Laser Scan Readings for Propeller Measurement

DESIGN DOCUMENT

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Executive Summary

This project aims to modify the current system used by Linden Propeller to measure and model propellers for repair. The current system is susceptible to damage, and Mr. Linden would like us to find an alternative measurement method. The current system uses two Newhall scales that rest on carbon fiber rods that are very fragile and easily damaged in a machine shop environment. These rods cost roughly $850 each to repair, not to mention the time wasted waiting for new rods to arrive or installing them. This project is important because Mr. Linden is facing about $4000 in damages yearly, and an alternative system could prevent these damages.

The key requirements for this project are that the system has to be accurate to 5 micrometers and the system has to cost roughly $1000. These requirements have been extremely limiting because systems that are accurate to 5 micrometers are much more expensive than $1000. This has caused us to look for alternative solutions.

Our current design idea is to use a sensor bank to transmit and receive multiple data sets. This data will then be combined using data fusion to make the final reading more accurate. The hope is to find two or three sensors that cost between $300 and $500 and construct a sensor bank with them. We decided to use data fusion after discussing our budget with our client. We had initially pushed for a slightly more expensive system, around $2500, to replace the scales, but Mr. Linden decided to stick with the budget of $1000.

We have made significant progress with our proposed design this semester. We have constructed two systems, one with ultrasonic sensors and one with infrared sensors. This allows us to test two different methods and compare the efficacy. Our project has slightly changed in our scope, in the sense that instead of replacing both scales in the design, we will only be replacing one scale, which will reduce the damages but allow us to stay within the budget much more easily. We have not started implementing data fusion, as our scope has recently changed.

Our current design does not meet all of the requirements listed. For instance, we do not have a system accurate to 5 micrometers, but we will work toward this in the future. We have been testing our current setups, and as we use very cheap sensors, we are only accurate to 1 cm.

Our project's future steps are to progress with data fusion and source some sensors that bring us closer to the requirements. Once thoroughly researching data fusion, we will apply it to our current system through an Arduino and then test the sensors at various ranges.

Learning Summary

Development Standards & Practices Used

Hardware Practices:

1. Component Testing: Verifying individual component functionality (IR and ultrasonic sensors) before integration.
2. Prototyping: Using Arduino microcontrollers for proof-of-concept testing to validate sensor performance.
3. Environmental Robustness: Designing mounts and housings to withstand shop conditions like dust, dirt, and tool impacts.

Software Practices:

1. Version Control: Using GitHub to manage and track software changes.
2. Documentation: Using Google Drive and Onedrive to manage relevant documents

Engineering Standards:

IEEE 2700-2017 – This standard provides a common framework for sensor performance parameter definitions across various types, including IR and ultrasonic sensors. It defines terminology, units, and conditions to ensure consistent performance specifications, which are essential for high-accuracy measurement applications in diverse fields.

IEEE 1454 – This standard, part of the IEEE 1451 family, outlines a common interface for smart sensors and actuators, focusing on mixed-mode communication protocols. This is particularly useful for IR and ultrasonic sensors used in integrated systems, such as those in IoT applications, enabling seamless data exchange and standardization across devices.

IEEE C95.1 - This standard defines exposure criteria and associated limits for protecting persons against established adverse health effects from exposures to electric, magnetic, and electromagnetic fields, in the frequency range of 0 Hz to 300 GHz. The exposure limits apply to persons permitted in restricted environments and the general public in unrestricted environments.

Summary of Requirements

- Must be accurate to 5 micrometers
- Must cost roughly $1000
- Must fit on the current frame
- Must be durable enough to withstand a shop environment
- Must be simple to use

Applicable Courses from Iowa State University Curriculum

- CPRE 288
- EE 185
- EE 333
- EE 230

New Skills/Knowledge acquired that was not taught in courses

1. Industrial Laser Scanners and Sensors

- Gained expertise in evaluating and selecting industrial laser and infrared sensors for precision measurement applications, including understanding performance metrics like accuracy, range, and environmental durability.
- Learned to integrate sensors into a custom hardware system, focusing on mounting, calibration, and environmental testing.

2. Small Business Collaboration

- Developed skills in working with a small business client, including understanding their specific constraints, such as budget, operational priorities, and long-term maintenance considerations.
- Learned to balance technical recommendations with the client's business needs, providing flexible solutions aligned with their goals.

3. Sensor Integration and Data Communication

- Acquired knowledge of integrating multiple sensors (IR and ultrasonic) into a unified system using microcontrollers.

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1. Introduction

○ PROBLEM STATEMENT

Our project aims to modernize and enhance the current propeller measurement system by converting it to an advanced infrared sensor system. Currently, we rely on Newall scales, which, while functional, are easily damaged in shop environments, resulting in costly repairs and downtime. Furthermore, the marine industry is increasingly adopting 3D scanning technologies, which renders our existing system outdated and less competitive. A key challenge in this transition is the ability to measure overlapping sections of propeller blades—a task our current system can accomplish with a specialized adapter on the drop probe. We must develop a solution to capture these complex geometries with the proposed infrared system accurately. The carbon fiber rods used for X and Y-axis measurements are prone to breaking, each costing approximately $850 to replace and requiring significant repair time. Our project seeks to address these issues by designing a more robust, precise, and industry-aligned scanning system that reduces maintenance costs and improves overall efficiency in propeller measurements.

In our design context, several vital issues impact the feasibility and success of converting the scan arm to an infrared sensor system. First, the cost is significant ($1000), as transitioning from the current system to the infrared sensor system involves high initial expenses. Infrared systems can be costly, particularly when purchasing from established suppliers like Keyence, which is why we are working directly with them to negotiate prices. Additionally, we are exploring data fusion with lower-end sensors, aiming to blend high-quality infrared data with more affordable sensor inputs. This approach allows us to maintain accuracy while controlling costs.

Another crucial issue is the ease of transition for current users. Since operators are accustomed to the existing system, we aim to minimize changes in the user interface and overall operation. Our approach involves mounting new sensors on the same frame, preserving the layout and workflow, while the infrared beams capture the X and Y-axis measurements. This setup ensures users can transition to the new technology without a steep learning curve.

Finally, market competitiveness is essential. With the marine industry shifting towards 3D scanning solutions, staying aligned with current trends is crucial. By adopting infrared sensor technology, we improve accuracy and durability, which enhances the system's appeal relative to other products. Addressing these issues effectively positions our design as a cost-effective, user-friendly, and cutting-edge solution in the propeller measurement market.

○ INTENDED USERS

Machine Shop Worker

- **Persona & Key Characteristics:** The machine shop worker uses measurement equipment to perform precise measurements on propeller blades or other surfaces. This worker is frustrated with the frequent equipment breakdowns and the need for costly repairs due to the current system's fragility, particularly the carbon fiber rods.

- **Needs Statement:** The machine shop worker needs a durable, low-maintenance measurement system that minimizes downtime and eliminates the need for excessive caution with delicate components.

- **Benefits:** The new infrared measurement system reduces the risk of equipment damage, which means fewer interruptions to their workflow. Additionally, by eliminating fragile parts like carbon fiber rods, the worker can operate the system without the constant concern of causing breakage/damage. This aligns to improve the system's durability and practicality in a shop environment, leading to enhanced productivity.

Small Business Owner

- **Persona & Key Characteristics:** The small business owner, such as the one running Linden Propeller, manages operations on a limited budget. They are highly conscious of costs associated with repairs and replacements, which impact the business's bottom line.

- **Needs Statement:** The business owner needs a cost-effective solution that minimizes equipment maintenance expenses and reduces the need for frequent replacements, thereby lowering long-term operational costs.

- **Benefits:** By investing in an infrared measurement system with lower susceptibility to damage, the business owner benefits from reduced repair costs and increased reliability. The reduced need for repairs and replacements aligns with their budget constraints, making the system a financially viable choice that maintains competitiveness. This connects directly to the problem statement by addressing the current system's cost inefficiencies and positioning the business more sustainably in the market.

High Accuracy Measurement Engineer

- **Persona & Key Characteristics:** This engineer specializes in precision measurement systems and is focused on achieving accurate and reliable results. They are cautious about adopting new technologies and worry about whether a new system will meet stringent accuracy requirements.

- **Needs Statement:** The measurement engineer needs a system that not only preserves the accuracy of current measurements but also enhances it, particularly when measuring complex topologies, like overlapping blade sections.

- **Benefits:** The infrared system provides more precise measurements than the current setup, meeting high accuracy standards and enabling the engineer to capture intricate details of propeller blade geometry. This precision satisfies the engineer's focus on quality and aligns with the industry's shift toward 3D scanning technologies, positioning them at the forefront of their field. By addressing accuracy and measurement quality, the project ties into the broader context of adopting cutting-edge technology to maintain relevance in a competitive industry.

By understanding and addressing these user groups' needs, our project delivers a comprehensive solution that enhances durability, reduces costs, and improves measurement accuracy.

