

PORTLAND STATE UNIVERSITY

CAPSTONE PROJECT PROGRESS REPORT

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

3D Metal Printer

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1 Project Overview

The team will interface a CNC machine with a MIG welder to create a 3D printer.

2 Project Proposal

2.1 Sponsor Proposal

The company is in the process of constructing an innovative 3D metal printer controlled by CNC (Computer Numerical Control). The project will be a combination of two machines:

- CNC mill – (3, 4 or 5 axis CNC mill)
- MIG/TIG welding machine.

The purpose for the CNC motion control (CNC mill) is to program and control motion of machine, in this case, the metal deposition process. The purpose for MIG welder is to deposit liquid metal. Many kinds of wire can be used by the welder to form the parts; carbon steel, titanium, stainless steel or aluminum. Idea for metal deposition and an example that uses a laser can be found at:

https://www.youtube.com/watch?feature=player_embedded&v=s9IdZ2pI5dA

A problem with laser use is its high cost. In this project it is planned to use the welding machine with the cost of 400. Another example can be found here:

<http://www.wired.co.uk/magazine/archive/2014/08/play/steel-sketch>

AKTechnology plan is to manufacture parts for pump and compressors, and R&D part for all use. The goal is to fabricate low cost and highly usable machines.

Company has CNC PC based CNC mill- motion controller.

<https://www.youtube.com/watch?v=Plf3t7o951U&list=UUIGufPQeEKdN1-50F89Ejig>

<https://www.youtube.com/watch?v=G-jokU7v92E&list=UUIGufPQeEKdN1-50F89Ejig>

<https://www.youtube.com/watch?v=bPQ5UNiGA4c&list=UUIGufPQeEKdN1-50F89Ejig>

The project is to upgrade this CNC motion controller – mill into 3D metal deposition printer by adding MIG welder instead of cutting tool spindle. The CNC motion control was reprogrammed. The MIG welder is operational.

The project will also build control to integrate CNC mill and MIG welding machine. Welder has 2 adjustment— feed of wire and current. A stepper motor is planned to be used to control those analog data for wire feed and power current. The PLC, programmable logical controller, will join the CNC motion controller and the MIG welding machine.

2.2 The Goal

The end goal of this project is to fully integrate the MIG welder with the LinuxCNC system. Integration will include a way to control all of the functions of the welder, i.e. wire speed, maximum current output, engaging and disengaging the welder at appropriate times. In

order for this to be done, electromechanical devices must be used to manipulate the knobs on the MIG welder. At the very least, the machine must be able to deposit material, reproducing a simple single object from a CAD drawing. This object is chosen to be a cylindrical tube, however, it is desired that the machine will be able to create complex structures on a single base. Precision of the deposition is not the primary concern, however it will be a requirement that the total amount of material deposited is more than the minimum tolerance of the part being created. This will allow for material to be machined away to a more precise tolerance.

2.3 Our Starting Point

The groundwork of this project has been completed by Aram Kasparov, the project sponsor. The project at its current state consists of a PC controlled CNC machine, a MIG welder, an infrared temperature sensor and a current measuring sensor. The PC controlling the CNC machine is running a Linux operating system. LinuxCNC an open-source software is used for programing and interfacing with the physical machine. Additional hardware is installed onto the PC, consisting of Mesa Electronics 5I20 FPGA based PCI Anything I/O card, 7i33 analog servo interface card and two 7i37-COM isolated I/O cards. The LinuxCNC software communicates the control signals and receives feedback through these cards. The CNC machine is a 3-axis machine-that is it can move in the X, Y and Z directions. Each axis is moved by a servo-motor and each servo motor is driven by a driver which receives its control commands from the PC. The machine is functional, though the motors will require some tuning and limit switches need to be programmed in (they are physically installed on the machine but not included in the program). The MIG/Flux cored welder is rated at 180 Amp-DC, 240 Volt with a duty cycle of 20% at 140 amps. The welder has current and wire feed adjustment capabilities for controlling the weld. These two knobs will be controlled by two stepper motors which have been installed onto the welder already. The current sensor has the ability to measure up to 225A. It has been demonstrated to be functional and will be used to monitor the current of the weld. The infrared non-contact temperature sensor is rated to measure temperatures up to 1800 degrees Celsius, though no tests have been performed yet.

