OPTICAL PICK AND PLACE MACHINE

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Optical Pick and Place Machine

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The current market does not contain a low-cost machine capable of building optical surface mounted devices (SMDs). This project attempts to design a machine capable of handling optical parts which are highly sensitive components that rely on accurate placement. The machine will be a mixture of existing technology and specifically designed parts. This machine was designed around a Computer Numeric Control (CNC) machine frame (OpenBuilds). A controller conducts all actions performed by the machine. These actions include motion along x-, y-, and z-axes along with rotational motion. There is also a dual-camera subsystem which helps the user to determine ideal optical part placement. The machine is reprogrammable by using opensource software. Overall, it will provide optical SMD design capability to a larger population by decreasing the cost of such a machine.

ACKNOWLEDGEMENTS

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NOMENCLATURE

SMD	Surface Mounted Device
OPnP	Optical Pick and Place Machine
mm	Millimeter
MDF	Medium Density Fiber
Hz	Hertz
V	Volt

CHAPTER I

INTRODUCTION

Researchers who build optical SMDs are required to build with high accuracy. This is due to the sensitivity of light as it travels as a ray. Therefore, modern, manufactured optical pick-and-place machines are expensive pieces of equipment. Not all laboratories can afford to pay the price of these machines. Through the combination of inexpensive existing equipment and custom subsystem designs this project develops a cheaper option for laboratories for small-scale optical SMD manufacturing.

Existing technologies

The 3-axis frame and lead screw motion systems are a CNC machine designed by OpenBuilds. This ensures accurate movement of the router. A Spark Concepts controller operates the CNC machine along with other subsystems (CNC XPRO Controller V3).

New and integrated designs

The router of the CNC machine is replaced by a new head for pickup and imaging of optical parts. This head includes a pan kit, a stainless-steel nozzle, and two cameras. The nozzle is operated by a vacuum which is controlled by the Spark Concepts controller. The cameras also provide the user with an ability to see transparent optical parts at an angle.

CHAPTER II

METHODS

Design of the OPnP is based on the requirements set forth by Dr. Madsen. The CNC machine was chosen by Dr. Madsen as it met her expectations and stability and axis motion accuracy. These expectations also set the requirements for choosing the optimal parts.

Table 1 depicts the logic behind each choice made for subsystem designs. All aspects of each subsystem were taken into consideration when choosing or designing parts. Parts were then chosen upon reaching the optimal solution for the specific subsystems. If any parts are to fail, then that part will undergo troubleshooting, and, if necessary, different parts will be purchased depending on requirements.

Table 1: Subsystem Specification Requirements for Subsystem Design

Optical Subsystem	**Nozzle Suction Subsystem**	**Lead Screw Motion Subsystem**	**Controller/Software Subsystem**	**Rotation Subsystem**
Must see objects of 1mm dimension	Must pick up parts of 1mm dimension	0.05mm – 0.1mm motion accuracy	Compatible with CNC machine and subsystems	1 degree of rotational accuracy
Must send live images to computer	Must set down parts without offset	Cost within budget	Cost within budget	Cost within budget

Final testing will determine if the placement of optical parts meet the motion accuracy and if the user interface allows for placement accuracy. Any failures that occur will incur the proper adjustments.

CHAPTER III

RESULTS

Lead Screw Motion Subsystem

The 3-axis motion subsystem performed to required standards along each axis. This ensures proper motion for placement of optical pieces. The x- and y-axes move along 500mm metal rails; meanwhile, the z-axis maneuvers along a 250mm rail. NEMA 23 Stepper motors drive each axis individually. The gantry plate, which is a block of Medium Density Fiber board, is driven linearly along the y-axis. The x-axis controls side-to-side motion of the head. Finally, the z-axis moves the head up and down in relation to the resting platform (OpenBuilds).

The pitch of each lead screw is 2mm. During validation testing, each stepper motor was fed at a rate of 500mm/minute. Each axis had 10 tests performed during this process. The following table describes the data results.

Table 2: Lead Screw Data Table

Data Type	X-axis (mm)	Y-axis (mm)	Z-axis (mm)
Sample Standard Dev.	0.1155	0.0699	0.0949
Sample Var.	0.0133	0.0049	0.0089
Population Standard Dev.	0.1096	0.0663	0.0900
Population Var.	0.0120	0.0044	0.0081
Mean	9.9840	10.04	10.07
Standard Error of Mean	0.0365	0.0221	0.0300

Rotation Subsystem

The rotation subsystem uses a professional camera lens pan kit. It is driven by a 0.5 rpm 7.52V motor. The motor is coupled to a gear which turns a second gear with a gear ratio of 4.2:1. Figure 1 displays the hollow-shaft gear drive pan kit (Gear Drive Pan Kit).

Figure 1: Hollow-Shaft Gear Drive Pan Kit

The second gear is attached to the nozzle via the 3-D printed coupling device shown in Figure 2. This device will be glued to the tubing which holds the nozzle. Thus, this enables rotation of the nozzle tip.

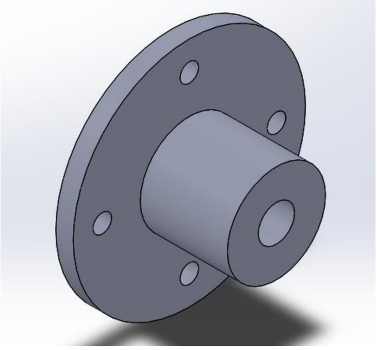


Figure 2: Tubing Fastener

Figure 3 shows the rotation subsystem. Pneumatic tubing is run through the center of the pan kit and touches the nozzle fastener. This allows parts to be picked up with suction, then rotated to meet their desired angle of placement.