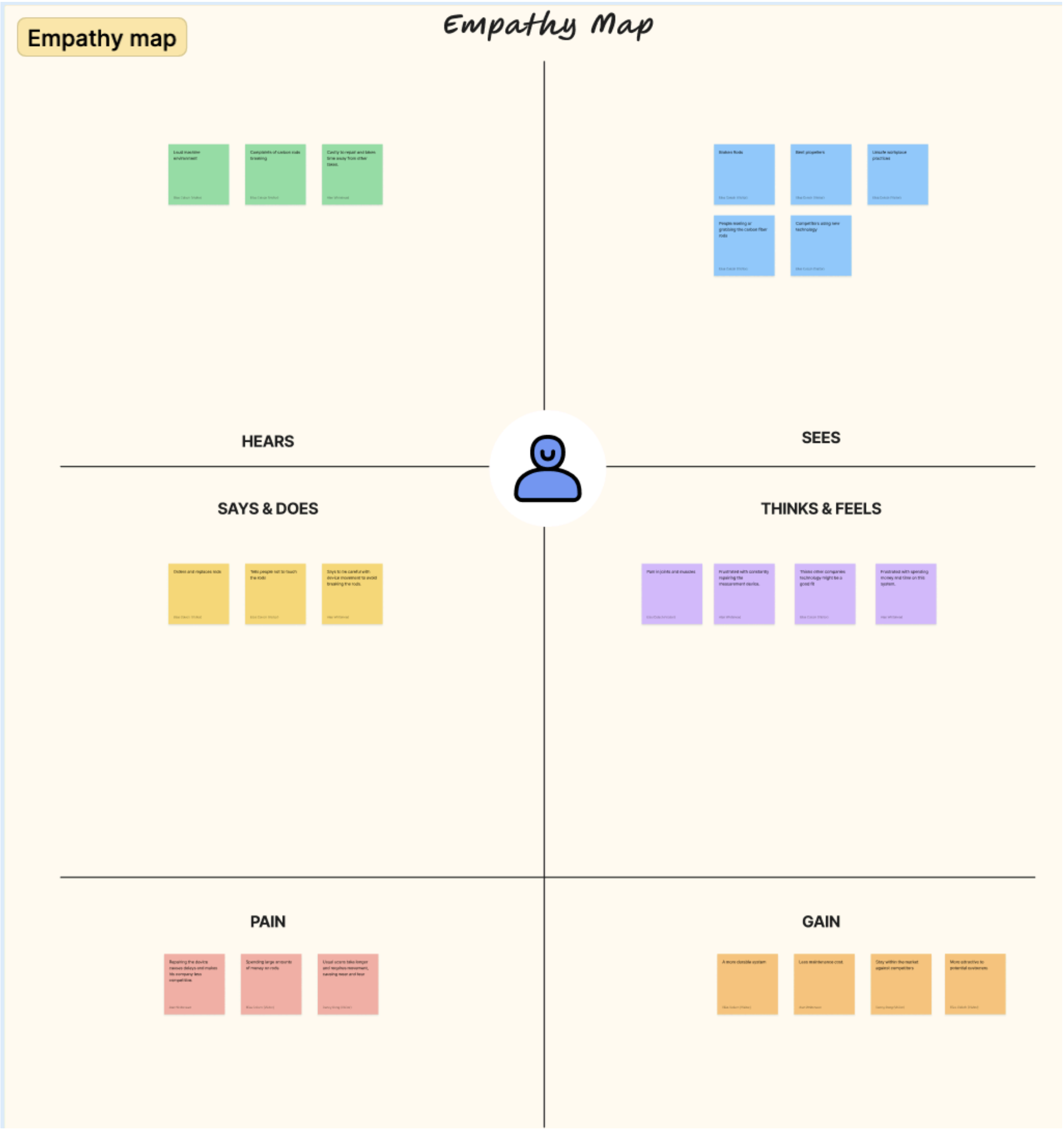

Figure 1

2. Requirements, Constraints, And Standards

○ REQUIREMENTS & CONSTRAINTS

Functional Requirement (Constraints)

3. It needs to be accurate to 5 micrometers
4. It needs to measure up to 50 inches

Physical

5. It needs to be compatible with the current setup

6. It needs to be small enough to be mounted to the current frame

Resources

7. It needs to cost roughly $1000
8. It needs to have software compatible with TruProp

User experiential

- It needs to be easy to use and learn
- It needs to maintain the current mobility of the setup

Environmental

9. It needs to be durable enough for a shop environment

○ Robust use
○ Tools dropping
○ Dust
○ Dirt

2.2. ENGINEERING STANDARDS

The Engineering Standards are extremely important for everyday life because they provide a safety net for everyone interacting with or using products. The standards make it so that no product violates laws or puts anyone in danger. They also allow engineers to check their work for mistakes and oversights that would make a product illegal or unsafe across all manufacturers.

These standards facilitate accurate and reliable sensor use by providing guidelines for performance measurement, system integration, and data communication.

IEEE 2700-2017 – This standard provides a common framework for sensor performance parameter definitions across various types, including IR and ultrasonic sensors. It defines terminology, units, and conditions to ensure consistent performance specifications, which are essential for high-accuracy measurement applications in diverse fields.

IEEE 1454 – This standard, part of the IEEE 1451 family, outlines a common interface for smart sensors and actuators, focusing on mixed-mode communication protocols. This is particularly useful for IR and ultrasonic sensors used in integrated systems, such as those in IoT applications, enabling seamless data exchange and standardization across devices.

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We each choose one standard, and each of them applied differently to our design. IEEE 2700-2027 deals with sensor-based measurements which is directly related to this project due to the fact we are trying to incorporate two different sensors to replace the old system. IEEE 1456 deals with the output of these sensors and how they communicate with the computer/microcontroller. This standard makes it so you can incorporate other sensors without having to interpret multiple different output formats. IEEE C95.1 deals with the exposure of electromagnetic fields when dealing with lasers. This standard will allow us to operate these sensors and keep the customer safe.

As we were planning to use an existing sensor product as our base and simply add our code and connections, we had already been considering these standards as part of our research process. We had been looking for lasers that met our client's requirements, and these standards were part of our selection process, particularly when it came to high accuracy and laser exposure.

3 Project Plan

3.1 PROJECT MANAGEMENT/TRACKING PROCEDURES

Project Management Style:
The project will adopt the Agile methodology. The following aspects justify this choice:

- Iterative Development: The project requires incremental improvements and testing of sensor technologies, making iterative progress essential for refining accuracy and durability.
- Flexibility in Design: Given the evolving needs of sensor technology and potential compatibility issues, flexibility is key to adapting designs as requirements shift.
- Incremental Testing: Quick feedback is crucial to refine the design with each new iteration or component addition (e.g., ultrasonic or IR sensors).
- Quick Feedback Loops: The Agile methodology enables rapid adjustments based on continuous feedback, essential for keeping the project aligned with customer requirements and expectations.

Key Milestones:

- Proof of Concept for X or Y Axis: Develop and test a prototype with the ultrasonic sensor to demonstrate feasibility.
- Identify a Cost-Effective Sensor: Find a viable sensor option within budget constraints ($1000) that meets technical requirements.
- Acquire the Chosen Sensor: Procure the selected sensor to prepare for integration and further testing.
- Deliver Final Solution to Customer: Complete the system design and implementation, ensuring full alignment with customer specifications.

Tracking Tools:
The team will use Discord for communication and OneDrive for version control and collaboration on code.

3.2 TASK DECOMPOSITION

Main Tasks and Subtasks:

1. Research and Selection of Sensors:
    a. Research ultrasonic and IR sensors suitable for high-accuracy measurements.

    b. Identify and compare options within budget and technical constraints.
    c. Verify compatibility with the existing setup and software.

2. Proof of Concept Development:
    a. Build a prototype using the chosen sensor for either the X or Y axis.
    b. Test for accuracy (5-micrometer precision) and range (up to 50 inches).

3. Procurement and Initial Integration:
    a. Purchase the selected sensor.
    b. Integrate it with the current setup, ensuring compatibility with TruProp.

4. User Experience and Durability Testing:
    a. Evaluate usability and durability in a shop environment.
    b. Test robustness against environmental factors (dust, dirt, tool drops).

5. Final System Integration and Testing:
    a. Finalize system assembly.
    b. Conduct comprehensive tests to meet all functional and performance requirements.
    c. Complete documentation and prepare for delivery.