2.4 Requirements

- Must use a wire feed welder
- Welder must have a Control System
- Must measure weld temperature
- Must measure weld current
- Must use both previous parameters to estimate current quality of weld
- Must use “G code” as inputs
- And must control when material is being deposited
- Must have user interface
- Should allow for welder thermal shutdown
- May show amount of wire left on spool



Figure 1: Single Cycle of a Sinusoid

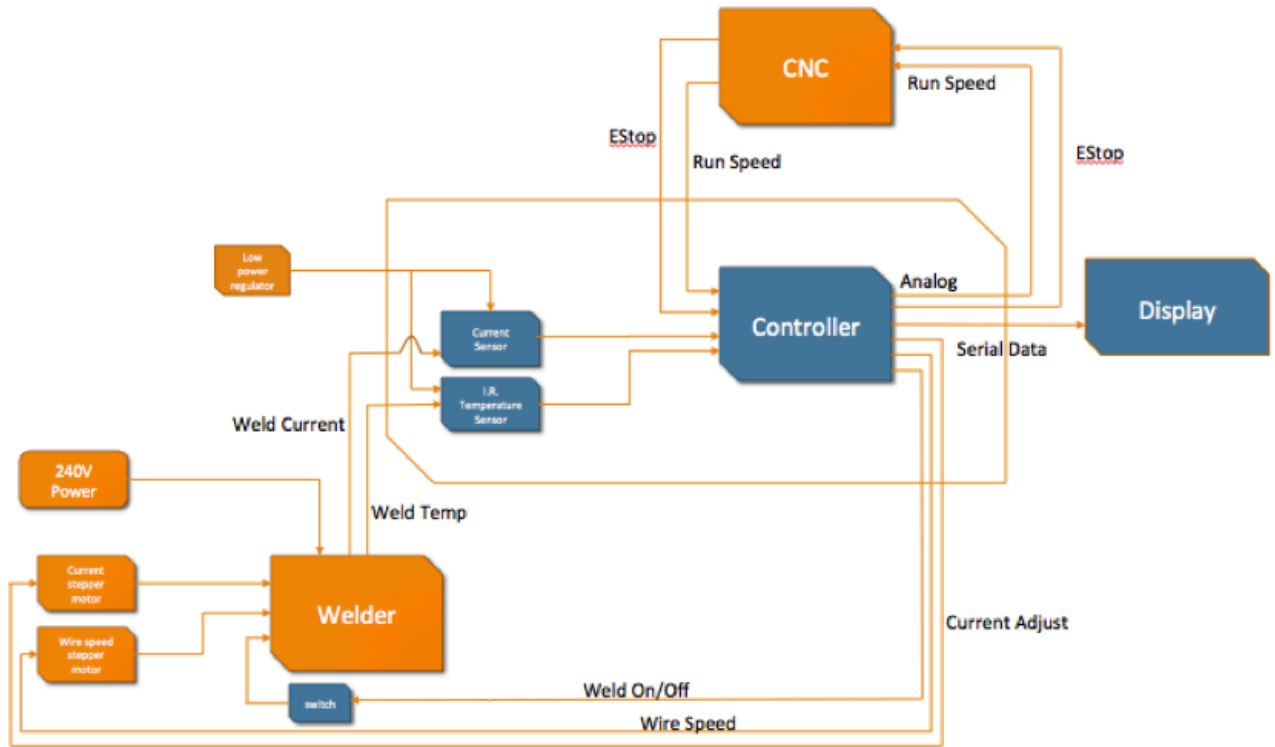


Figure 2: Single Cycle of a Sinusoid

3 Hardware

3.1 Welder Control

To control the welder, a central control module will be used. This was a hot topic of debate for several weeks, as the number of choices available for this project are very high. The sponsor's requirements for the project was that all of the control work was done by a separate computer from the one used by Linux CNC, this only narrowed it down to a debate between a PCIe DAC board and a single board computer. Based on the need for both analog and digital control pins and the need for future expansion, we researched and came up with several options.

Single Board Computers	DAC
Raspberry-Pi	Sensoray 826
Intel Galileo	MCC DAS1602/16
SBC 8600B	
Wander Board Solo	
Beagle Bone Black	

In the end we chose the Sensoray 826 board because for the price it outperforms all other boards on the market by having 16 analog inputs, 8 analog outputs, and 48 digital I/O pins.

This board was chosen for the high level of future expandability that it has, and because it is a PCIe card which can be packaged into its own desktop as per request from the sponsor.