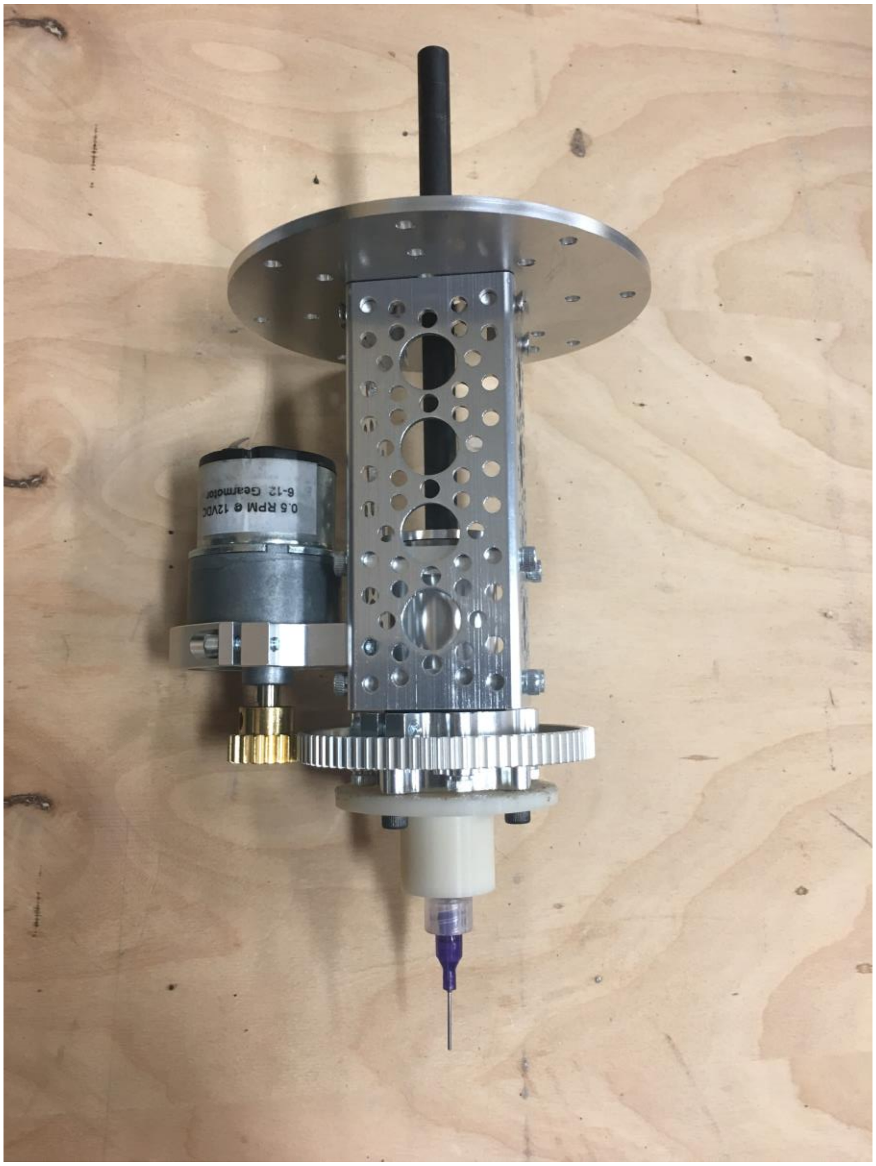


Figure 3: Full Rotational Subsystem Build

Table 3 shows four tests completed to determine rotational accuracy. The second column displays the angular speeds of the pan kit and the average of these speeds. This average speed was used to calculate the time it would take to rotate exactly fifteen degrees. Then it was calculated how many degrees each angular speed would incur if rotating for the same amount of time. This gives the rotational precision in relation to the mean angular speed. Rotation sometimes gave the desired accuracy of within 1 degree, but other times it did not. This will be further mitigated to provide the greatest accuracy possible.

Table 3: Rotational Accuracy Testing Results

Test Number	Angular Speed (degrees/s)	Calculated Angle (degrees)
1	0.4545	15.07
2	0.4982	16.52
3	0.4390	14.55
4	0.4176	13.85
Average	**0.4523**	**15.00**

Imaging Subsystem

The ELP USB camera has a lens which is 2.1mm wide that displays at a resolution of 2.1 Megapixels. It was tested at this resolution and a framerate of 30 frames per second. It also has a flicker reduction which operates at 60 Hz. This camera connects to a computer's USB port (ELP USB2.0 Webcam).

The camera was tested at 3 inches from a resolution target. This test determined that the spatial resolution of the camera is 0.2677364mm at this distance. This is well within the 1mm resolution requirement of the OPnP. Figure 4 displays the result of this test.