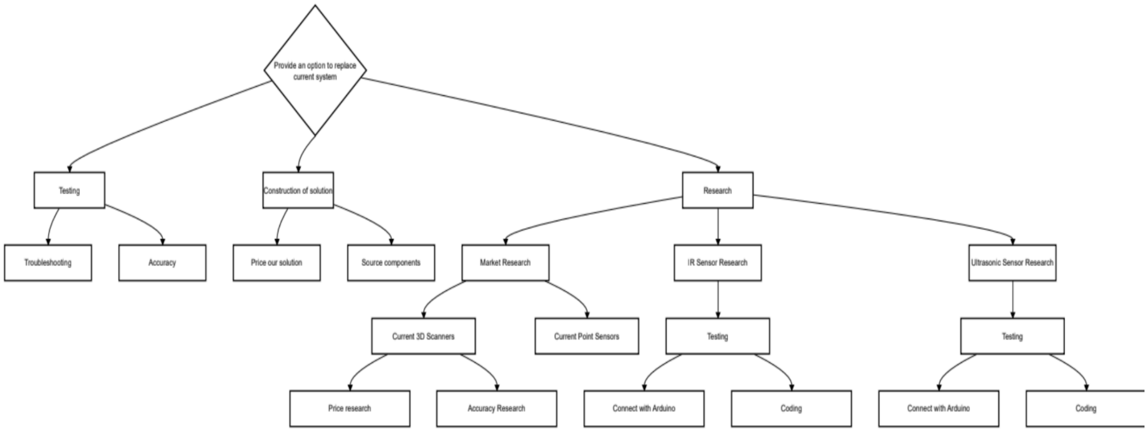


Figure 2

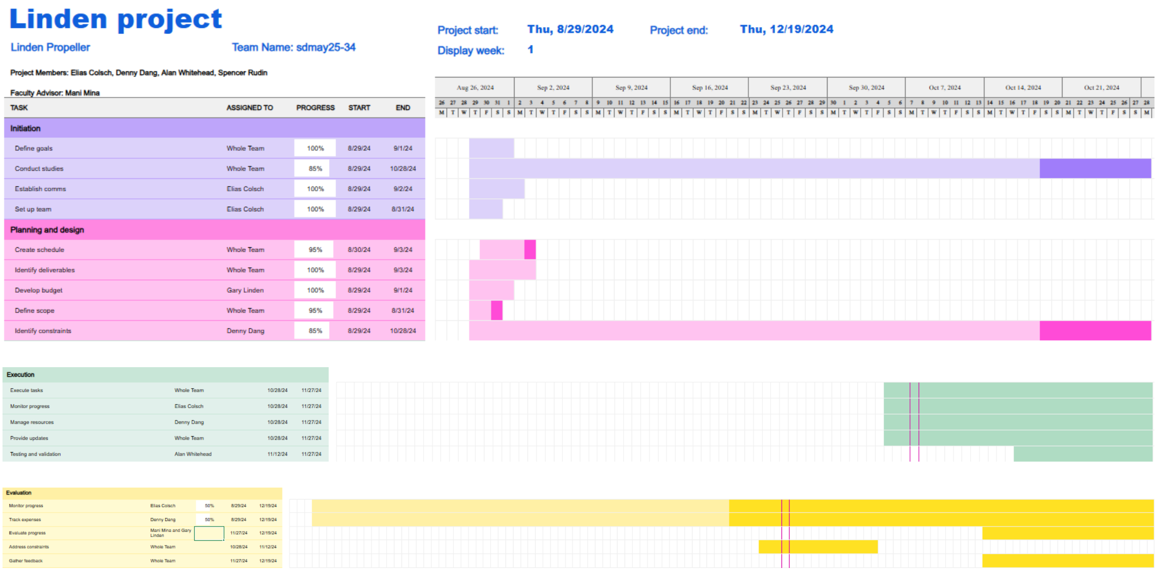
3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Key Milestones and Metrics:

- Proof of Concept Testing: Demonstrate a working prototype with 90% functional accuracy for X- or Y-axis measurements.
- Sensor Identification: Select a sensor that meets budget (<$1000) and accuracy requirements.
- Acquisition of Sensor: Ensure the sensor is procured within the timeline and budget.

- Usability Test: Validate that the new system can be operated effectively with minimal training, achieving at least a 4/5 user satisfaction score.
- Environmental Robustness Test: Ensure the system withstands simulated shop conditions with at least 95% functionality retention.
- Final Customer Delivery: Deliver a fully functional, tested system that meets all specified criteria.

3.4 PROJECT TIMELINE/SCHEDULE



Linden project

Linden Propeller   Team Name: sdmay25-34

Project Members: Elias Colsch, Denny Dang, Alan Whitehead, Spencer Rudin

Faculty Advisor: Mani Mina

Project start: Thu, 8/29/2024   Project end: Thu, 12/19/2024

Display week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Initiation				
Define goals	Whole Team	100%	8/29/24	9/1/24
Conduct studies	Whole Team	85%	8/29/24	10/28/24
Establish comms	Elias Colsch	100%	8/29/24	9/2/24
Set up team	Elias Colsch	100%	8/29/24	8/31/24
Planning and design				
Create schedule	Whole Team	95%	8/30/24	9/3/24
Identify deliverables	Whole Team	100%	8/29/24	9/3/24
Develop budget	Gary Linden	100%	8/29/24	9/1/24
Define scope	Whole Team	95%	8/29/24	8/31/24
Identify constraints	Denny Dang	85%	8/29/24	10/28/24
Execution				
Execute tasks	Whole Team		10/28/24	11/27/24
Monitor progress	Elias Colsch		10/28/24	11/27/24
Manage resources	Denny Dang		10/28/24	11/27/24
Provide updates	Whole Team		10/28/24	11/27/24
Testing and validation	Alan Whitehead		11/12/24	11/27/24
Evaluation				
Monitor progress	Elias Colsch	50%	8/29/24	12/19/24
Track expenses	Denny Dang	50%	8/29/24	12/19/24
Evaluate progress	Mani Mina and Gary Linden		11/27/24	12/19/24
Address constraints	Whole Team		10/28/24	11/12/24
Gather feedback	Whole Team		11/27/24	12/19/24

Figure 3

3.5 RISKS AND RISK MANAGEMENT/MITIGATION

Key Risk: Difficulty in finding a sensor that meets accuracy and cost requirements.

- Impact: Loss of competitiveness and failure to meet customer expectations.
- Mitigation: Constantly research new technologies and maintain communication with suppliers. Explore university discounts with sensor providers and continuously engage with clients to manage expectations regarding sensor specifications.

Other potential risks include:

- Compatibility Issues with TruProp Software: Mitigate by conducting early integration tests with existing software to identify any potential conflicts.
- Environmental Durability Concerns: Test sensors and mountings in simulated conditions to ensure robust performance in a shop environment.

3.6 PERSONNEL EFFORT REQUIREMENTS

Task:	**Estimate:**
Research and selection of sensors	20
Proof of concept	40
Procurement and initial integration	15

User experience and testing	30
Final system integration	50
Project documentation	20
Total	**175**

Table 1

3.7 OTHER RESOURCE REQUIREMENTS

Materials and Resources Needed:

- Ultrasonic or IR Sensor: Must fit within the $1000 budget constraint, ideally with additional discounts.
- Frame and Mounting Materials: For secure sensor mounting to the current system.
- Software Licenses: TruProp or other necessary software for compatibility testing.
- Environmental Testing Materials: Dust, dirt, and other shop materials for durability tests.

This project plan layout provides a comprehensive roadmap for the project, aligning with the Agile methodology, risk management practices, and a clear set of milestones and metrics to ensure the successful delivery of the final product.

4 Design

4.1 DESIGN CONTEXT

4.1.1 Broader Context

Area	Description	Examples
Public health, safety, and welfare	Our design does not introduce any new risks and eliminates one carbon fiber rod, making it safer.	Helping machined shop workers work safely by providing a robust system that doesn't shatter.
Global, cultural, and social	This project reflects the values and desires of engineers and machine shop workers by providing a reliable, robust system that can be easily used.	Our design removes the chance of breaking the system on the x-axis, allowing for a more reliable work environment.
Environmental	This project impacts the environment by decreasing the number of broken carbon fiber rods.	Removing one rod from each system reduces the number of broken rods per year to two, or potentially to one, depending on which rods break more often.
Economic	This project allows Linden Propeller to save up to $3000 annually. This will also result in less downtime, meaning that the business can stay in production for longer.	Removing the costs of damages every year by providing a robust alternative.

Table 2

4.1.2 Prior Work/Solutions

Relevant Background and Literature Review

1. Laser and Infrared Measurement Systems

Laser and infrared-based measurement systems have been widely used in industries for high-precision tasks, including machining and propeller geometry analysis. For instance, Keyence offers advanced IR sensors with micrometer accuracy designed for industrial environments [1]. These systems are known for their precision and reliability but come at a high cost, often exceeding budgetary constraints for small businesses like Linden Propeller.

2. 3D Scanning Technologies

Research on 3D scanning technologies, such as Creaform HandySCAN 3D, highlights their ability to accurately capture complex geometries [2]. However, such systems are cost-prohibitive for small-scale applications. The complexity of overlapping propeller blade measurements often requires custom solutions to achieve comparable results at a fraction of the cost.

