WIRE ARC ADDITIVE MANUFACTURING (WAAM)

Ryan Burdi and Jackson Lyon
Mechanical Engineering Technology Program at Colorado Mesa University

Problem Definition

Numerous additive manufacturing (AM) processes have emerged for crafting metallic components. Metal AM processes, such as direct metal laser sintering and concentrated energy deposition, can achieve complex geometries unattainable through traditional subtractive manufacturing processes like machining, but require the use of powdered metal which can cause problems in certain environments. In addition, the ownership and operational costs of metal additive manufacturing machines are substantial, exceeding $99,000 for entry-level machines. Metal fused deposition modeling processes are more cost-effective and can be used to fabricate parts by layering sintered metallic material to build up a three-dimensional component.

The purpose of this project was to develop a cost-effective metal FDM printer by combining a metal inert gas welder with a 3D printer gantry system. This wire arc additive manufacturing (WAAM) machine is a work in progress. A team in 2022-2023 designed and fabricated the bulk of the machine and the team during the 2023-2024 academic year focused on troubleshooting the system and optimizing its function.

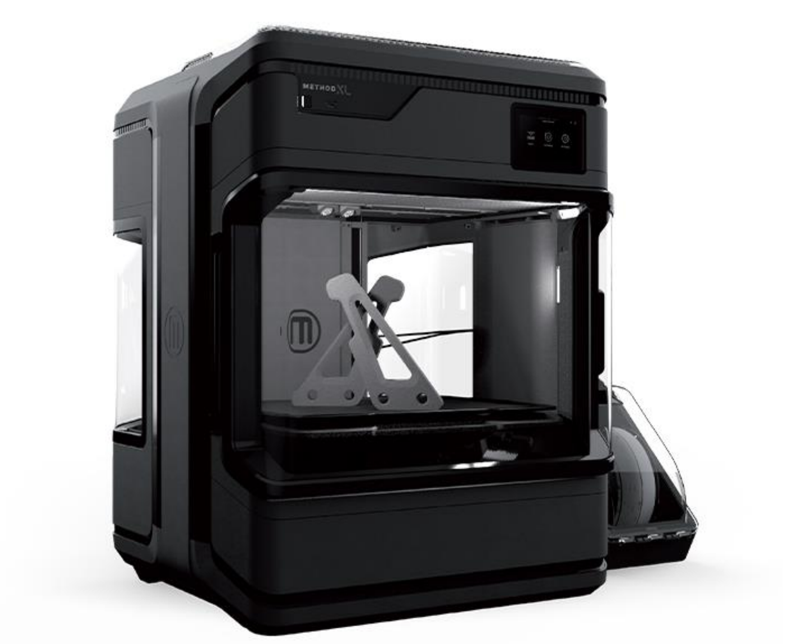


Figure 1. UltiMaker Method XL 3D Printer (metal FDM)

Figure 2. BeAM Modulo 400 3D Printer (metal CED)

Design Requirements

The project deliverable was a functioning WAAM machine that:

- Incorporates software that allows the user to insert a CAD model and generate G-code (the G-code must activate the welder)
- Has a design platform (print bed) that resists heat warping
- Incorporates siding to protect the user from arc flash and weld spatter
- Incorporates a gantry to support the welding torch
- Incorporates an emergency stop
- Can be fabricated within a $5000 budget

In addition to designing the WAAM machine, a part removal process needs to be developed to remove the printed component from the print bed.