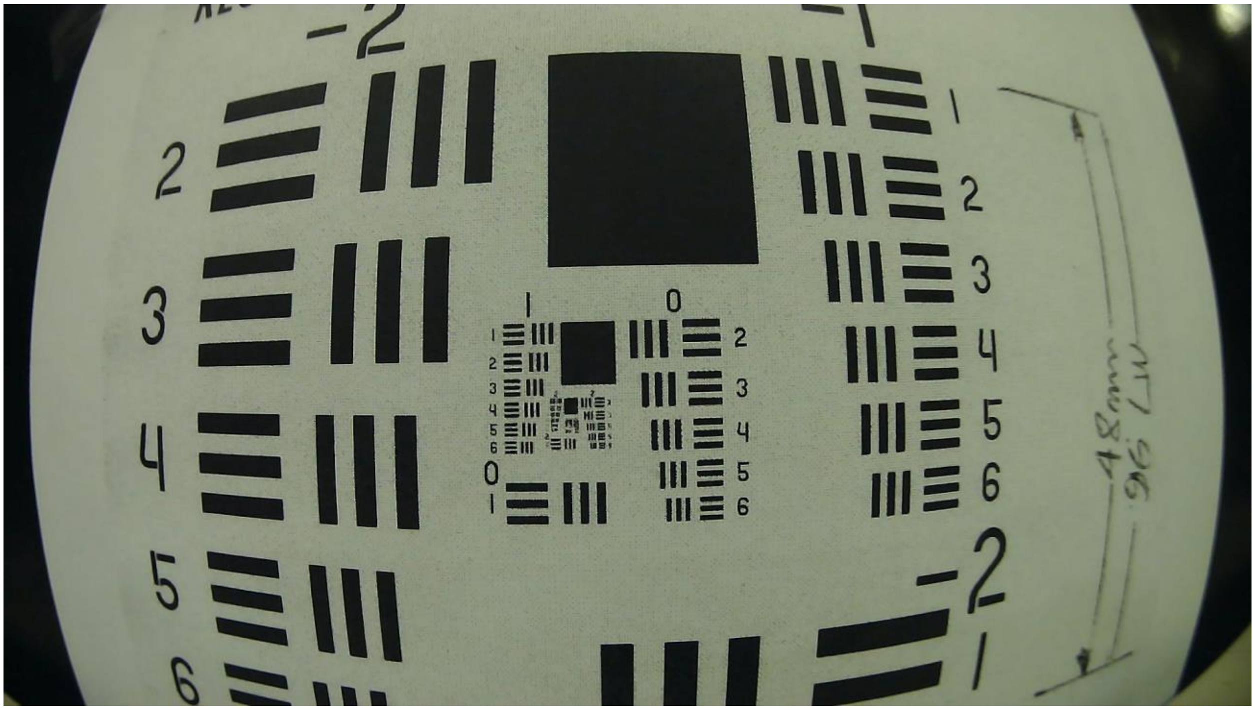


Figure 4: Spatial Resolution Test

Additional tests were performed to ensure that the camera could distinctly display small parts with detail. These tests were performed with grid lines 16/17mm apart. Figure 5 displays a test taken from 10.16cm away and Figure 6 displays a closeup test.