Existing Solutions: Pros and Cons

Solution	Pros	Cons
Keyence IR System	High accuracy, robust in industrial environments, supports modern software integration.	High cost, requires advanced training for optimal use.
Creaform HandySCAN 3D	Extreme precision, captures complex geometries, aligned with industry trends.	Very high cost, overkill for smaller businesses, requires specialized training.
Ultrasonic Sensors	Cost-effective, durable, and easy to integrate.	Insufficient accuracy for fine measurements and struggles with overlapping geometries.
Hybrid IR and Ultrasonic	Balances cost and performance, customizable for specific requirements, suitable for shop use.	Moderating precision requires careful calibration and testing for optimal performance.

Table 3

Our solution distinguishes itself by combining cost-effective components with the precision necessary to meet the client’s needs while maintaining a budget-conscious approach. Balancing durability and accuracy offers a practical alternative for small businesses without sacrificing essential features.

References

1. Keyence Corporation, “High-Precision Measurement Sensors,” Keyence Official Website, 2023. [Online]. Available: https://www.keyence.com
2. Creaform, “HandySCAN 3D: Portable 3D Scanner,” Creaform Official Website, 2023. [Online]. Available: https://www.creaform3d.com

4.1.3 Technical Complexity

Multiple Components and Subsystems

Our project integrates several distinct subsystems, each requiring the application of specialized scientific, mathematical, or engineering principles:

1. Measurement Subsystem: Incorporates the Keyence IR sensor and an ultrasonic sensor for precise X and Y-axis measurements. This subsystem utilizes optics, signal processing, and metrology principles to achieve high precision.
2. Data Integration Subsystem: A microcontroller processes sensor data and formats it for TruProp software. This subsystem relies on data communication protocols and software engineering for compatibility and accuracy.
3. Environmental Durability Subsystem: Sensor mounting designs were tested for resilience against dust, tool drops, and vibrations. Engineering principles related to materials science and mechanical design were employed.

Challenging Requirements

1. Accuracy: Achieving 5-micrometer precision is a high standard that matches or exceeds many existing solutions.
2. Durability: The design must withstand shop conditions, requiring innovative mounting and housing designs.
3. Cost Constraints: Delivering these features within a $1000 budget requires a creative approach to component selection and system integration.
4. Complex Geometry Measurement: Measuring overlapping sections of propeller blades adds a layer of complexity that hybrid systems must address effectively.

These factors make the project sufficiently complex and reflective of current industry challenges. The integration of advanced technologies and adherence to stringent performance requirements ensure the project meets the technical and ethical standards of engineering design.

4.2 DESIGN EXPLORATION

4.2.1 Design Decisions

Sensor Selection: One critical design decision is selecting the Keyence IR sensor for measurement accuracy. This model meets the specified accuracy requirement of 5 micrometers while being the most cost-effective solution among the options considered. Choosing this sensor ensures the system meets the precision required for propeller measurements and aligns with the budget constraint of approximately $1000.

Compatibility and Mounting: We chose to mount the Keyence IR sensor on the existing frame of the current measurement device, which minimizes disruption for users familiar with the current setup. This decision simplifies the transition process, making the new system easy for employees to adopt without extensive retraining.

Replacement of Carbon Fiber Rods: Another key decision was to replace the carbon fiber rod in the X-axis direction with an industrial ultrasonic sensor. Carbon fiber rods are fragile and costly to replace; the ultrasonic sensor improves durability and reduces repair costs, meeting budget and environmental robustness requirements.

4.2.2 Ideation

To ideate potential options, we utilized a brainstorming approach, focusing on compatibility, cost, and durability for sensor choices. Here are five options we considered:

- High-End IR Sensors: Sensors with high accuracy but above-budget costs.
- Ultrasonic Sensors: Cost-effective and robust, but with limitations on extreme precision.
- Hybrid Sensor Fusion: Combining IR and lower-cost sensors to balance accuracy and budget constraints.
- Creaform HandySCAN 3D: A high-speed, accurate 3D scanning system, though significantly over budget.
- Magnescale BS78 Laser Scale: Highly accurate with a mount, but limited range for this specific application.

4.2.3 Decision-Making and Trade-Off

We used a weighted decision matrix, evaluating each option against cost, accuracy, durability, compatibility, and ease of integration factors. The Keyence IR sensor scored highest for its balance of accuracy and cost-effectiveness, making it our primary choice. Although ultrasonic sensors lack extreme precision, they are effective for the X-axis replacement, offering durability and cost benefits. The trade-off with other, more expensive systems was primarily budgetary, as options like Creaform HandySCAN far exceeded our financial limitations while offering features not necessary for immediate application.

4.3 Proposed Design

4.3.1 Overview

Until recently, our design was a modernized propeller measurement system utilizing an infrared sensor and ultrasonic technology for accurate, durable measurements. Mounted on the existing frame, the infrared sensor would capture precise measurements along multiple axes, while the ultrasonic sensor replaces fragile carbon fiber rods. These components would provide a cost-effective solution that enhances measurement accuracy and durability without altering the user experience.

With our updated scope, we kept the sensors on the x-axis, replacing the rod that stuck out the most from the system. We will continue testing IR and ultrasonic sensors to see which type provides more accurate readings.

4.3.2 Detailed Design and Visual(s)

Here is our original design:

The system comprises two primary subsystems: the Keyence IR sensor for high-precision measurements and an ultrasonic sensor for stability in the X-axis. These sensors are connected to a central microcontroller, which processes measurement data and outputs it in a format compatible with TruProp software. The layout includes mounting adapters to fit the existing frame, ensuring easy installation and minimal adjustment for users. Visual support could include a block diagram illustrating sensor connections and data flow to the microcontroller.

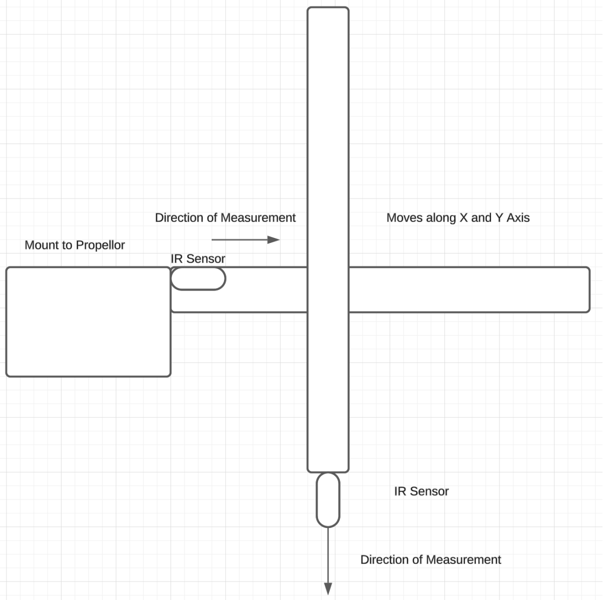


Figure 4

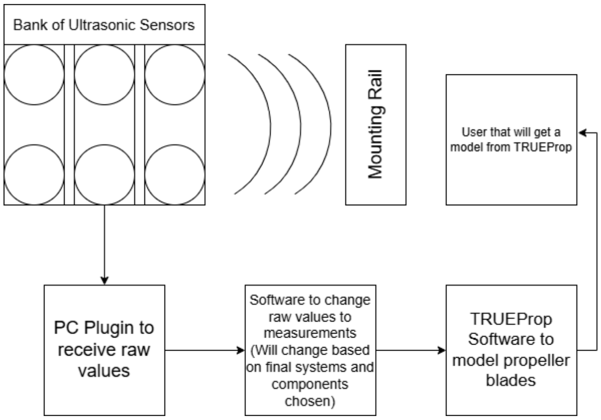


Figure 5

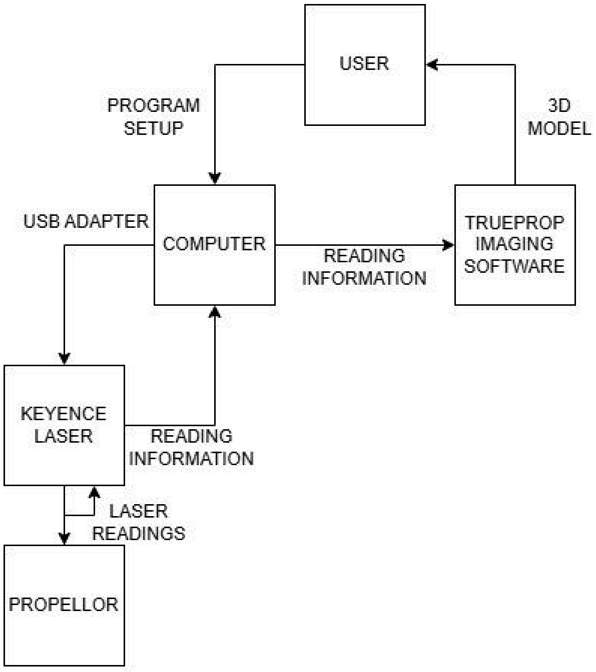


Figure 6

Now that we have updated our scope, our design looks like the figure below.

