PnPAL – Pick and Place with Acoustic Levitation

Group 33 Members

Jonathan Williams	Ryan Houck	Omari John
Project Manager, Engineer	*Engineer*	*Engineer*
B.S. Electrical Engineering	B.S. Electrical Engineering	B.S. Electrical Engineering

Project Review Committee

Dr. Piotr Kulik	ECE Professor, AIMS Lab
Dr. Daniel Hedlund	Post-Doctorate Scholar, AIMS LAB
Mr. Mark Maddox	ECE Lecturer, University of Central Florida

Advisor

Dr. Sreeram Sundaresh	ECE Lecturer, Senior Design I and II

Motivation

Amidst an ever-inflating demand for electronics manufacturing, there is also a need for more precise and efficient systems of assembling printed circuit boards. Traditional pick and place machines on pneumatic (or suction grips) can lead to damage on surface-mount components and more importantly collect residue like dirt and dust over time. There are also issues arising from equipment problems such as inadequate vacuum pressure, component malfunction, and surface irregularities. Acoustic levitation, a non-contact manipulation technique, presents a novel solution to the problem by using sound waves to suspend and move objects. Our project aims to harness technology to create a new generation of pick-and-place machines, addressing the limitations of current methods. This project will serve as a proof-of-concept, demonstrating the feasibility of using acoustic levitation for precise, non-contact component placement.

Goals and Specifications

Basic Goals

- **Functionality:** A functional prototype capable of picking up and placing a two types of different SMC sizes (e.g., a simple resistor or capacitor).
- **Accuracy:** Achieve a placement accuracy of about +-2 mm.
- **Control:** Implement a basic user interface for initiating the pick and place sequence.

Advanced Goals

- **Multiple Components:** Ability to handle and place at least five different types of SMCs.
- **Fiducial Recognition:** Implement a vision system to recognize fiducial markers on the PCB for automated alignment.
- **Speed:** Complete a single pick and place cycle within 30 seconds.

Stretch Goals

- **Component Orientation:** Implement a vision system to detect and correct the orientation of components.
- **Advanced UI System:**
- **Increased Speed:** Reduce the pick and place cycle time to under 15 seconds.
- **Variable Payload:** The ability to levitate and place components of varying sizes and weights within a specified range.
- **Improved Accuracy:** Improve placement accuracy to about +-1 mm.

Features and Functionalities

The system will operate in three primary stages:

1. **Pickup:** The gantry system will move the acoustic levitator array above a component. The levitator will then be activated, lifting the component off its holder.
2. **Transport:** The gantry system will move the levitating component to the designated location on the PCB.
3. **Placement:** The levitation will be deactivated, allowing the component to be gently deposited onto the solder paste on the PCB.

These operations are controlled by a central microcontroller and are monitored by a vision system. The user will interact with the system via a simple console to start and stop the process.

Existing Product/Past Projects/Prior Related Work

Acoustic levitation has been explored for various applications, including material handling, fluid manipulation, and medical research. However, its use in a dedicated, high-precision pick-and-place machine for SMCs remains a niche area of study. While commercial pick-and-place machines are mature, they do not utilize this non-contact method. This project builds on foundational research in acoustic levitation and applies it to a practical engineering problem, drawing inspiration from the control and gantry systems of existing CNC machines and 3D printers.

Engineering Specifications

Table 1: Overall System Specifications

Specification	Description	Target Value and Unit(s)
Placement Accuracy*	The deviation between the target location on the PCB and the final placed position.	+- 0.5 mm
Cycle Time*	The total time taken for one complete pick and place operation.	$\leq 15\ seconds$
Power Consumption	The total power drawn by the entire system under full load.	$\leq 200\ W$
Noise Level	The maximum sound level generated by the ultrasonic transducers.	$\leq 85\ dB$
Dimensions	The overall footprint of the machine.	60 x 60 x 45 cm
Levitation Capacity	The maximum weight of a component that can be levitated.	$\leq 10\ grams$
System Reliability*	The percentage of successful pick and place operations out of a total of 100 trials.	$\geq 95\%$

Component Throughput*	The number of components placed per minute.	2 components/minute
Component Size Range	The range of component sizes the machine can handle.	0603 and 0805 packages