To control the current to the weld and the wire speed of the welder, two stepper motors have been fitted to the manual control knobs, and are connected to a motor driver module. The Sensoray board will be controlling the motor drivers using a sequence of rising and falling edges. To allow the controller board to control at what time the welder is depositing and when it is not depositing, a relay with a transistor driver will be used.

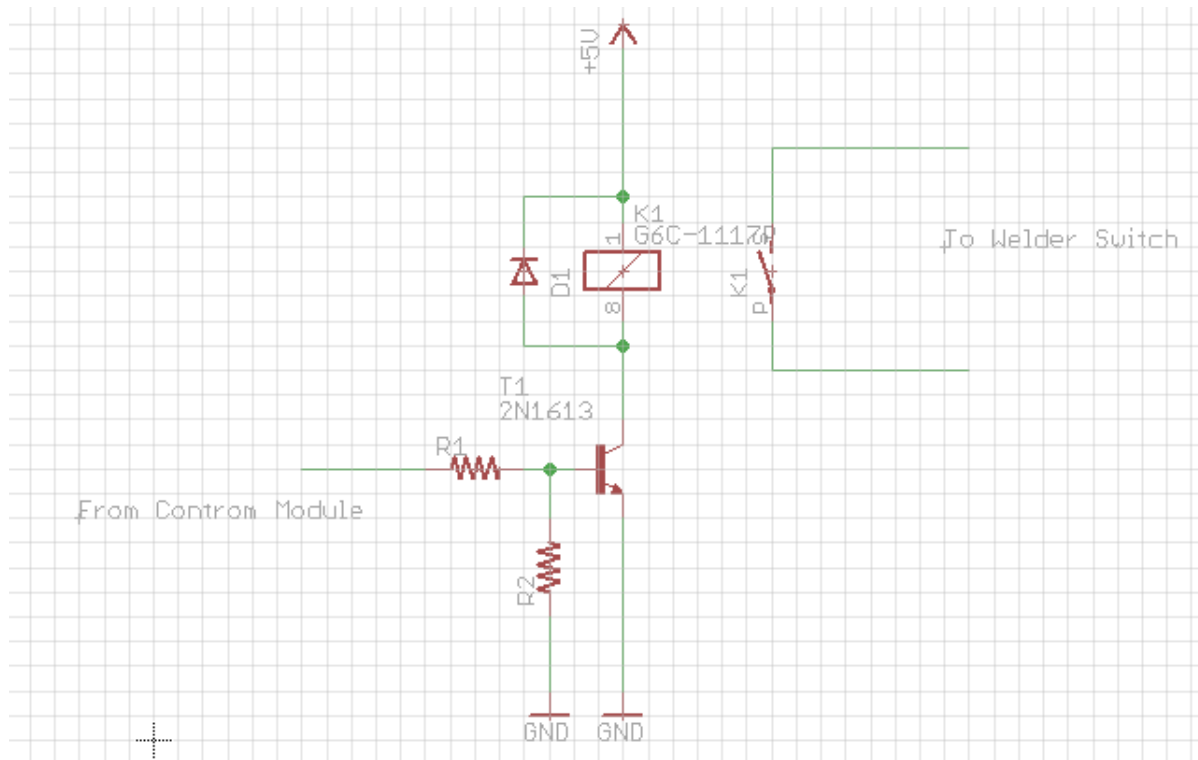


Figure 3: Single Cycle of a Sinusoid

The signal to that tells the controller will be coming from the CNC machine's I/O card. It is a switch type signal which means that when the signal is sent, an internal switch will be closed, causing what ever is on the input to be shown on the output. The CNC machine uses G-Code, and Linux CNC allows outputs to be asserted when a particular G-Code instruction is executed. G1 and G0 are going to be used to tell the I/O card to close and open the switch, which will assert 5VDC to the input to the control module. The control module will assert an output high or low which will open or close the welder switch, turning the welder on and off.

The Sensoray 826 I/O card has three 50 pin connectors and a single 26 pin connector. To allow easy access to these pins, a breakout board with screw terminals has been made so that wires can easily be disconnected and switched.