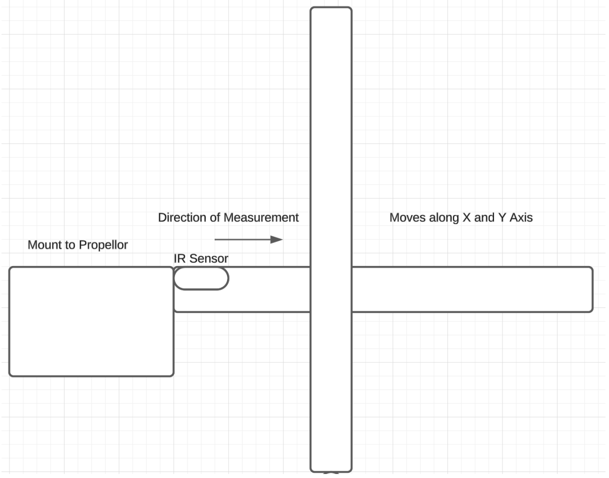


Figure 7

4.3.3 Functionality

In real-world use, the operator selects the desired measurement, and the infrared and ultrasonic sensors gather precise data on the propeller's dimensions. The device processes and displays this information, allowing users to view detailed measurements without additional calibration steps. This setup reduces the risk of breakage from routine handling, allowing for more efficient and frequent measurements.

4.3.4 Areas of Concern and Development

Our design meets key requirements; however, concerns remain regarding the adaptability of the infrared sensor under various environmental conditions, such as dust or debris in the shop environment. Immediate development steps include environmental testing of sensors, consulting with clients on specific use-case scenarios, and refining the software interface to ensure seamless integration with existing systems. We also need to convince our client that the sensors we found are his best shot at resolving the issues while they may be over budget.

4.4 Technology Considerations

Our primary technologies include the Keyence IR sensor and an industrial ultrasonic sensor. The IR sensor provides high accuracy but with increased sensitivity to environmental factors. The ultrasonic sensor is durable and cost-effective but less precise for fine measurements. By blending these technologies, we balance accuracy and durability. Alternatives considered included laser-based systems, which offer extreme precision but were cost-prohibitive.

4.5 Design Analysis

We have initially tested our sensor integration, our proof of concept that works with Arduino. To show our proposed design is feasible; however, adjustments may be needed to improve environmental resilience and measurement consistency. The upcoming development will focus on enhancing sensor stability under shop conditions and refining the mounting interface for increased ease of use. So far, our approach has demonstrated feasibility, and we plan to proceed with testing and continued development to ensure reliable operation in real-world conditions. We observed a demonstration of the KEYENCE system that we had proposed, proving that it was as accurate as we needed. This justifies the KEYENCE design, even with the higher initial cost.

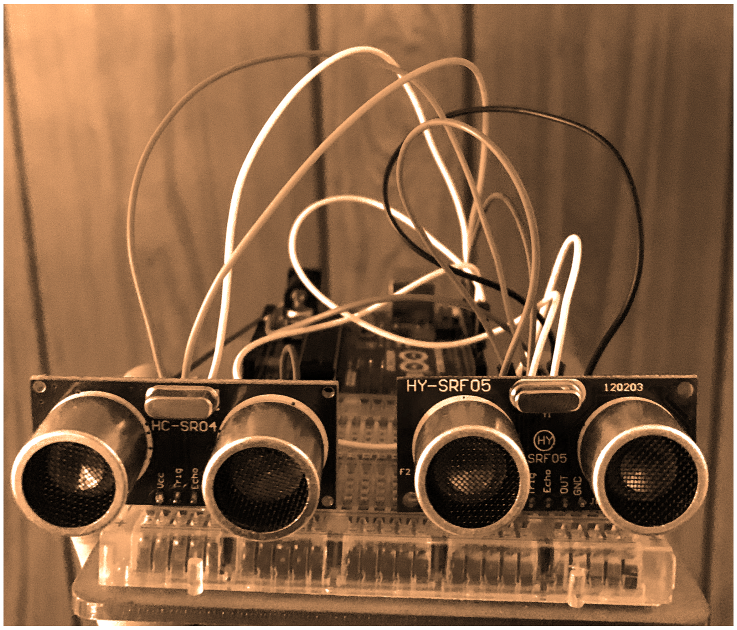


Figure 8

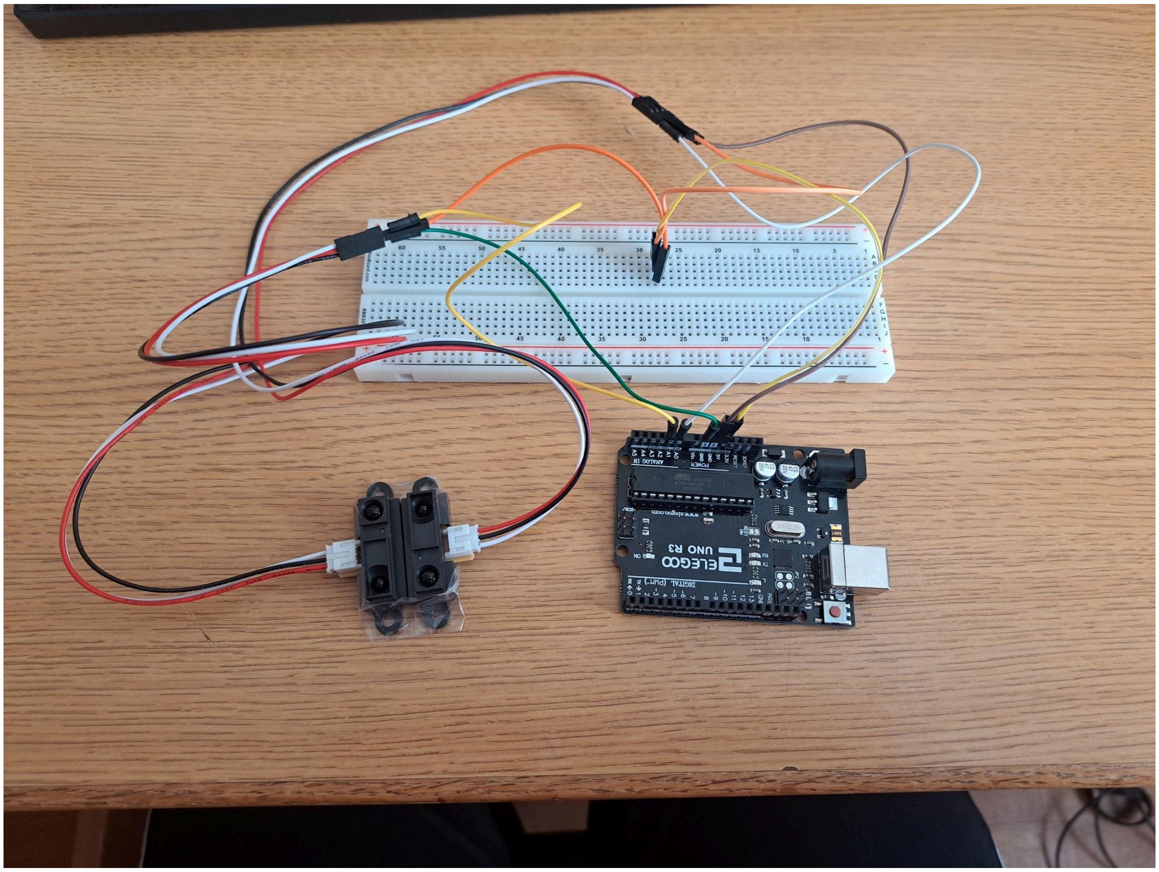


Figure 9

5 Testing

Our testing plan consists of the following:

1. Source sensors
2. Connect sensors to an Arduino
3. Run code to get the current accuracy of one sensor by measuring the between the sensor and a wall
4. Once all sensors have been tested, mount multiple sensors together
5. Run the same code as before, and then run an algorithm to perform data fusion
6. Check the accuracy of this setup by measuring the distance between the sensors and a wall

This testing plan tests for all requirements that apply to functionality. All cost-related requirements have already been accounted for by using cheap sensors. We will be testing these sensors whenever we make changes to our code or when we alter our algorithm. We plan on testing these sensors from ranges varying from 5 centimeters to 50 centimeters. This will allow us to estimate how accurate the sensor is as the distance increases. this is important because the maximum propeller size Linden Propeller currently measures is 50 centimeters.

5.1 Unit Testing

We are testing ultrasonic and infrared sensors separately. Alan has been testing an ultrasonic sensor setup, and Elias has been working on an infrared setup. Due to some difficulties with a former group member, the development of the infrared setup has been delayed, which is why Elias is not in the testing phase yet.

5.2 Interface Testing

To date, our focus has been on unit testing. Integration of our design into Mr. Linden's current system has been evaluated, and it has been determined that our design can be mounted to the existing frame in a way that is not intrusive to the worker. We did this by using a 3D Solidworks model from Mr. Linden to check the size of the frame. A small bracket would need to be constructed to mount our device, which our sensors could be bolted to. Most sensors that are designed to be mounted come with bolts, so Mr. Linden would only need to create a bracket, which he agreed would not be difficult for him and his team.