**Demonstrable Specifications: Placement Accuracy, Cycle Time, System Reliability, Component Throughput*

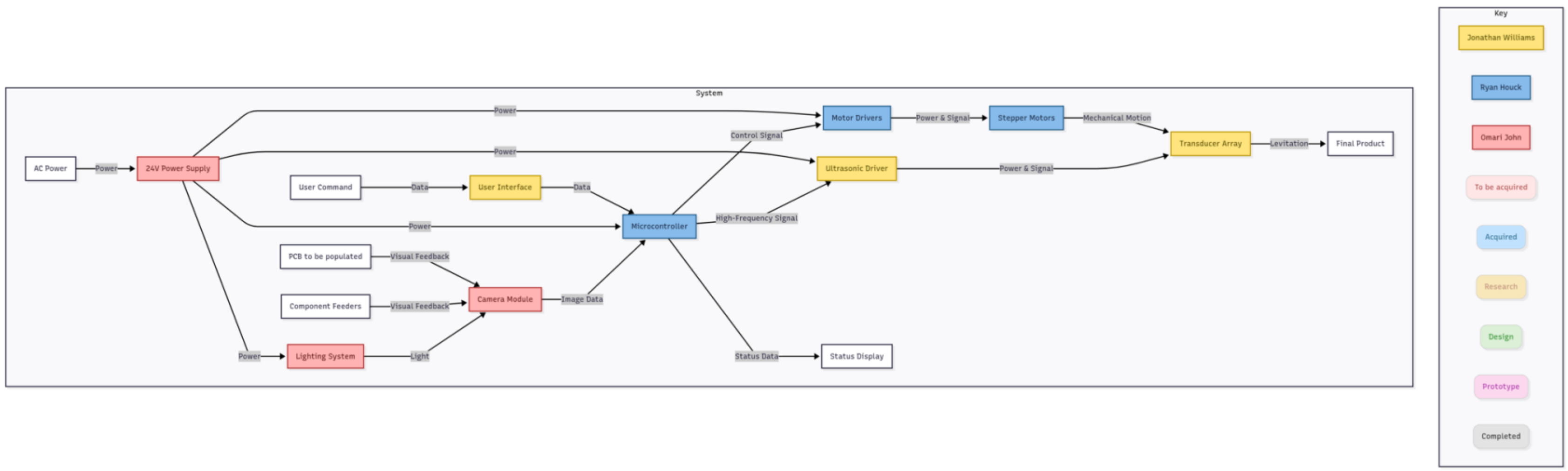
Table 2: Component Specifications

Component	Parameter	Target Value and Unit(s)
Microcontroller	Processing Speed	$\geq 100\ MHz$
Ultrasonic Transducer	Frequency Range	$38 - 42\ kHz$
Stepper Motors	Positional Resolution	$0.01\ mm/step$
Gantry Rails	Backlash	$\leq 0.05\ mm$
Camera Sensor	Resolution	$\geq 5\ Megapixels$
Power Supply	Output Power	$\geq 250\ W$
Motor Drivers	Rated Current	$\geq 2\ A/phase$