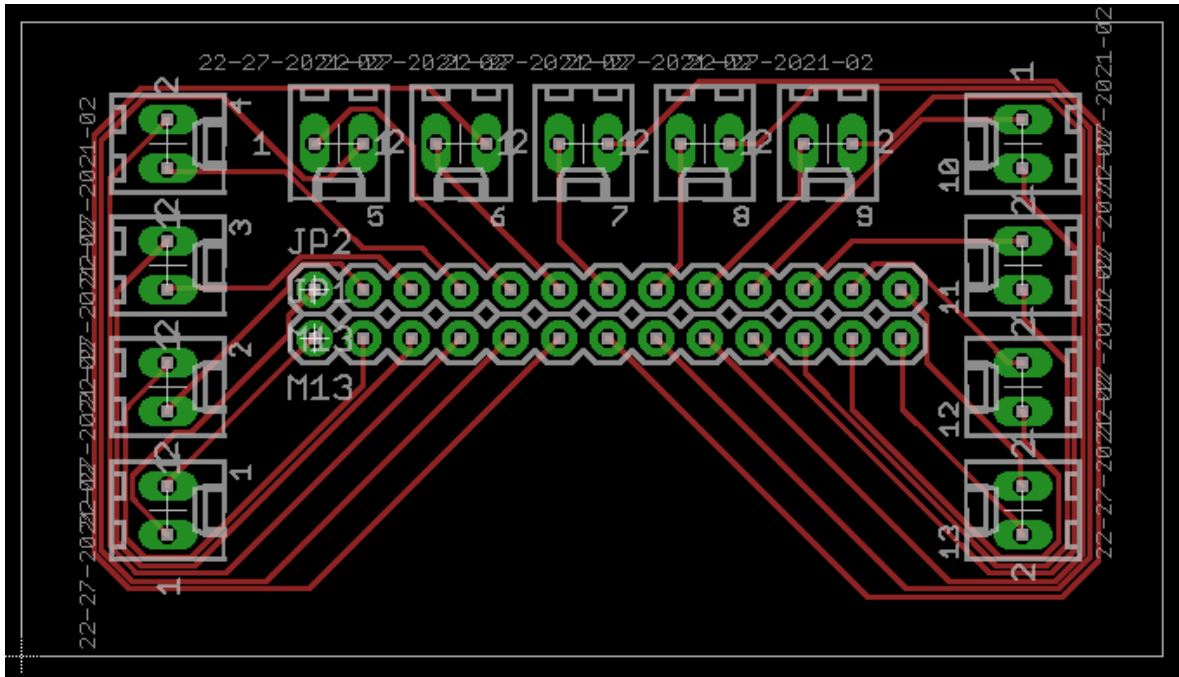


Figure 4: Single Cycle of a Sinusoid

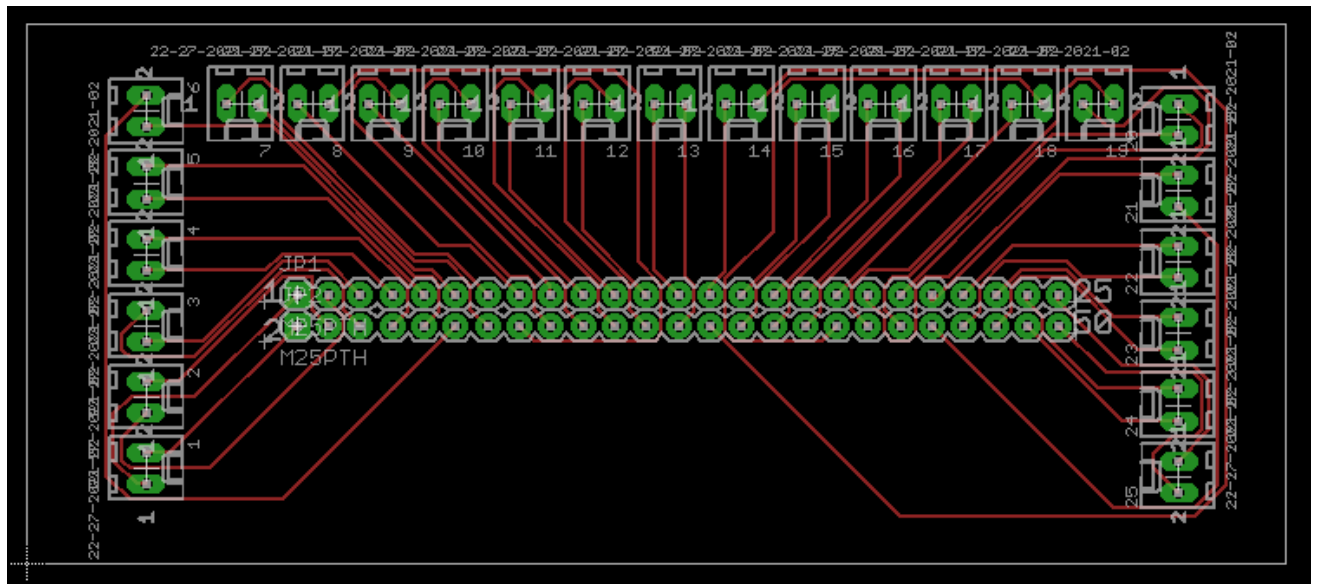


Figure 5: Single Cycle of a Sinusoid

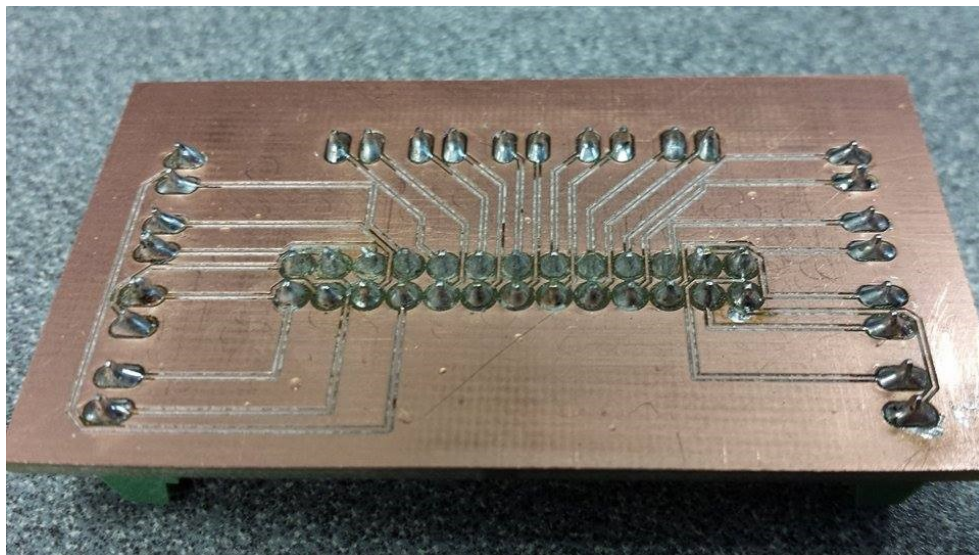


Figure 6: Single Cycle of a Sinusoid

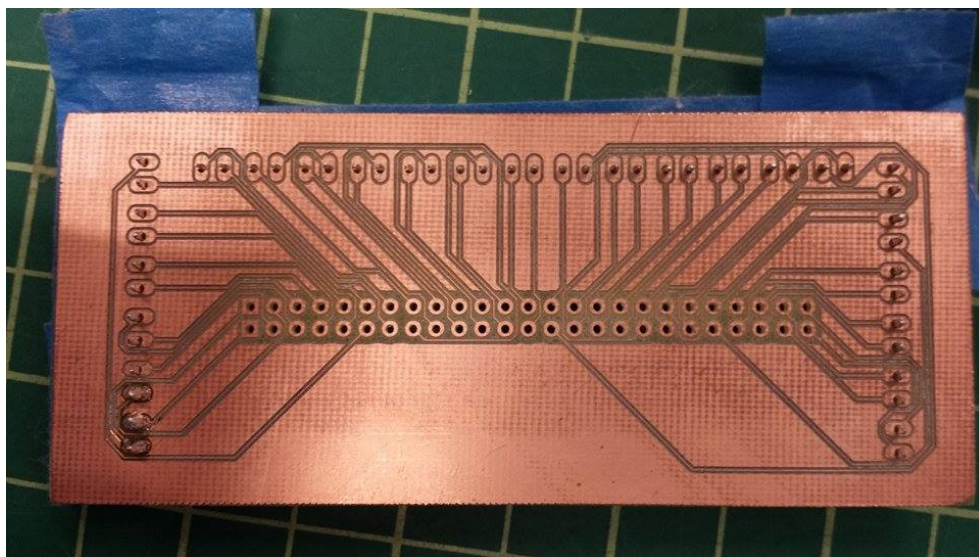


Figure 7: Single Cycle of a Sinusoid