We must also integrate our code into TruProp, Mr. Linden's software. We have not been able to get a good look at how the TruProp software operates, but we plan to get an extensive look at it next semester. Mr. Linden has assured us that as long as we can send raw values to the software, TruProp can process them into the model.

5.3 Integration Testing

The two critical integration paths we need to consider are the bracket being mounted to the frame and the data transmission from the sensor to TruProp. Mr. Linden’s current design has several protected wires that transmit data; we can use similar wires to transmit our data. The bracket being mounted to the frame would be relatively small, and we have been looking at the size of industrial sensors. We have discovered that the bracket will not interfere with the system's functionality and require minimal modification.

5.4 System Testing

At this point, we have not progressed to testing our design as a whole system. We have not been able to contact Mr. Linden to set up a meeting for two weeks as of the time of this writing due to Mr. Linden's Thanksgiving Plans. Next semester we plan to set up a time for Mr. Linden to give us a frame to test on, where we will find the exact specifications of the bracket that will be mounted. Once we find those, we will construct a testing bracket and test our design using TruProp. We anticipate this will be the most difficult due to our lack of knowledge of TruProp's operations. We will test our design by moving the arm away from our sensors at various speeds and comparing the accuracy of the data collected.

5.5 Regression Testing

We have communicated with Mr. Linden throughout our design process to ensure that our additions will not interfere with the system's current functionality. We have also tested our design in similar environments to check the functionality. We are also working on making our code as simple as possible to make it easier to apply our code to TruProp.

5.6 Acceptance Testing

Our acceptance testing will be done once we have finalized our design and have thoroughly checked that the values we receive meet the requirements. To involve Mr. Linden, we plan to invite him to the Senior Design lab to demonstrate our final design. This will be convenient for Mr. Linden as he must pick up the frame once we finish it. It will also allow him to see how we use the system to compare it to how he uses it now.

5.7 Security Testing (if applicable)

No security concerns are associated with our project, so this section is not applicable.

5.8 Results

Our current testing has resulted in us receiving data from the sensors and getting a measurement reading. The current accuracy of our system is about 5 centimeters, but that will be improved as we finalize our testing area. We do not have any numerical data other than the 5 cm accuracy, but we will be getting numerical data next semester as we start implementing data fusion.

6 Implementation

Proof of Concept

- Description: A proof-of-concept prototype was developed using an Arduino to test the integration of an IR sensor and an ultrasonic sensor.

Progress:

- Successfully captured data from the IR and ultrasonic sensor sensor and verified the precision of measurements.
- Simulated shop conditions (dust and tool vibrations) to evaluate sensor resilience.
- Initial tests confirmed the sensor’s performance.

7 Ethics and Professional Responsibility

7.1 Areas of Professional Responsibility/Codes of Ethics

Table: Areas of Professional Responsibility and Project Adherence

Area of Responsibility	Definition	Relevant Items from the IEEE Code of Ethics	Team Interaction/Adherence
Work Competence	Performing tasks at a level of skill and accuracy expected for a professional.	“To improve the understanding of technology, its appropriate application, and potential consequences” (IEEE 1).	The team conducted thorough research on IR sensors to ensure technical competence and proper

			selection of components for the project.
Financial Responsibility	Managing resources wisely to avoid unnecessary costs and ensure budgetary adherence.	“To avoid real or perceived conflicts of interest whenever possible” (IEEE 4).	The team negotiated with sensor suppliers like Keyence to keep costs below $1000 while ensuring quality, demonstrating fiscal responsibility.
Communication Honesty	Providing truthful, clear, and accurate communication in all aspects of the project.	“To be honest and realistic in stating claims or estimates based on available data” (IEEE 3).	Regular updates are communicated to the advisor, including accurate project challenges and progress representations.
Safety, Health, Welfare	Prioritizing the well-being of individuals and ensuring the design does not pose undue risks.	“To hold paramount the safety, health, and welfare of the public” (IEEE 1).	The team incorporated standards like IEEE C95.1 to address electromagnetic exposure from lasers and ensure safety compliance.
Property Ownership	Respecting intellectual and physical property, including designs and documentation.	“To avoid injuring others, their property, reputation, or employment” (IEEE 9).	The team respects intellectual property by using licensed software (e.g., TruProp) and adhering to supplier agreements.
Environmental Impact	Designing solutions that minimize environmental harm and promote sustainability.	“To improve the environment to the fullest extent possible” (IEEE 10).	The design reduces reliance on fragile carbon fiber rods, aligning with durability goals and reducing waste.

Table 4

Team Performance Analysis

Strong Area: Work Competence

Our team excels in work competence, as demonstrated by our careful research and technical evaluations when selecting sensors and components. For example, our decision to use the Keyence IR sensor was supported by performance testing, ensuring it met our accuracy requirement of 5 micrometers. Additionally, the team’s proof-of-concept testing with Arduino showcases our ability to apply technical knowledge effectively. This competence is key to delivering a high-quality system aligned with project goals.

Area for Improvement: Environmental Impact

While the team has taken steps to improve durability by eliminating fragile carbon fiber rods, our consideration of environmental sustainability could be enhanced. We focus primarily on cost and durability but have not evaluated the lifecycle impact of the chosen materials or the system's energy efficiency. The team should conduct a sustainability assessment, including evaluating sensor manufacturing processes and considering energy-efficient power sources. Such steps will ensure the design aligns more fully with broader environmental responsibility goals.

7.2 FOUR PRINCIPLES

Broader Context-Principle Pair: Beneficence & Safety

One important broader context-principle pair for our project is beneficence and safety. Our design improves safety by eliminating fragile carbon fiber rods prone to breaking and causing disruptions. Additionally, the new system avoids introducing unsafe components, ensuring it aligns with the existing safety standards of the old design. We enhance user confidence and operational safety by improving reliability and reducing the risk of accidents. To ensure this benefit, we conduct rigorous testing and use durable materials that withstand shop environments.

Broader Context-Principle Pair: Environmental Impact

Our project lacks slightly in the environmental impact area, as it still relies on components that are not entirely eco-friendly. While eliminating carbon fiber rods reduces waste, other parts of the design could have environmental implications, such as limited recyclability. However, this drawback is mitigated by significant economic and functional positives. For instance, the design saves thousands of dollars annually in maintenance costs and improves the system's overall efficiency. To address this shortfall further, our team could explore alternative materials or processes with lower environmental impact to enhance sustainability.

	Beneficence	Nonmaleficence	Respect for Autonomy	Justice
Safety	Improves safety by eliminating parts that could break.	The design does not add unsafe components.	Allows for the same decision-making as the old design.	The design does not make the system less safe for any group of people.
Environmental	Eliminates carbon fiber rods that are wasted.	The design does not include any components that	We have multiple options if environmental	The design will not impact the surrounding

	Beneficence	Nonmaleficence	Respect for Autonomy	Justice
		produce waste	concerns arise	environment.
Economic	Saves several thousand dollars per year.	Uses affordable parts and systems.	We have multiple options for different budgets.	The price of the design is as low as possible for small businesses.
Competence	Provides a quicker and more customer-appealing process.	The design does not make the process less accurate.	The tradeoff between accuracy and price is solely up to the client.	The design will not affect the quality of work.

Table 5

7.2.1 BENEFICENCE TO THE ECONOMIC SITUATION

The primary virtue of our project lies in beneficence—specifically, its potential to significantly improve Linden Propeller's economic situation. By transitioning from fragile and damage-prone carbon fiber rods to a robust infrared sensor system, our design reduces the likelihood of costly damage and repairs that have historically impacted the company's bottom line.

Key Economic Benefits:

1. Reduced Repair Costs: The current system's carbon fiber rods are expensive to replace (approximately $850 per rod) and susceptible to frequent breakage. Our robust design eliminates this issue, translating to substantial annual savings for Linden Propeller.
2. Minimized Downtime: By creating a more durable and reliable system, the project ensures fewer disruptions in measurement operations. Propeller measurements can be conducted more consistently, improving overall productivity.
3. Cost-Effective Design: By carefully negotiating with suppliers like Keyence and exploring cost-efficient alternatives, we have managed to stay within the budgetary constraints of approximately $1000, ensuring the affordability of the new system without compromising performance.
4. Longevity and Sustainability: The reduced need for frequent repairs and replacements means that the system will have a longer service life, further contributing to the economic viability of the business.

Importance to Small Businesses:

Like many small businesses, Linden Propeller operates under tight budget constraints, making every dollar saved critical. By prioritizing cost efficiency in our design, we directly address the client's top priority—ensuring that their investment yields long-term financial benefits.

Furthermore, this focus on economic beneficence not only aids Linden Propeller's sustainability but also positions the business to remain competitive in the increasingly high-tech marine industry.

This focus on the economic well-being of our client demonstrates our commitment to aligning the project with their highest priorities while adhering to professional values such as financial responsibility and beneficence.

7.2.2 RESPECT FOR AUTONOMY OF COMPETENCE

Our approach to designing the propeller measurement system prioritizes respect for the client's autonomy and competence by providing multiple solutions that cater to different needs and priorities. By presenting these options, we empower clients to make informed decisions based on their unique business requirements and values.

