SYNRAD, "SYNRAD 48 series $CO_2$ laser operation manual". J version http://www.synrad.com/Products/manuals.htm.
4.  National Instruments, AT-MIO-16E series DAQ board manual