Detailed Hardware and Software Diagrams

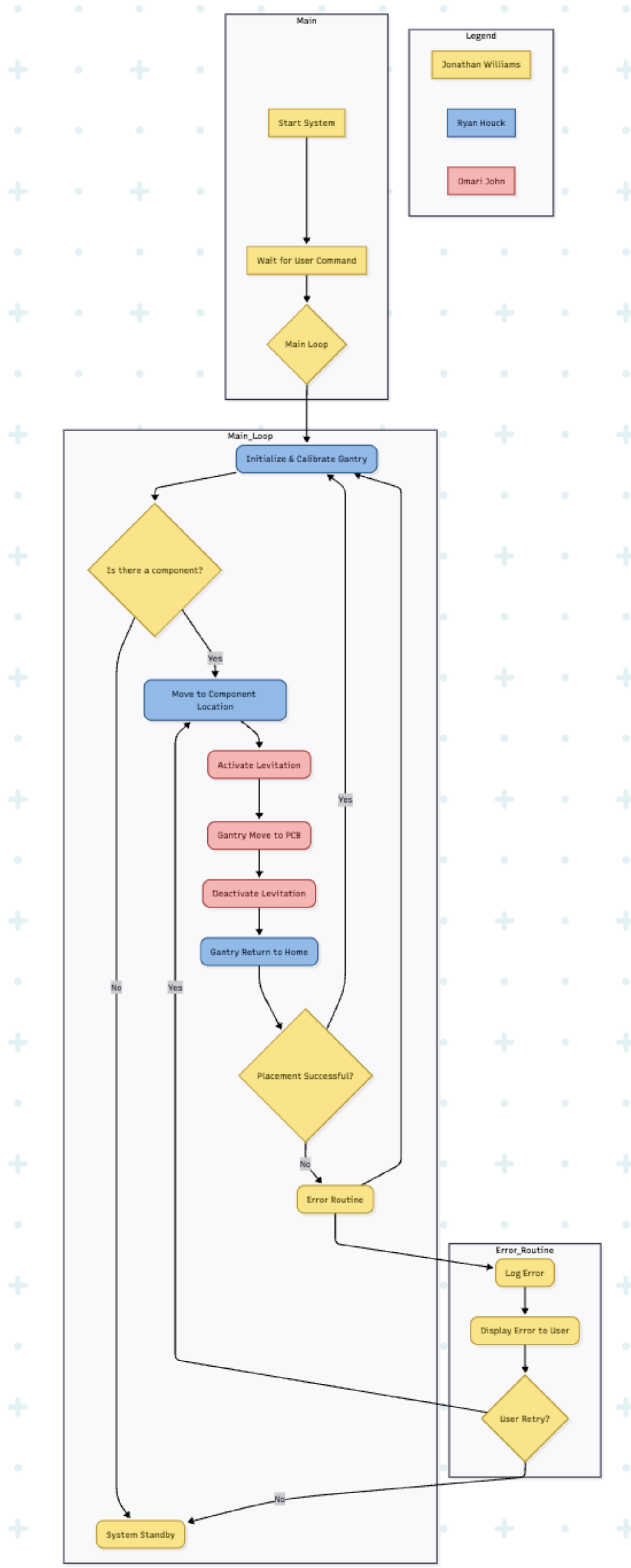
Hardware Block Diagram

This diagram shows the interconnection of all physical components. The work distribution is indicated by color-coded blocks.


System
AC Power
Power
24V Power Supply
Power
Power
Power
Power
User Command
Data
User Interface
Data
Microcontroller
PCB to be populated
Visual Feedback
Component Feeders
Visual Feedback
Lighting System
Light
Camera Module
Image Data
Control Signal
High-Frequency Signal
Status Data
Motor Drivers
Power & Signal
Stepper Motors
Mechanical Motion
Ultrasonic Driver
Power & Signal
Transducer Array
Levitation
Final Product
Status Display
Key
Jonathan Williams
Ryan Houck
Omari John
To be acquired
Acquired
Research
Design
Prototype
Completed