Options Provided

1. High-Accuracy, Higher-Cost Solution
- Description: Utilizes the Keyence IR sensor, which meets the strict accuracy requirement of 5 micrometers and offers durability in shop conditions.
- Trade-Off: Slightly over budget but aligns with industry trends and ensures long-term reliability.
- Value: Ideal for clients prioritizing precision and competitiveness in the marine industry.

2. Cheaper, Potentially Less Reliable Solution
- Description: A lower-cost IR sensor with adequate performance but reduced environmental durability.
- Trade-Off: More budget-friendly but may require higher maintenance costs in the long term.
- Value: Suitable for clients looking for immediate cost savings without prioritizing durability.

3. Alternative Solution with Trend Limitations
- Description: A hybrid sensor solution that combines ultrasonic sensors for the X-axis with lower-cost IR sensors for other measurements.
- Trade-Off: This does not fully align with the latest trends in the marine industry but reduces costs while maintaining reasonable accuracy.
- Value: Ideal for clients who prioritize budget over cutting-edge technology.

Supporting Autonomy

By presenting these options transparently, we respect the client's competence to evaluate what works best for their business. We ensure the client has full control over balancing cost, precision, and alignment with industry trends, enabling them to take ownership of the decision-making process. This approach reflects our commitment to the ethical principle of autonomy while fostering a collaborative and respectful relationship with the client.

7.3 VIRTUES

1. Collaboration

Definition: The ability to work effectively with others to achieve a common goal.

Team Actions:

- Regular team meetings ensure everyone is aligned on project goals and tasks.
- Use communication tools like Slack and GitHub for seamless collaboration and version control.
- Delegating tasks based on team members' strengths while supporting each other in areas where help is needed.

2. Integrity

Definition: Upholding honesty and strong moral principles in all actions and decisions.

Team Actions:

- Accurate representation of data and challenges during updates to stakeholders.
- Following the IEEE Code of Ethics in all design and decision-making processes.
- Respecting intellectual property by using licensed software and properly sourcing materials.

3. Resilience

Definition: The ability to recover from setbacks and remain committed to the project goals.

Team Actions:

- Addressing technical challenges like sensor compatibility issues with creative problem-solving.
- Adapting to feedback from the client and advisor by revising designs and strategies.
- Supporting team morale through open communication and mutual encouragement during tough times.

Individual Contributions

Alan Whitehead

- Virtue Demonstrated: Integrity

Why It Is Important: Integrity ensures trust among team members and stakeholders and aligns our work with professional standards.

How It Was Demonstrated: I maintained honesty when communicating project challenges, such as sensor cost and compatibility issues, to our advisor and client, ensuring realistic expectations.

Virtue Not Yet Demonstrated: Empathy

Why It Is Important: Understanding the perspectives of stakeholders, particularly the end-users like machine shop workers, ensures the system meets their needs effectively.

What Might I Do to Demonstrate It: I plan to engage more with the shop workers at Linden Propeller to understand their pain points firsthand and incorporate their feedback into the system's usability design.

Denny Dang

- Virtue Demonstrated: Collaboration

Why It Is Important: Effective teamwork drives success in complex projects.

How It Was Demonstrated: I took the initiative to organize team meetings and ensure everyone was on the same page regarding the project timeline and tasks.

- Virtue Not Yet Demonstrated: Patience

Why It Is Important: Patience is essential for navigating delays and challenges without compromising quality.

What Might I Do to Demonstrate It: I will approach technical challenges with a calmer mindset and focus on solving them methodically rather than rushing to solutions.

Elias Colsch

- Virtue Demonstrated: Resilience

Why It Is Important: Resilience is crucial in senior design work because setbacks are inevitable, and the ability to adapt and push forward ensures the project stays on track.

How It Was Demonstrated: I demonstrated resilience by troubleshooting issues with sensor integration during the proof-of-concept phase. Despite initial failures, I continued refining the setup until we achieved functional results.

- Virtue Not Yet Demonstrated: Attention to Detail

Why It Is Important: Precision is vital in engineering, especially when dealing with high-accuracy systems like our propeller measurement device.

What Might I Do to Demonstrate It: I will thoroughly verify all calculations, review sensor performance metrics, and double-check integration points to ensure no overlooked design errors. Additionally, I plan to allocate more time for careful documentation to ensure clarity and accuracy in our reports.

8 Closing Material

8.1 CONCLUSION

We have made substantial progress in designing and implementing a modernized propeller measurement system for Linden Propeller. Our efforts have included thorough research and selection of sensors, development of a proof-of-concept prototype, environmental testing, and initial integration of the measurement system with TruProp software. Key decisions, such as selecting the Keyence IR sensor and selecting models with a robust mounting system, have been guided by our goals of improving durability, precision, and cost-effectiveness. Additionally, we have worked to ensure our design aligns with industry trends while offering the client flexibility through multiple solution options.

Reiteration of Goals

Our primary goals are:

1. Durability: Eliminate the frequent damage associated with the current system's fragile carbon fiber rods.
2. Accuracy: Achieve precision of 5 micrometers and a measurement range of up to 50 inches.
3. Cost-Effectiveness: Deliver a solution within the $1000 budget while minimizing long-term maintenance costs.
4. User Experience: Ensure a seamless transition for users by maintaining compatibility with the existing setup and TruProp software.

Best Plan of Action

The most effective plan to achieve our goals is implementing the Keyence IR sensor solution, which balances precision, durability, and alignment with industry standards. This solution:

- Meets the required accuracy of 5 micrometers.
- Demonstrates excellent resilience in shop environments during preliminary testing.
- Aligns with industry trends, ensuring the system remains competitive in the market.

Constraints Encountered

1. Budgetary Limitations: Some high-accuracy solutions exceeded the $1000 budget (such as Keyence), limiting options for advanced features.
2. Software Integration: Compatibility with TruProp required significant effort to establish a reliable data transfer protocol (which Keyence offers).

Improvements for Future Iterations

1. Early Engagement with End-Users: Involve machine shop workers in the design process to gain insights into their workflow and usability needs.
2. Expanded Sensor Research: Explore additional sensor technologies to identify cost-effective alternatives with similar performance metrics.
3. Focus on Sustainability: Evaluate the environmental impact of selected materials and components to improve the overall sustainability of the design.

8.2 REFERENCES

KEYENCE Corporation of America, Ultra High-Speed/High-Accuracy Laser Displacement Sensor LK-G5000 Series, KEYENCE, 2023

8.3 APPENDICES

We would like to mention that we had one more group member at the start of this project. We gave him an Arduino and our IR sensors when he told us he would work on it. He then vanished for two weeks, and we found out he had dropped the class after a wellness check. This delayed our development of the IR setup as he refused to reply to any of us and did not return our equipment.