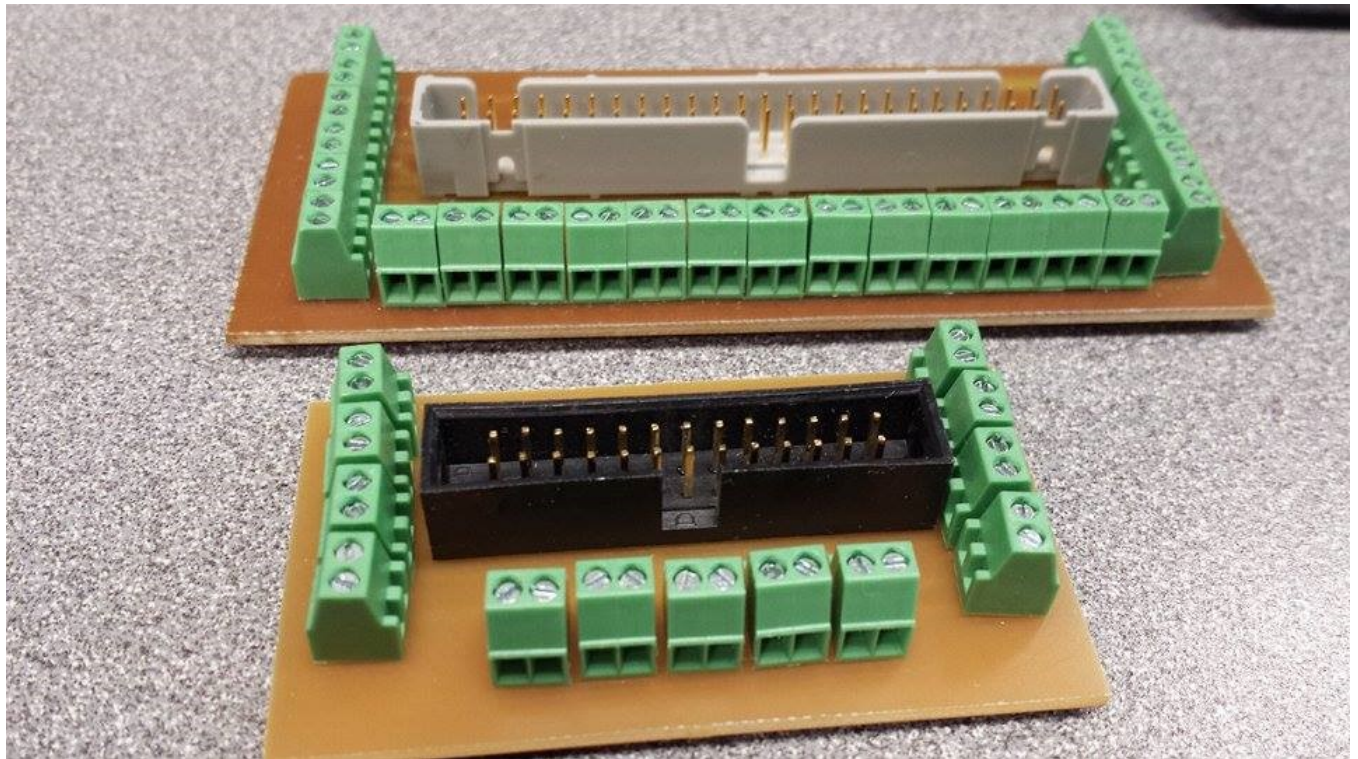


Figure 8: Single Cycle of a Sinusoid

4 Software

4.1 GUI Description

Our software will have a GUI in which the user can see real-time graphed data coming from the current and temperature sensors as well as see the current wire speed. The system should use this feedback to automatically adjust the weld and keep it in a state that can be considered a "good weld". Also included here will be manual overrides for the user to adjust the current and wire speed to their own desired result. Below is an initial GUI layout that we will be aiming for.