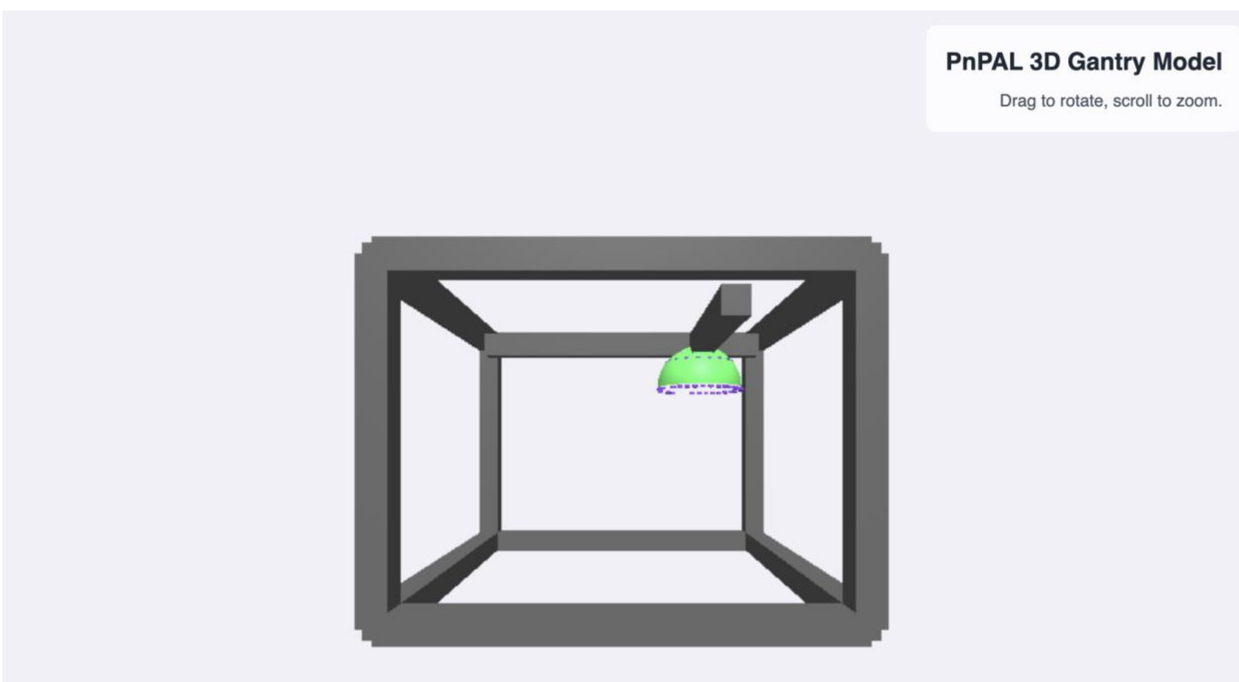
Software Flowchart

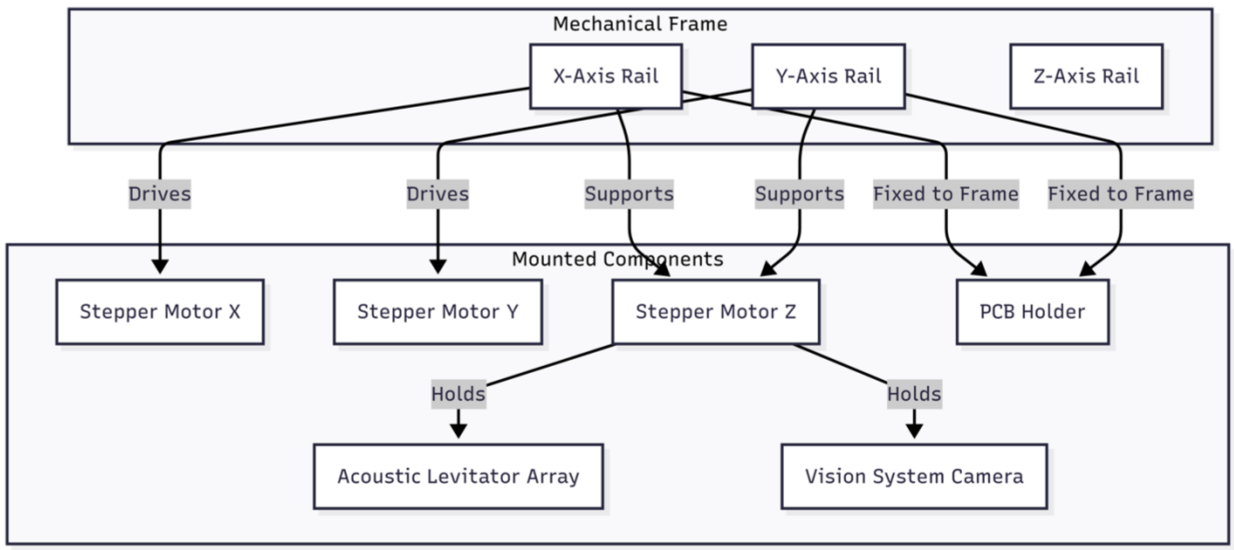
This diagram details the sequence of operations within the software, from startup to a complete placement cycle.


Main
Start System
Wait for User Command
Main Loop
Legend
Jonathan Williams
Ryan Houck
Omari John
Main_Loop
Initialize & Calibrate Gantry
Is there a component?
Yes
Move to Component Location
Activate Levitation
Gantry Move to PCB
Deactivate Levitation
Gantry Return to Home
Placement Successful?
Yes
No
Yes
No
Error Routine
Error_Routine
Log Error
Display Error to User
User Retry?
No
System Standby

Prototype Illustration

The prototype will be constructed using aluminum extrusion for the gantry frame to ensure rigidity and minimize vibration. The motion system will utilize NEMA 17 stepper motors for the X and Y axes and a smaller motor for the Z axis to control the levitator's height. The ultrasonic transducer array, comprised of 72 transducers, will be mounted at the end of the Z-axis. A down-facing camera will be mounted parallel to the levitator for component and fiducial detection. All electronics will be housed in a separate enclosure for safety and organization.