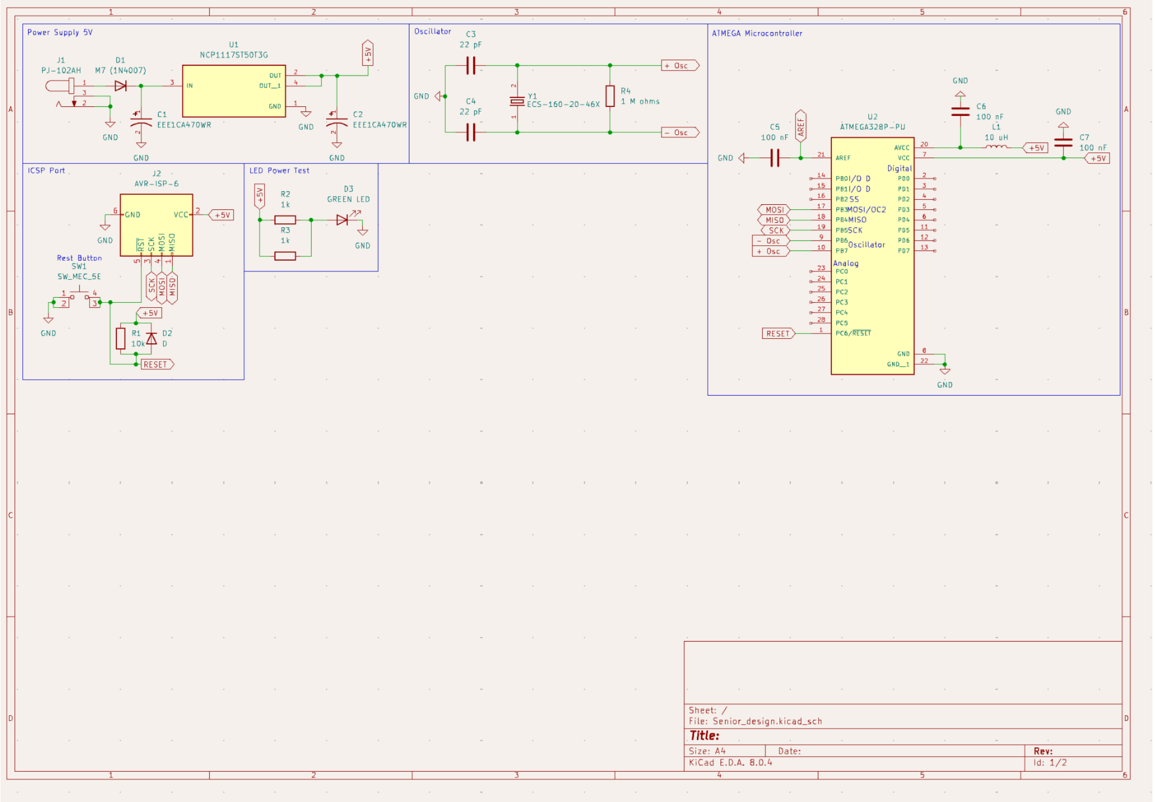


Figure 10

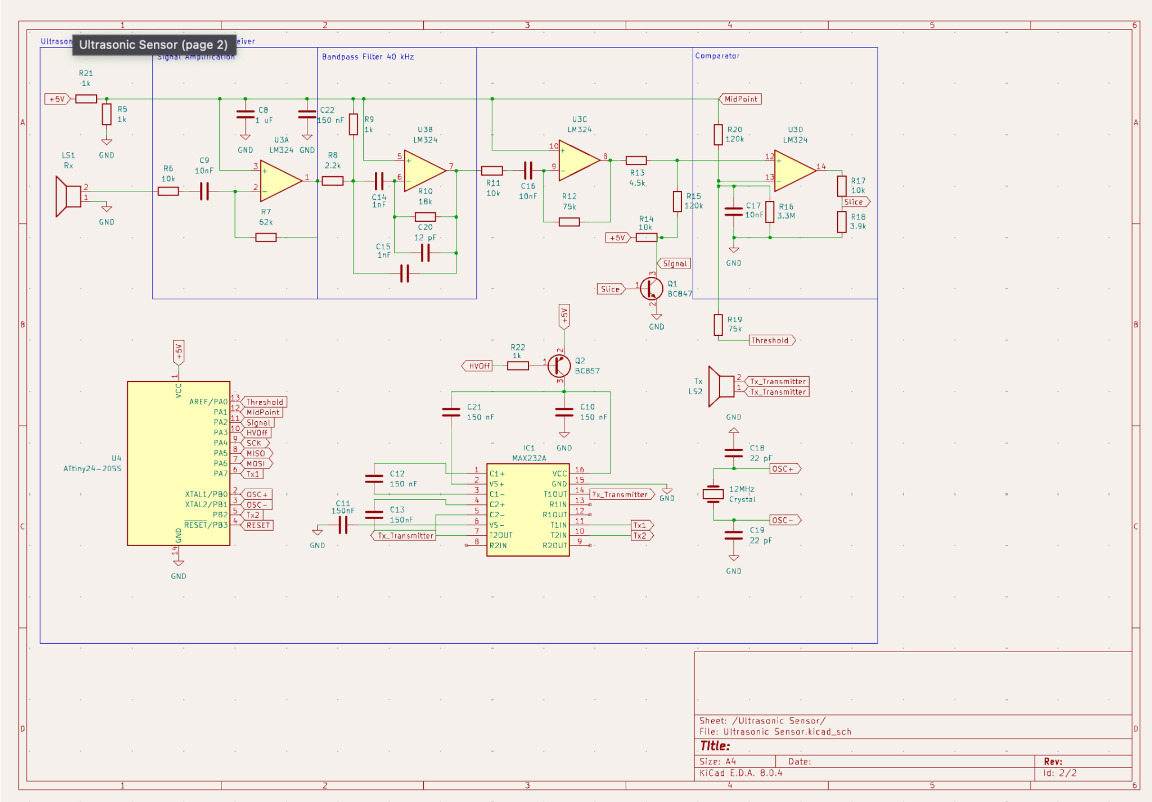


Figure 11

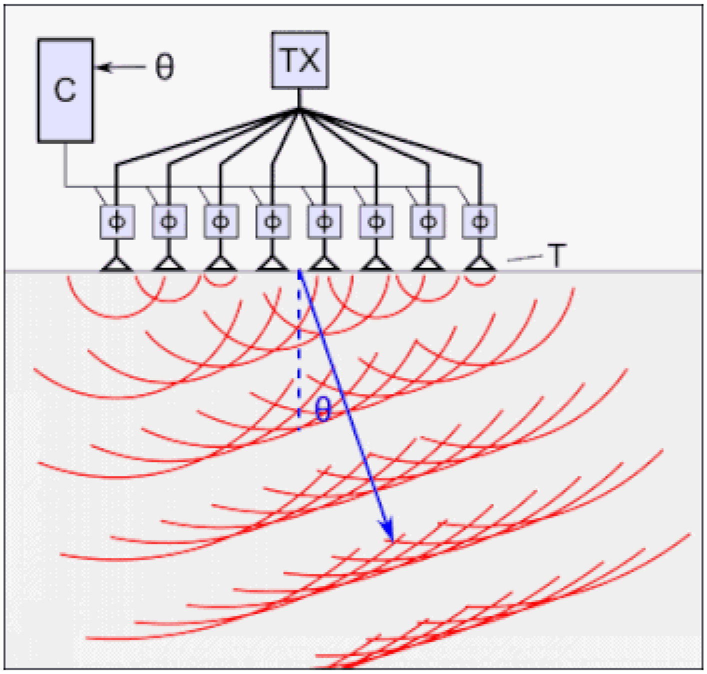


Figure 12

9 Team

9.1 TEAM MEMBERS

9.2 REQUIRED SKILL SETS FOR YOUR PROJECT

- Arduino coding
- Professional communication skills
- Knowledge of IR and ultrasonic sensors
- Circuitry

9.3 SKILL SETS COVERED BY THE TEAM

Elias Colsch: Professional communication, Knowledge of IR and ultrasonic sensors, and Circuitry

Denny Dang: Knowledge of IR and ultrasonic sensors, Arduino Coding, and Circuitry

Alan Whitehead: Knowledge of IR and ultrasonic sensors, Arduino Coding, and Circuitry

9.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

We have adopted an agile management style for this project

9.5 INITIAL PROJECT MANAGEMENT ROLES

Elias Colsch: Client Interaction and Research

Denny Dang: Individual Component Design

Alan Whitehead: Testing and Prototyping

9.6 Team Contract

Team Members:

1) ______Elias Colsch______ 2) ______Denny Dang______

3) ______Alan Whitehead______

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings: **Monday with Mani Mina at his office at 3:30.**

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face): **face-to-face, email reminders for meetings and using Discord for updates and informal discussion on the project.**

3. Decision-making policy (e.g., consensus, majority vote): **Majority vote.**

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived): **Spencer Rudin via handwritten note, or documented in text and put on discord.**

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings: **Everyone is expected to show up on time.**

2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines: **We will work with Mani Mina to create and assess timelines to make the project.**

3. Expected level of communication with other team members: **Team members are expected to communicate whenever there is a problem or complication.**

4. Expected level of commitment to team decisions and tasks: **Team members are expected to commit and work toward team decisions and tasks.**

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
   Client Interaction and Research: Elias Colsch
   Individual Component Design: Denny Dang
   Testing and Prototyping: Alan Whitehead

2. Strategies for supporting and guiding the work of all team members: **Mani Mina and all team members will be available for questions or help. Any problems should be brought to the team meeting, where we can devise a solution and assign new tasks.**

3. Strategies for recognizing the contributions of all team members: **All names and contributions will be listed on a slide for the project presentation.**

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.
   - **Elias brings the experience of working with multiple teams and clients to complete projects, as well as previous experience with smaller scale IR sensors.**
   - **Denny brings insight from manufacturing industry procedures and technology, and brings unique ideas.**
   - **Alan brings insight and experience with troubleshooting high voltage and high power systems.**

2. Strategies for encouraging and supporting contributions and ideas from all team members: **All ideas are open to debate during team meetings, where we can evaluate the cost/benefit of each idea.**

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a

team member inform the team that the team environment is obstructing their opportunity or ability to contribute?) **See below.**

Strategies for planning and assigning individual and teamwork

1. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?): **Any issues should be brought to the attention of all team members during meetings unless it is a private issue. If an issue only involves one person, that person should be told privately, and the issue should be resolved between those members.**
2. How will you handle infractions of any of the obligations of this team contract?: **Warnings will be issued for initial and minor infractions. Any major or continued infractions will lead to complaints submitted to Mani Mina or the Senior Design professors.**
3. What will your team do if the infractions continue?: **If serious infractions continue and the team member makes no attempt to fix them, eventually, it could lead to trying to get them moved from the project**

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the

consequences as stated in this contract.

1) _____Elias Colsch_____ DATE ________9/19/2024______

2) _____Denny Dang_____ DATE _______9/19/2024_______

3) _____Alan Whitehead_____ DATE _______9/19/2024_______