Troubleshooting

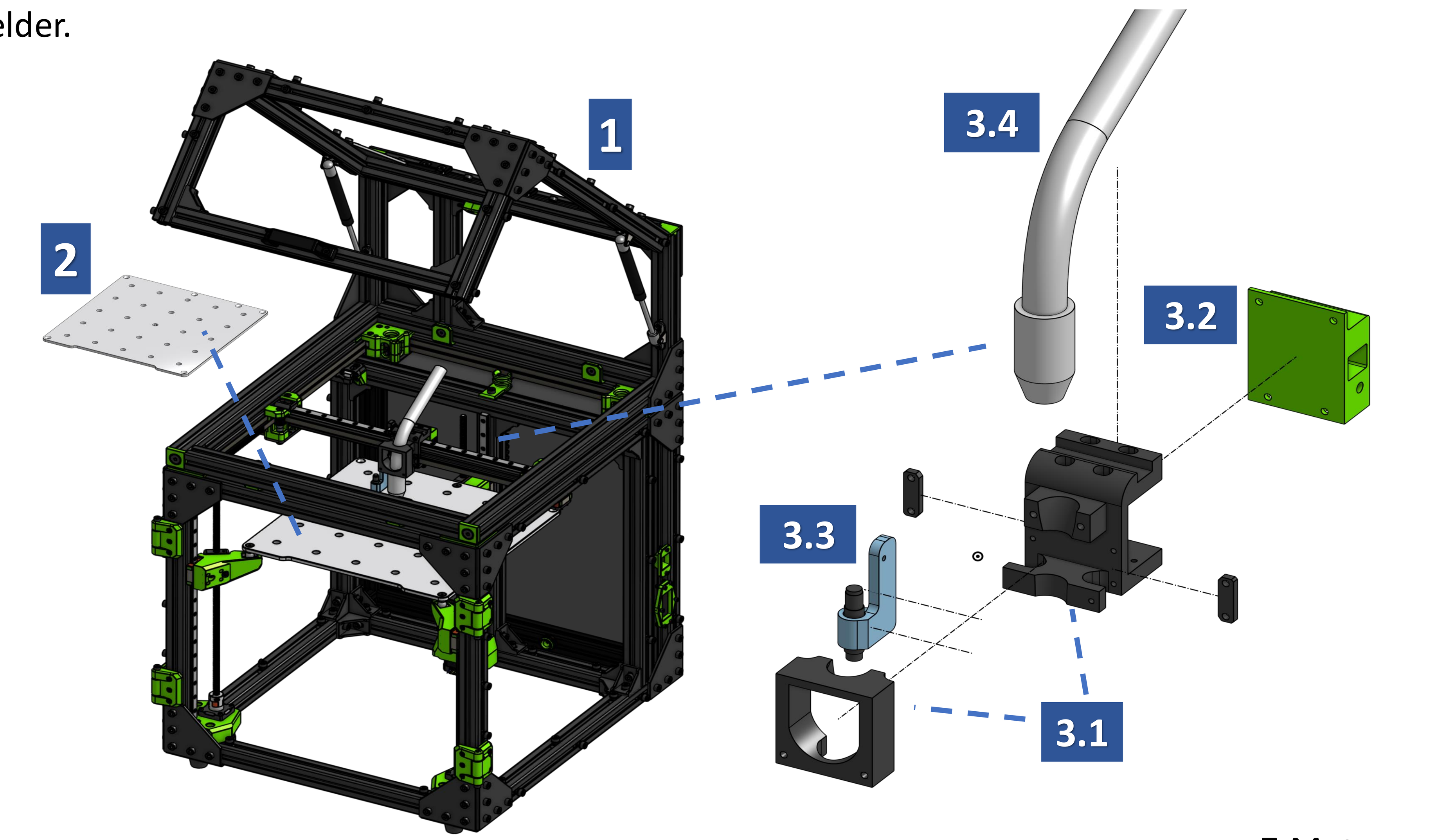
For computer connection and control, the following are needed:

- Raspberry Pi 3 Model B V1.2
- BIGTREETECH SKR Pro V1.2 Control Board

Most complications came from altering the 'printer.cfg' program to allow these components to communicate with the various motors and sensors

Design & Results

The WAAM machine consists of an Esab Rebel EMP 215 ic welder and three main subsystems (labeled 1, 2, and 3 below) that make up the system gantry. The printer utilizes three NEMA 17 Stepper motors to control the Z-axis and two more for the XY-axes. A hotbed rubber heating mat with a thermistor lies under the bed plate which works with a solid-state relay wired between the mat and control board. There are 2 limit switches for homing of the XY-axes and wires were spliced from the welder to the control board to remotely trigger the welder.



1 — 3D Printer: RatRig V-Core 3.1 printer assembly with custom aluminum walls to protect viewers and surrounding area from weld arc and spatter

2 — Bed Plate: ¼" thick 6061 Aluminum with 25 holes and an air gap of 1" to control heat buildup

3 — Torch Mount Assembly:

- **3.1 Torch Mount:** Maintains 90° working/travel angle
- **3.2 Belt Tensioner:** Tightens/loosens the timing belt
- **3.3 Z-Axis Probe:** Allows for homing of the z-axis
- **3.4 MIG Torch:** Heats and feeds wire to bond metal