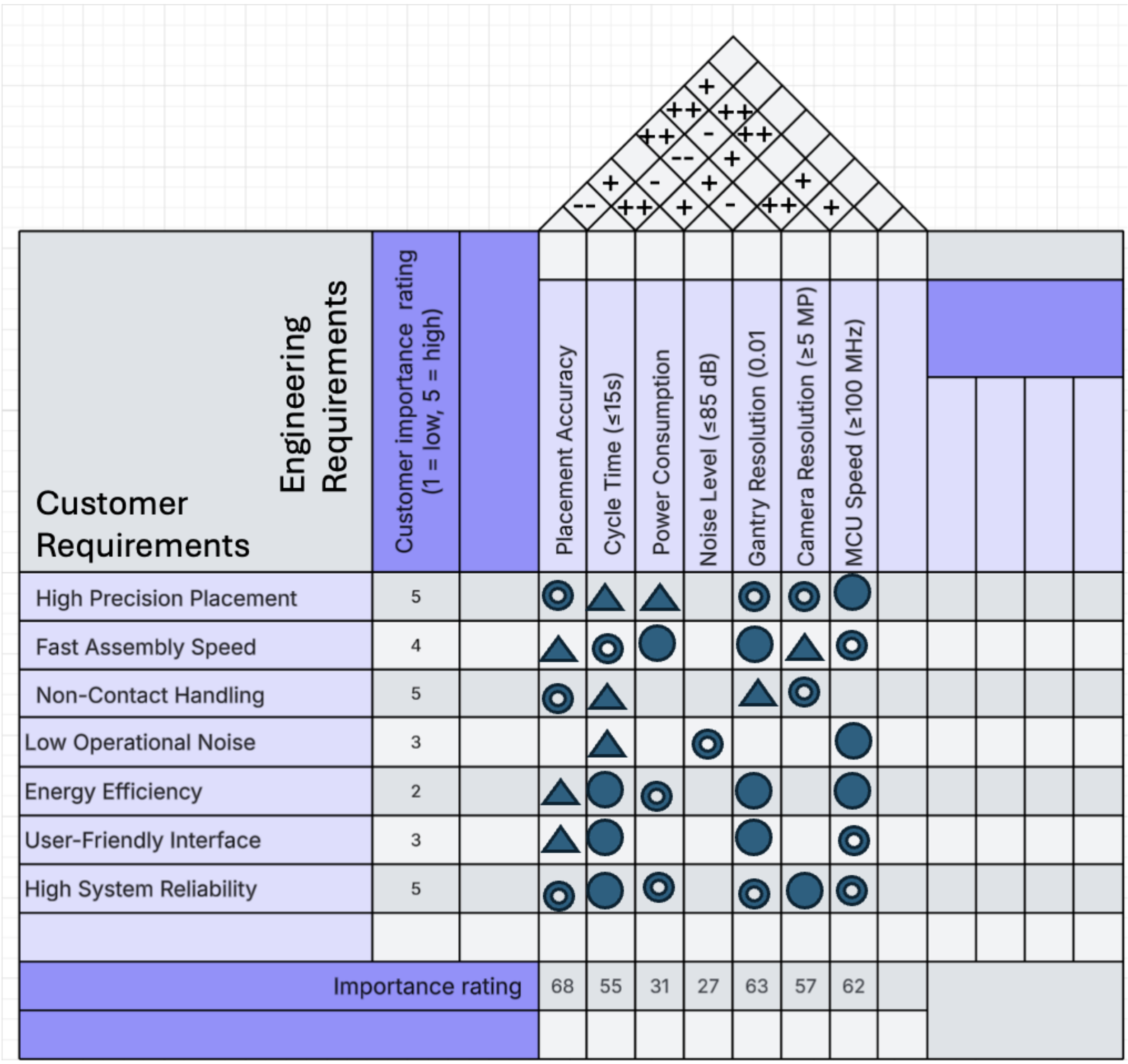


House of Quality

A House of Quality (HoQ) matrix will be developed to formally link customer desires (e.g., "fast assembly," "non-contact handling") to our engineering specifications. This will help us prioritize which engineering requirements, such as "cycle time" and "levitation capacity," have the most significant impact on the final product's success.