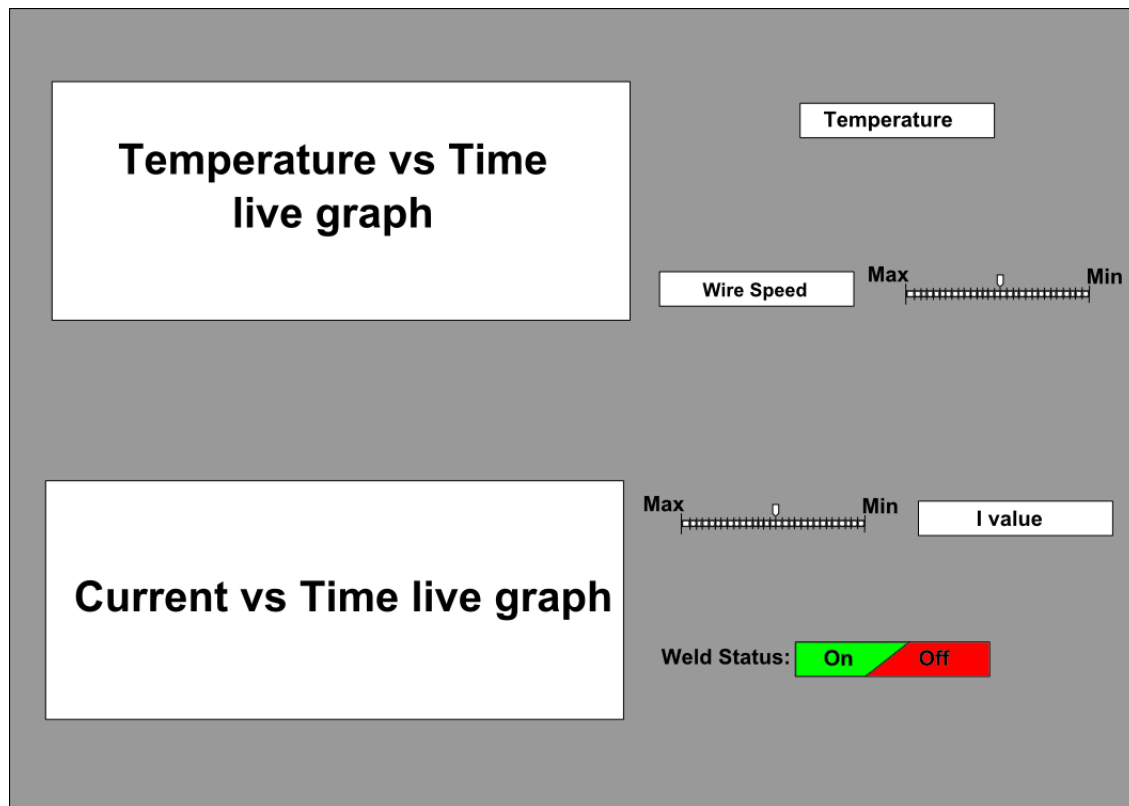


Figure 9: Single Cycle of a Sinusoid

4.2 The Graphical User Interface (GUI)

We are using GTK+ in C programming language to generate the Graphical User Interface in order to view the different data and also control different settings.

The GTK+ is a library for creating graphical user interfaces. The library is created in C programming language. The GTK+ library is also called the GIMP toolkit. Originally, the library was created while developing the GIMP image manipulation program. Since then, the GTK+ became one of the most popular toolkits under Linux and BSD Unix. Today, most of the GUI software in the open source world is created in Qt or in GTK+. The

GTK+ is an object oriented application programming interface. The object oriented system is created with the Glib object system, which is a base for the GTK+ library. The GObject also enables to create language bindings for various other programming languages. Language bindings exist for C++, Python, Perl, Java, C#, and other programming languages.

The GTK+ itself depends on the following libraries.

- **Glib**

GLib provides the core application building blocks for libraries and applications written in C. It provides the core object system used in GNOME, the main loop implementation, and a large set of utility functions for strings and common data structures.

Description

- New types which are not part of standard C (but are defined in various C standard library header files) - gboolean, gsize, gssize, goffset, gintptr, guintptr.
- Integer types which are guaranteed to be the same size across all platforms - gint8, guint8, gint16, guint16, gint32, guint32, gint64, guint64.
- Types which are easier to use than their standard C counterparts - gpointer, gconstpointer, guchar, guint, gushort, gulong.

GLib also defines macros for the limits of some of the standard integer and floating point types, as well as macros for suitableprintf() formats for these types.