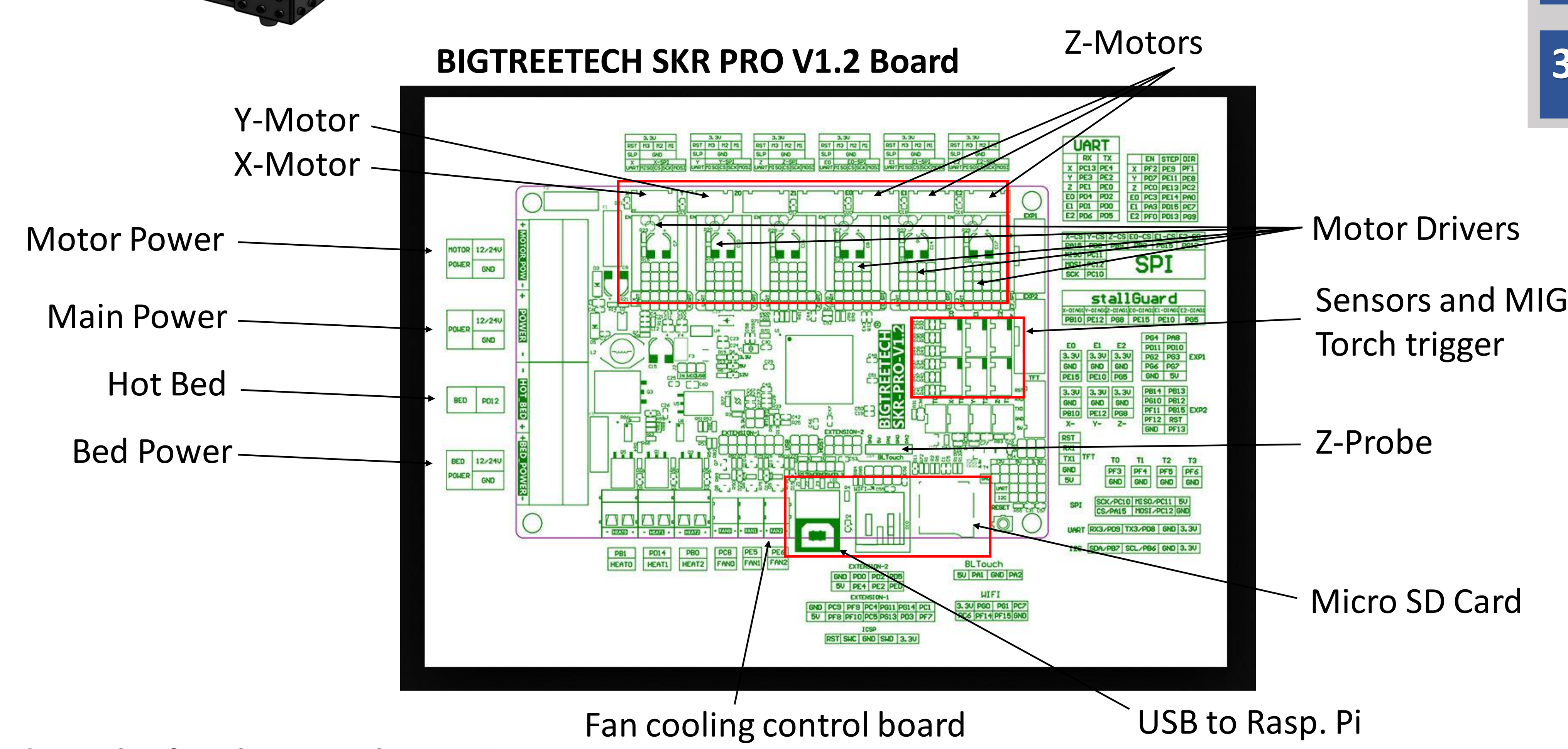


Table 1. Testing methods and results for the metal 3D printer.

Requirement	Objective	Test Method	Results
XYZ Motion	Pass	Functionality Test	Pass
Control board triggers welder	Pass	Functionality Test	Pass
Base plate resists warping due to heat	Pass	Visual Test	Pass
Frame blocks arc and spatter	Pass	Visual Test	Pass
Wi-Fi compatible control system	Wirelessly monitor and control printer	Functionality Test	Pass

Next Steps

- Establish the system's capabilities and determine achievable angle of overhang, minimum wall thickness, maximum wall height without support structure, etc.
- Test printed material for mechanical properties and microstructure to ensure adequate strength, ductility, and layer adhesion
  - Conduct Rockwell hardness tests per ASTM E18 and tensile tests per ASTM E8
- Quantify the heat buildup in the printed parts and print bed and, depending on need, add a cooling system within the machine that does not affect the shielding gas
- Develop a method to remove parts within the enclosed system. Without an EDM, the build plate needs to be milled off which creates an excess of wasted material.

Project Sponsor: Sarah Lanci, Associate Professor of Mechanical Engineering, CMU | Acknowledgments: Karl Castleton, Associate Professor of Computer Science, CMU; Chris Penick, Assistant Professor of Mechanical Engineering, CMU