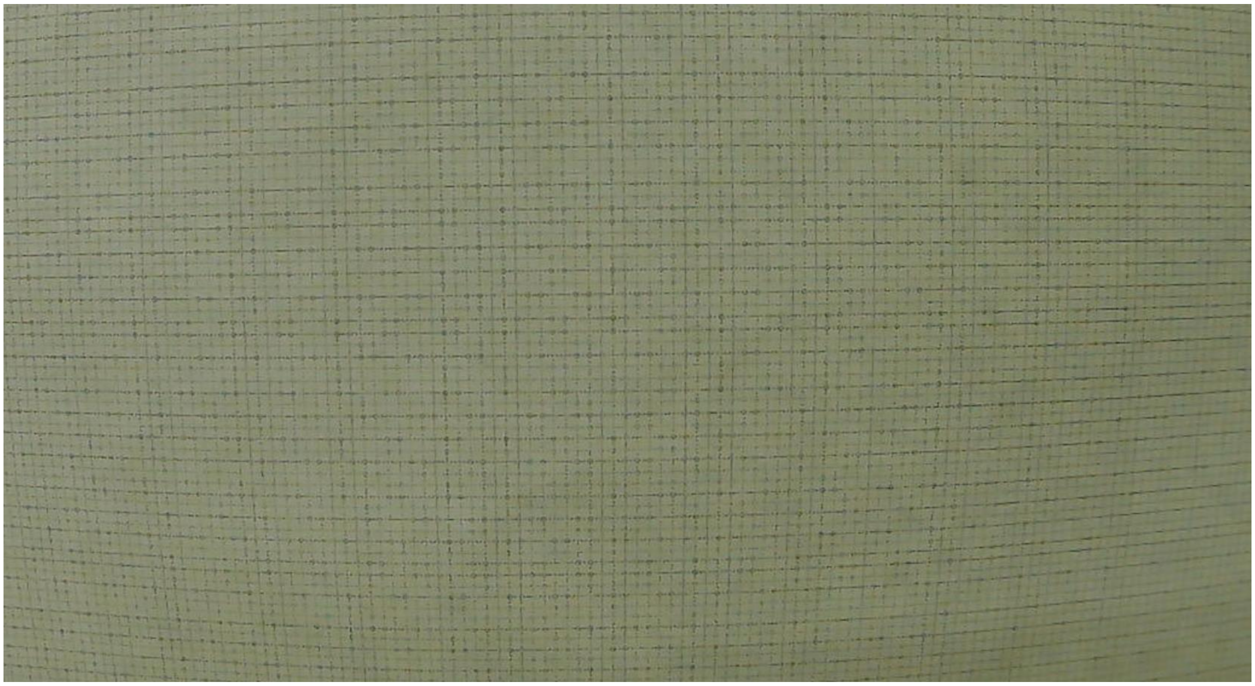


Figure 5: Image with Camera 10.16cm Away

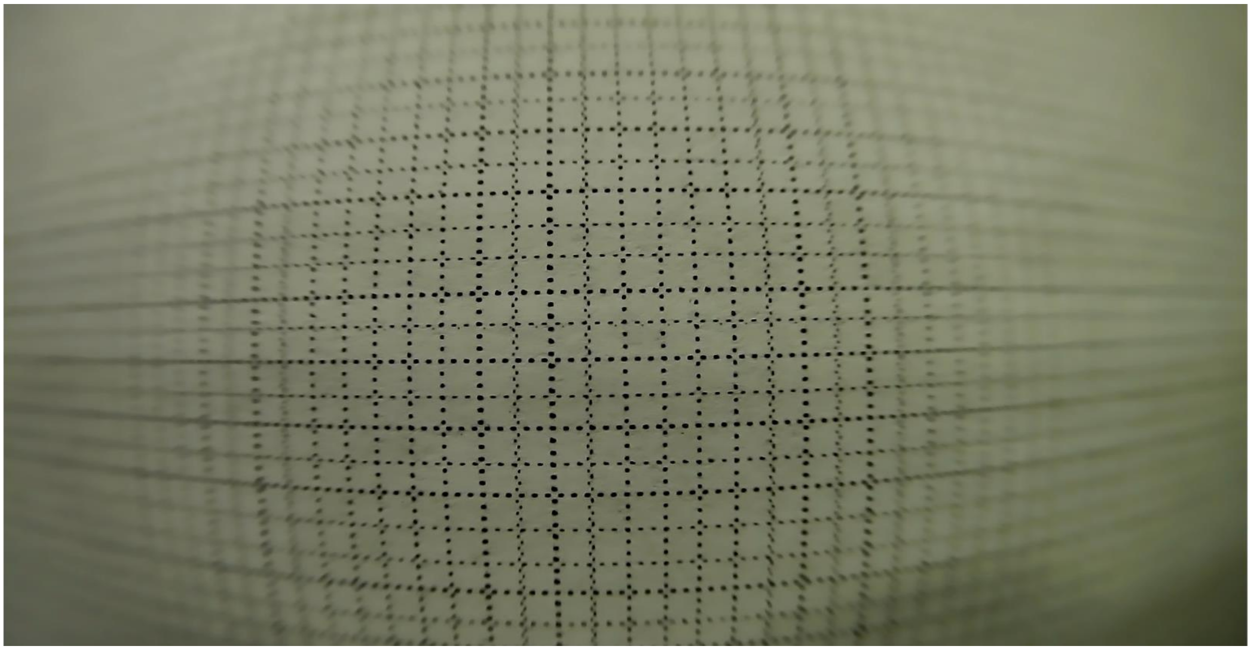


Figure 6: Camera Closeup of Grid

Figure 7 shows a prism being picked up by the nozzle. The prism is of dimensions 6.5mm x 6.5mm x 2mm, and it is 7.5cm away from the camera. All lights in the laboratory were turned off apart from one flashlight. This gives the camera superior distinguishing abilities over total overhead lighting conditions. The prism was difficult to see in bright conditions.

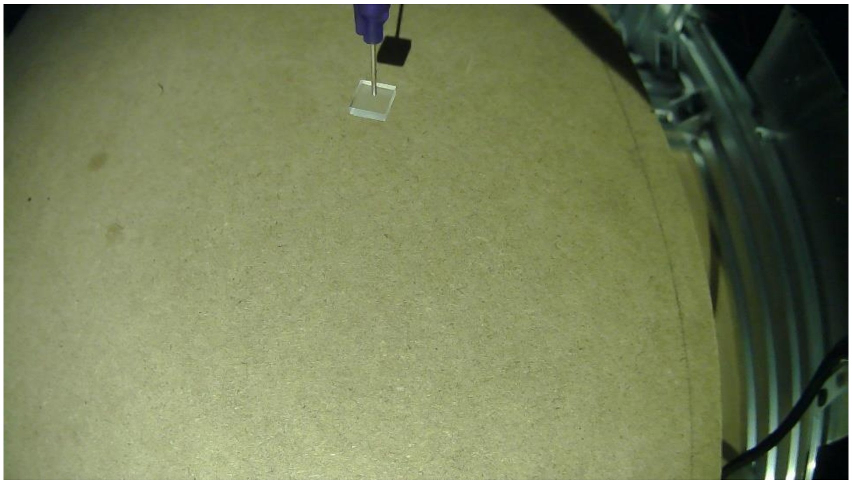


Figure 7: Nozzle Holding Prism in Dark Lighting

Figure 8 shows the same prism held with all overhead lights activated.

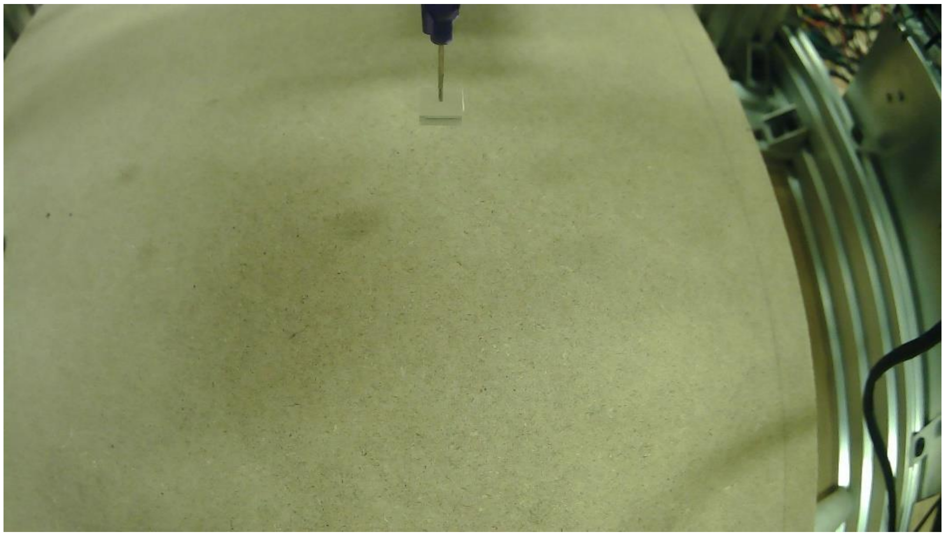


Figure 8: Prism from Figure 7 Held in Total Overhead Lighting Conditions

Figure 9 shows the nozzle holding 10mm x 2mm x 1mm prism. This is visible in total overhead lighting.

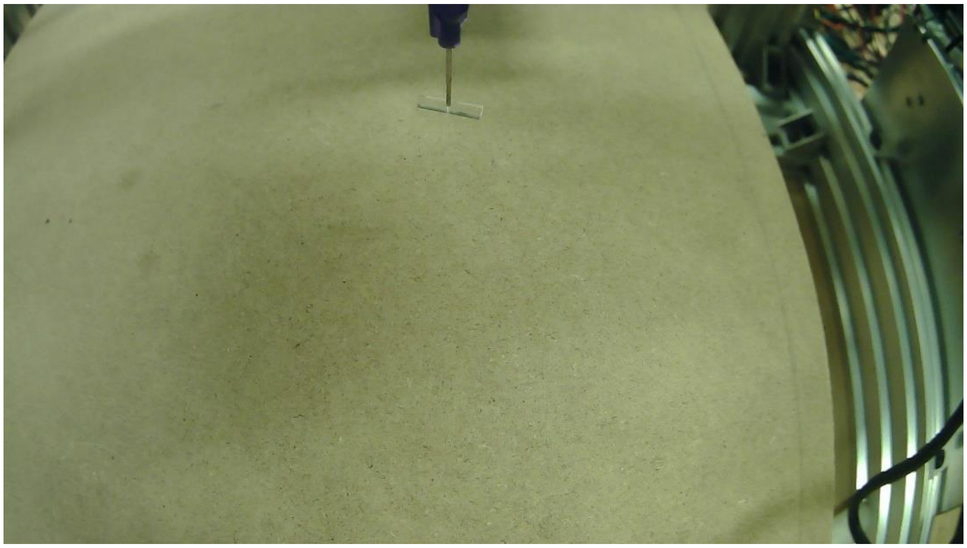


Figure 9: Long Prism Held and Imaged Successfully

Figure 10 also displays the nozzle holding an 8mm x 2mm x 1mm prism. This image was conducted in total overhead lighting.