Relationship Key	
◎	Strong Relationship (9 pts)
●	Medium Relationship (3 pts)
▲	Weak Relationship (1pt)

Interrelationships Between Engineering Characteristics	
++	Strong Positive Relationship
+	Weak Positive Relationship
-	Weak Negative Relationship
--	Strong Negative Relationship
	No correlation



Budget and Bill of Materials

The total estimated budget for this project is currently $2,250. This budget includes funds for component procurement, PCB fabrication, mechanical parts, and prototyping tools.

Table 3: Estimated Bill of Materials Breakdown

Category	Item	Cost
Mechanical Parts	Frame, rails, motors, lead screws, and other hardware.	$355.00
Electronics & Control	MCU, motor drivers, power supply, and other electronics.	$220.00
Vision System	Camera module, lighting, and related components.	$35.00
User Interface	LCD display and pushbuttons.	$30.00
Miscellaneous	Wires, screws, and general assembly hardware.	$55.00
Total Estimated Cost		$695.00

Table 4: Budget and Buffer

Item	Cost

Total Bill of Materials	$695.00
Contingency Buffer	$105.00
Total Project Budget	$800.00

Rights and Intellectual Property

All intellectual property, including design schematics, software code, and documentation generated as part of this project, will be jointly owned by the group members: Jonathan Williams, Ryan Houck, and Omari John. All members shall have equal rights to the project's intellectual property.

Project Milestones

Senior Design I (SD1)

- **Week 1-4:** Finalize project plan, define roles and responsibilities, and complete all initial research and component selection.
- **Week 5-8:** Complete the design of the high-power ultrasonic driver and the gantry system. Order all major components.
- **Week 9-12:** Assemble the mechanical frame and begin testing individual subsystems (e.g., gantry movement, vision system).
- **Week 13-16:** Complete the hardware and software block diagrams. Prepare the final report and presentation for SD1.

Senior Design II (SD2)

- **Week 1-4:** Integrate the subsystems and begin initial end-to-end testing of the pick and place cycle.
- **Week 5-8:** Debug the system, optimize component placement accuracy and speed.
- **Week 9-12:** Conduct full system validation and prepare a demonstration for a final presentation.
- **Week 13-16:** Finalize the user manual, create a project video, and submit the final report.

Appendices

References

A. Marzo, A. Ghobrial, L. Cox, M. Caleap, A. Croxford, B. W. Drinkwater; Realization of compact tractor beams using acoustic delay-lines. *Appl. Phys. Lett.* 2 January 2017; 110 (1): 014102. https://doi.org/10.1063/1.4972407

Asier Marzo, Adrian Barnes, Bruce W. Drinkwater; TinyLev: A multi-emitter single-axis acoustic levitator. *Rev. Sci. Instrum.* 1 August 2017; 88 (8): 085105. https://doi.org/10.1063/1.4989995

"Investigation of MEMS-Based acoustic levitation for Pick-and-Place Machines." https://scholar.googleusercontent.com/scholar?q=cache:VURyeK1zIg8J:scholar.google.com/+Investigation+of+MEMS-Based+Acoustic+Levitation+for+Pick-and-Place+Machines+ALEJANDRO+BERGSTRAND+LUKAS+MALM&hl=en&as_sdt=0,10

James W. E. Drewitt, Barnaby Emmens, Zhe-Hui Kong, Bruce W. Drinkwater, Adrian C. Barnes; MightyLev: An acoustic levitator for high-temperature containerless processing of medium- to high-density materials. *Rev. Sci. Instrum.* 1 October 2024; 95 (10): 103903. https://doi.org/10.1063/5.0221899

Xiaozhen Wang, Qin Chang, Pengfei Wu, Delong Xu, Weijun Lin, Hao Chen; On the instability of single-axis acoustic levitation under radial perturbations. *J. Appl. Phys.* 21 September 2024; 136 (11): 114901. https://doi.org/10.1063/5.0218163