Standard Macros — commonly-used macros

Type Conversion Macros — portably storing integers in pointer variables

Byte Order Macros — a portable way to convert between different byte orders

Numerical Definitions — mathematical constants, and floating point decomposition

Miscellaneous Macros — specialized macros which are not used often

Atomic Operations — basic atomic integer and pointer operations

GLib Core Application Support

- **The Main Event Loop** — manages all available sources of events
- **Threads** — portable support for threads, mutexes, locks, conditions and thread private data
- **Thread Pools** — pools of threads to execute work concurrently
- **Asynchronous Queues** — asynchronous communication between threads
- **Dynamic Loading of Modules** — portable method for dynamically loading 'plug-ins'
- **Memory Allocation** — general memory-handling

- **Memory Slices** — efficient way to allocate groups of equal-sized chunks of memory
- **IO Channels** — portable support for using files, pipes and sockets
- **Error Reporting** — a system for reporting errors
- **Message Output and Debugging Functions** — functions to output messages and help debug applications
- **Message Logging** — versatile support for logging messages with different levels of importance

GLib Utilities

- **String Utility Functions** — various string-related functions
- **Character Set Conversion** — convert strings between different character sets
- **Unicode Manipulation** — functions operating on Unicode characters and UTF-8 strings
- **Base64 Encoding** — encodes and decodes data in Base64 format
- **Data Checksums** — computes the checksum for data
- **Secure HMAC Digests** — computes the HMAC for data
- **Internationalization** — gettext support macros
- **Date and Time Functions** — calendrical calculations and miscellaneous time stuff
- **GTimeZone** — a structure representing a time zone
- **GDateTime** — a structure representing Date and Time
- **Random Numbers** — pseudo-random number generator
- **Hook Functions** — support for manipulating lists of hook functions
- **Miscellaneous Utility Functions** — a selection of portable utility functions
- **Lexical Scanner** — a general purpose lexical scanner
- **Timers** — keep track of elapsed time
- **Spawning Processes** — process launching
- **File Utilities** — various file-related functions
- **URI Functions** — manipulating URIs
- **Hostname Utilities** — Internet hostname utilities
- **Shell-related Utilities** — shell-like commandline handling
- **Commandline option parser** — parses commandline options
- **Glob-style pattern matching** — matches strings against patterns containing '*' (wildcard) and '?' (joker)

- **Perl-compatible regular expressions** — matches strings against regular expressions
- **Regular expression syntax** — syntax and semantics of regular expressions supported by GRegex
- **Simple XML Subset Parser** — parses a subset of XML
- **Key-value file parser** — parses .ini-like config files
- **Bookmark file parser** — parses files containing bookmarks
- **Testing** — a test framework
- **UNIX-specific utilities and integration** — pipes, signal handling
- **Windows Compatibility Functions** — UNIX emulation on Windows

GLib Data Types

- **Doubly-Linked Lists** — linked lists that can be iterated over in both directions
- **Singly-Linked Lists** — linked lists that can be iterated in one direction
- **Double-ended Queues** — double-ended queue data structure
- **Sequences** — scalable lists
- **Trash Stacks** — maintain a stack of unused allocated memory chunks
- **Hash Tables** — associations between keys and values so that given a key the value can be found quickly
- **Strings** — text buffers which grow automatically as text is added
- **String Chunks** — efficient storage of groups of strings
- **Arrays** — arrays of arbitrary elements which grow automatically as elements are added
- **Pointer Arrays** — arrays of pointers to any type of data, which grow automatically as new elements are added
- **Byte Arrays** — arrays of bytes
- **Balanced Binary Trees** — a sorted collection of key/value pairs optimized for searching and traversing in order
- **N-ary Trees** — trees of data with any number of branches
- **Quarks** — a 2-way association between a string and a unique integer identifier
- **Keyed Data Lists** — lists of data elements which are accessible by a string or GQuark identifier
- **Datasets** — associate groups of data elements with particular memory locations
- **GVariantType** — introduction to the GVariant type system
- **GVariant** — strongly typed value datatype
- **GVariant Format Strings** — varargs conversion of GVariants

- **GVariant Text Format** — textual representation of GVariants

Deprecated APIs

- **Deprecated thread API** — old thread APIs (for reference only)
- **Caches** — caches allow sharing of complex data structures to save resources
- **Relations and Tuples** — tables of data which can be indexed on any number of fields
- **Automatic String Completion** — support for automatic completion using a group of target strings

GLib Tools

- **glib-gettextize** — gettext internationalization utility
- **gtester** — test running utility
- **gtester-report** — test report formatting utility

- **Pango**

Pango is a library for laying out and rendering of text, with an emphasis on internationalization. Pango can be used anywhere that text layout is needed, though most of the work on Pango so far has been done in the context of the GTK+ widget toolkit. Pango forms the core of text and font handling for GTK+-2.x