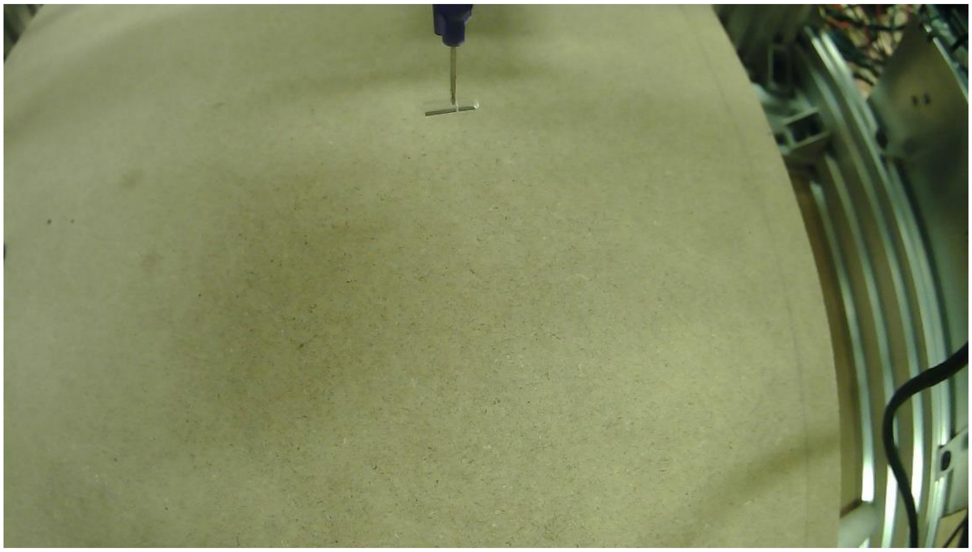


Figure 10: 8mm Long Prism Held and Imaged Successfully

Figure 11 was taken under total overhead light conditions, but the background was white paper instead of MDF board. The dimensions of the part are 5mm x 2mm x 1mm. User preference and application will determine which lighting system is best for their project.

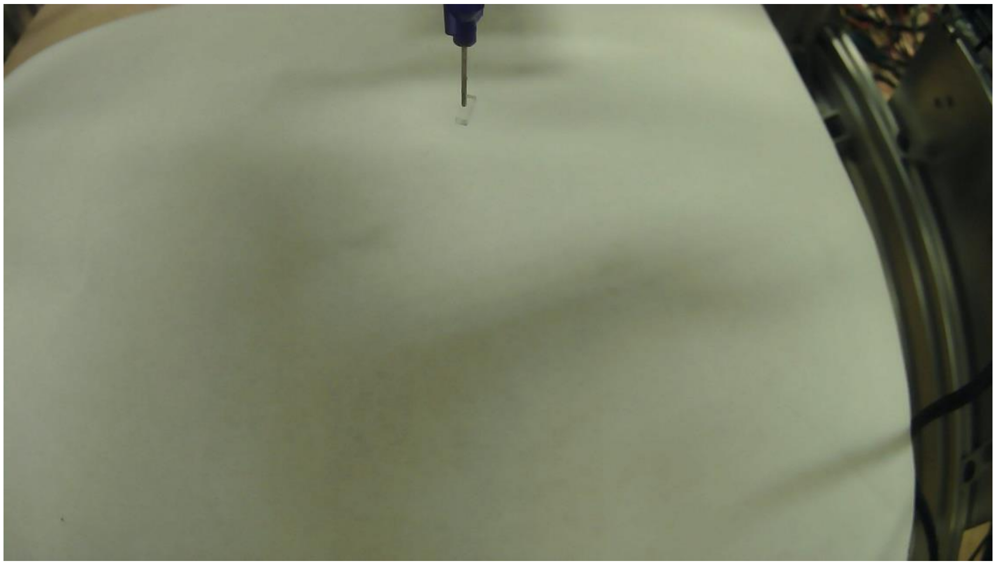


Figure 11: Small Prism Imaged with White Background

The cameras are affixed to the head via 3-D printed material which will be screwed to the pan kit. Their mounts are displayed in Figure 12. These were 3D printed with ABS plastic for stability.

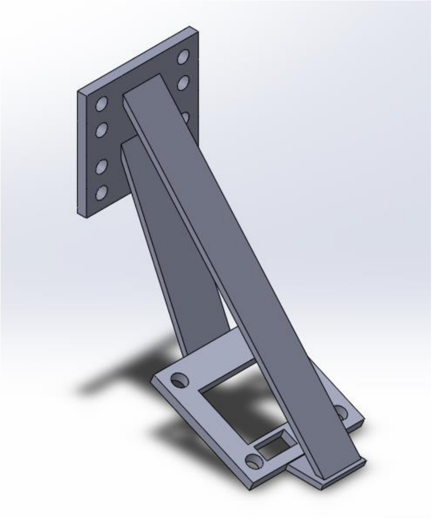


Figure 12: Camera Mount

Table 4 shows the specifications of the USB camera. These specifications establish the limits of the cameras' capabilities.

Table 4: ELP USB Camera Specifications

Sensor Type	1/3'' CMOS OV2710
Lens Characteristics	2.0MP, 200W
Maximum Resolution	1920 x 1080p
Image Format	MJPEG
Driver	UVC 1.1
Voltage	5V DC
Current	150 mA
Operating Temperature	20 – 70 °C
Dimensions	1.5'' x 1.5''

Vacuum Subsystem

The Meanwell 24V power supply provides the controller with the requisite power to create suction to pick up the required optical pieces. It powers the controller and a MOSFET attached to the pump. As the Coolant output is activated on the controller, the pump is turned on and provides suction through the nozzle. This nozzle is part of the LitePlacer pick-and-place machine, and it was reused on this machine due to it meeting the size requirements. Figure 13 displays the stainless-steel nozzle. The nozzle has an outer diameter of 0.79mm (LitePlacer).

Figure 13: Stainless-Steel Nozzle

This nozzle is fixed to the tubing via a metal pipe. Figure 14 shows how the nozzle will be fastened to the head, and how suction power fidelity is achieved. Plastic tubing runs from the pump, through the pipe, and to the nozzle cap. Since the tubing has to run through the pipe, air does not escape. This pipe runs through the hollow shaft of the pan kit where it is securely fastened to the rotational subsystem.

Figure 14: Head Plate with Dimensions

Table 5 displays the power validations across the pump.

Table 5: Pump Power Validation

Pump Power Validation	
Measurement	**Voltage (V)**
5V Controller Output	4.6
Power Supply Voltage	24
Voltage Across MOSFET	4.6

Figure 15 shows the fully integrated head design with cameras looking at the nozzle tip. The pump successfully picked up and held pieces with dimensions shown in Table 6.

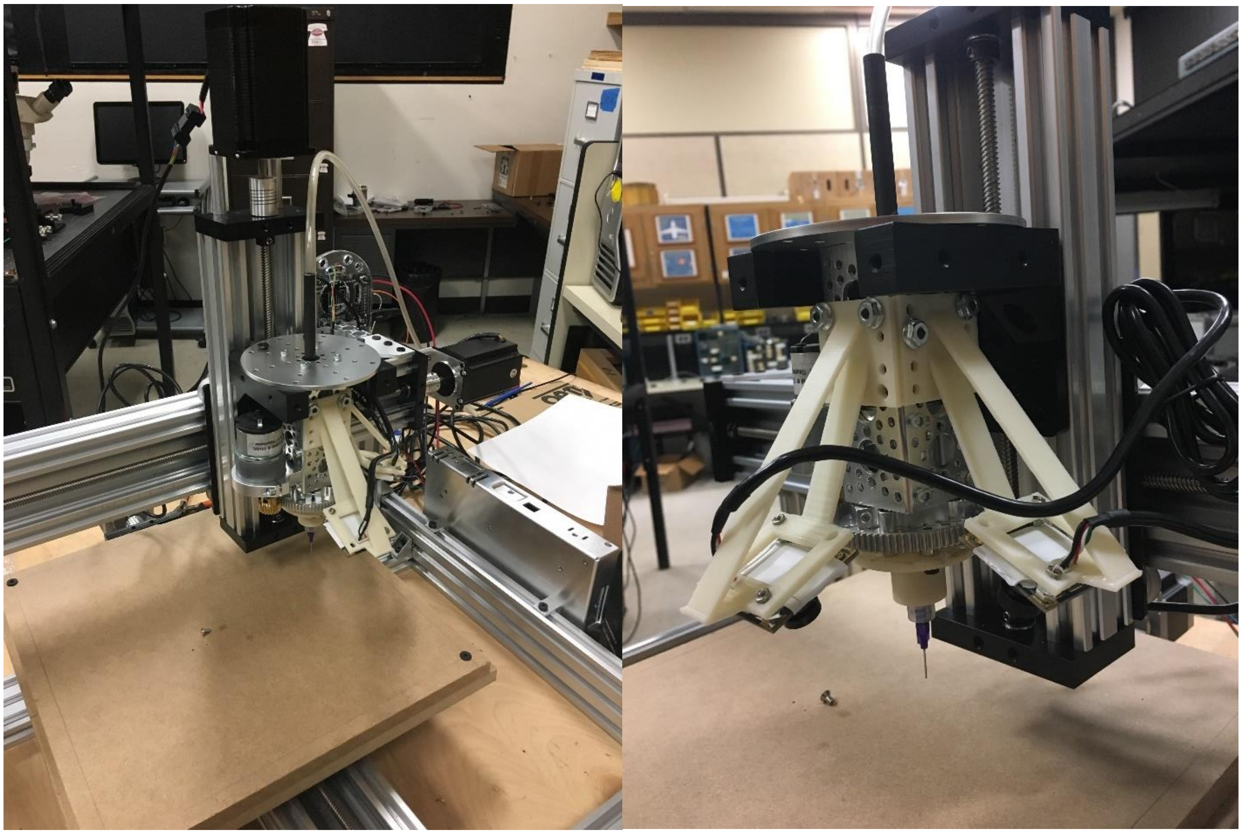


Figure 15: Complete Head Design

Table 6: Validated Prism Dimensions

	Prism Number			
	Prism 1	**Prism 2**	**Prism 3**	**Prism 4**
Length (mm)	6.5	10	8	5
Width (mm)	6.5	2	2	2
Depth (mm)	2	1	1	1

Software Subsystem

A SparkConcepts xPRO V3 controller receives its power from the Meanwell 24V power supply. The purpose of this is to controls the motion of the three axes. It also has a variable 4.6V Coolant output for the pump and a variable 5V spindle output for the DC motor. The spindle output, however, can only put out 2V. Therefore, it powers a transistor which enables the power supply to run the DC motor when the spindle is activated. Figure 16 displays the wiring schematic.

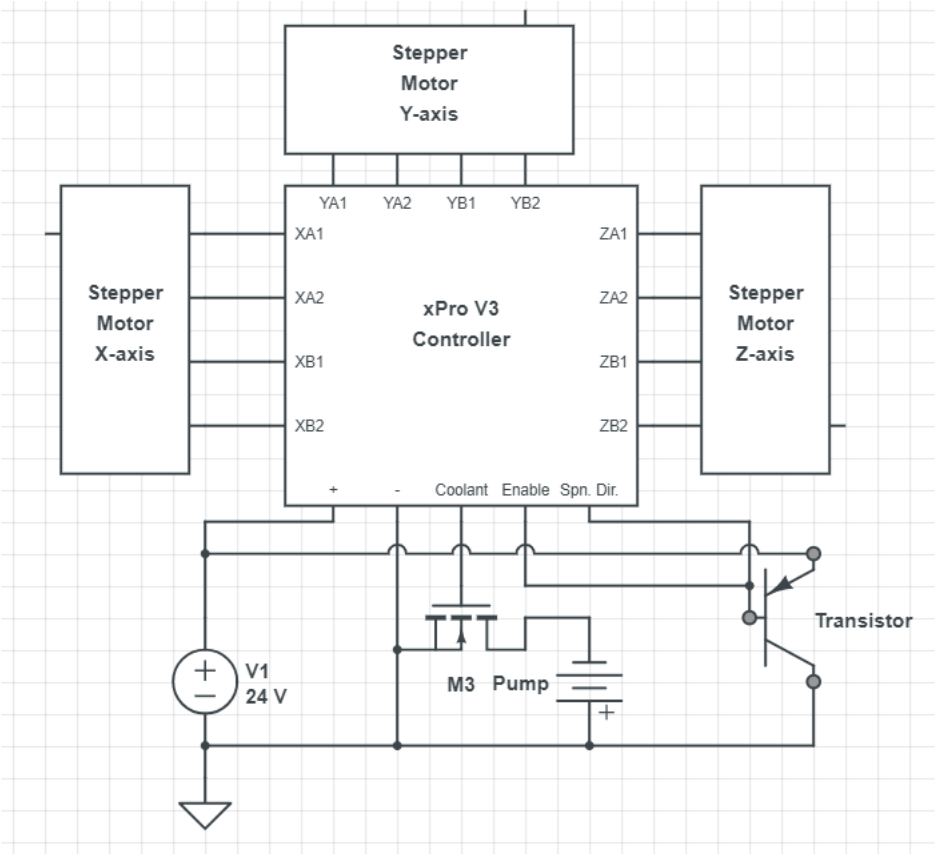
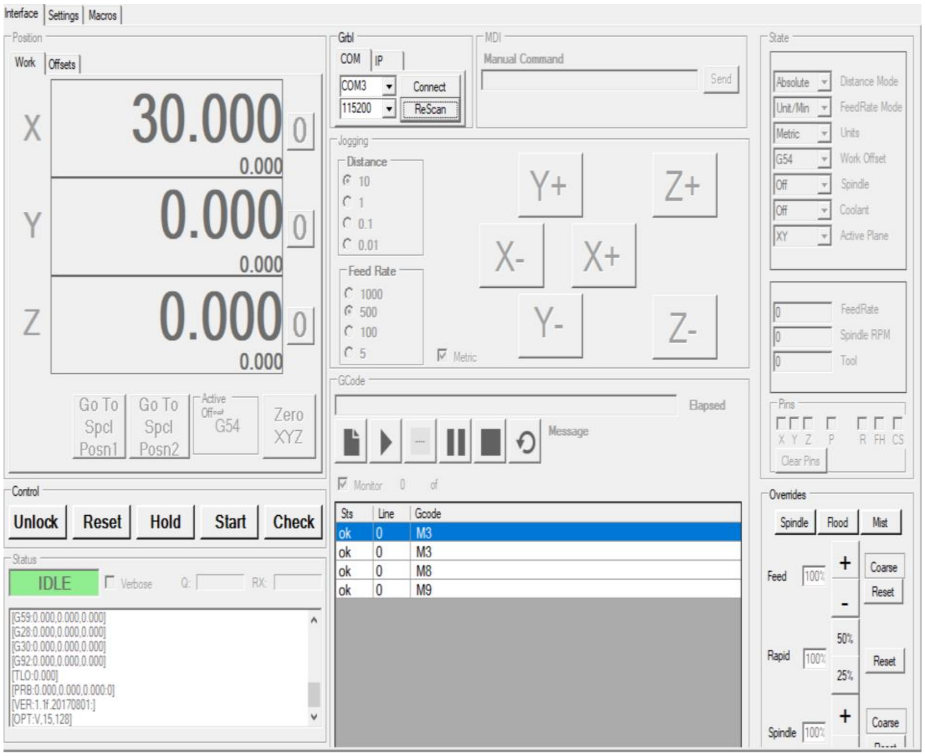


Figure 16: OPnP Wiring Schematic

The user interacts with the OPnP via a program called Grbl Panel. This panel is an interface between GRBL software and the controller. Importantly, this program allows the user to individually control all three axes, the pump power, and the spindle. The spindle output requires both the ‘Enable’ and ‘Spindle Direction’ to be activated to output a voltage. Figure 17 displays the user-controller interface for Grbl Panel. The ‘Position’ section shows the user where the nozzle tip is located on a user-designated grid. The ‘MDI’ section allows the user to input individual commands using GRBL’s language, GCode. Moreover, the user can press buttons to easily step across the three axes in the ‘Jogging’ section. ‘Distance’ describes the size of the step, and ‘Feed Rate’ determines how quickly the nozzle will move. The ‘State’ section allows the user to drop down options to determine specific actions for the machine. For instance, the ‘Spindle’ dropdown turns the DC motor on and off, and ‘Coolant’ operates the pumps. The user does not have to use these dropdowns to control these functions, however. The user can also operate these with GCode.



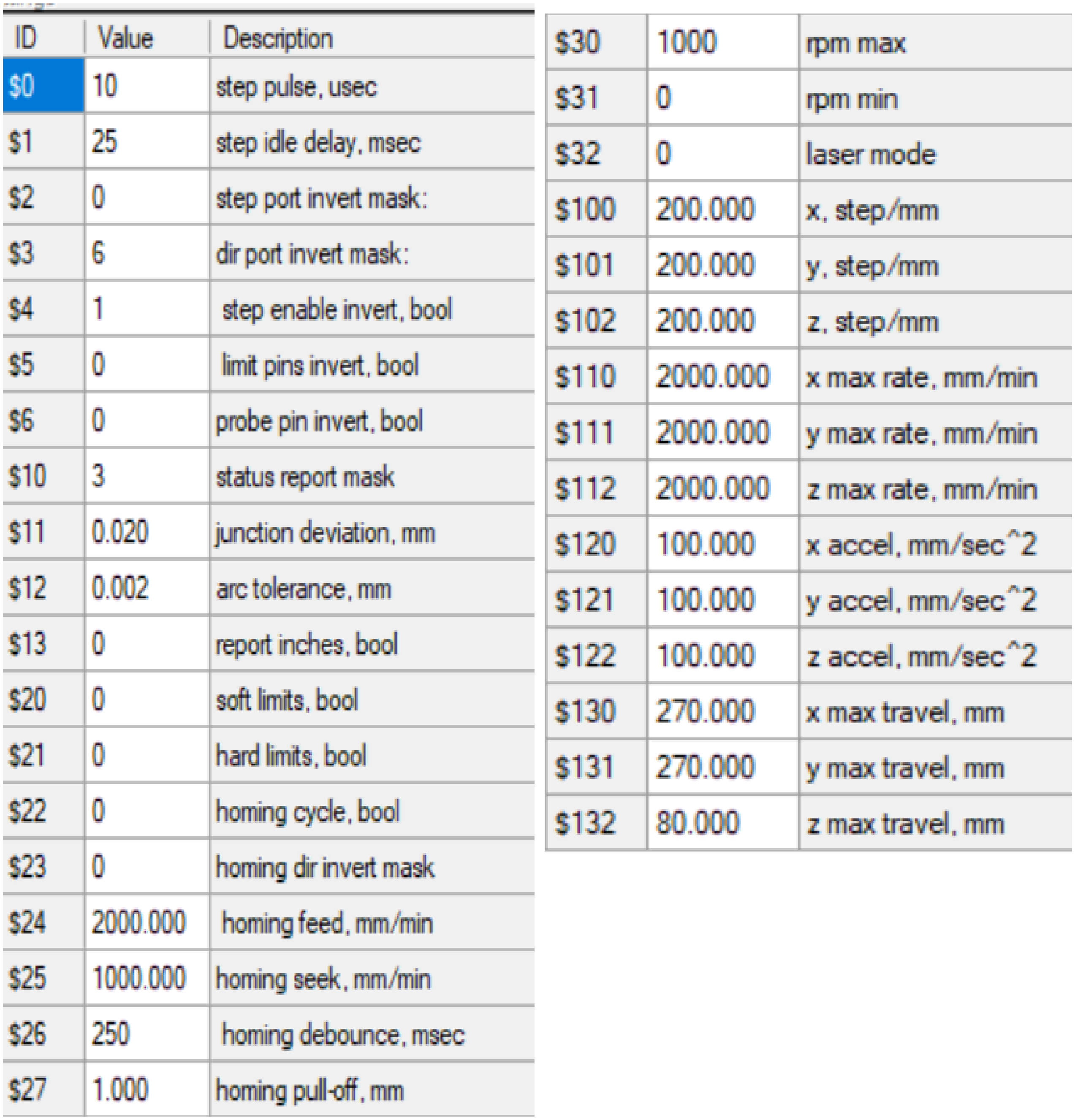
```
[G59:0.000,0.000,0.000]
[G28:0.000,0.000,0.000]
[G30:0.000,0.000,0.000]
[G92:0.000,0.000,0.000]
[TLO:0.000]
[PRB:0.000,0.000,0.000:0]
[VER:1.1f.20170801:]
[OPT:V,15,128]
```

Sts	Line	Gcode
ok	0	M3
ok	0	M3
ok	0	M8
ok	0	M9

Absolute Distance Mode
Unit/Min FeedRate Mode
Metric Units
G54 Work Offset
Off Spindle
Off Coolant
XY Active Plane
0 FeedRate
0 Spindle RPM
0 Tool

Figure 17: Grbl Panel User Interface

Figure 18 displays the settings required to operate the OPnP machine. Some of these settings can be changed, as specified by the user, but Booleans must remain the same.



ID	Value	Description
$0	10	step pulse, usec
$1	25	step idle delay, msec
$2	0	step port invert mask:
$3	6	dir port invert mask:
$4	1	step enable invert, bool
$5	0	limit pins invert, bool
$6	0	probe pin invert, bool
$10	3	status report mask
$11	0.020	junction deviation, mm
$12	0.002	arc tolerance, mm
$13	0	report inches, bool
$20	0	soft limits, bool
$21	0	hard limits, bool
$22	0	homing cycle, bool
$23	0	homing dir invert mask
$24	2000.000	homing feed, mm/min
$25	1000.000	homing seek, mm/min
$26	250	homing debounce, msec
$27	1.000	homing pull-off, mm
$30	1000	rpm max
$31	0	rpm min
$32	0	laser mode
$100	200.000	x, step/mm
$101	200.000	y, step/mm
$102	200.000	z, step/mm
$110	2000.000	x max rate, mm/min
$111	2000.000	y max rate, mm/min
$112	2000.000	z max rate, mm/min
$120	100.000	x accel, mm/sec^2
$121	100.000	y accel, mm/sec^2
$122	100.000	z accel, mm/sec^2
$130	270.000	x max travel, mm
$131	270.000	y max travel, mm
$132	80.000	z max travel, mm

Figure 18: OPnP Settings

CHAPTER IV

EXPECTATIONS

The expectations for the OPnP revolve around the ability to place parts within the accuracy defined by the lead screw motion subsystem and the ability for the user to operate the machine. A machine capable of operating optical rectangular prisms with dimensions of 10mm x 2mm x 1mm, 8mm x 2mm x 1mm, 5mm x 2mm x 1mm, and 6.5mm x 6.5mm x 2mm is required. The camera subsystem also must help the user see these small, transparent parts. Thus, there will be two cameras on the OPnP. One camera looks down the x-axis, and the other looks down the y-axis. The reason for the two cameras is to center the nozzle’s position above optical pieces. Ultimately, the process should become fully automated as the user writes scripts for the machine to follow. By the end of the year, however, the goal will be to take parts, pick them up, rotate and move them, then set them down with desired accuracy. This will be accomplished and demonstrated to judges on April 22, 2019. The successful operation on all optical pieces will allow for a viable Optical Pick and Place machine.

CHAPTER IV

CONCLUSION

The purpose of this project is to fulfill a niche in the market for a small-scale, low-cost pick-and-place machine that operates optical pieces. Designs from other manufacturers are combined with new design to provide a proof-of-concept that this machine can exist. Its intent is to provide optical SMD manufacturing capability to a larger audience.

Overall, this was a high-level design project. Much of the project was focused on successfully building and integrating existing technologies. Physical modifications were required to integrate the subsystems. When this was not possible, 3D printed parts were used for integration.

Low level design includes the circuitry for the controller’s electrical outputs. Each port was chosen to maximize efficiency and minimize cost of the project. Thus, the project was kept to an affordable price, and it provided proof-of-concept that this machine can be created for small-scale manufacturers.

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