Active Soil Dust Collection System with Raspberry Pi Machine Visual Characterization

Final Report

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

This comprehensive report encapsulates the development, features, and outcomes of an innovative automated soil dust collection and characterization system. This system is engineered to revolutionize research on Valley Fever, an infectious disease caused by Coccidioides immitis, by addressing the inefficiencies of traditional soil dust collection methods.

At the heart of this project is the integration of advanced machine vision technology with a practical, portable design. The system boasts a compact footprint with a total volume of 0.038m^3 and a minimal weight of 2.716kg, enabling seamless deployment in diverse field conditions. Its innovative design and functionality represent a significant stride in environmental health research, specifically targeting the efficient collection and detailed analysis of soil samples critical in studying Valley Fever. A standout feature of this system is its high-resolution imaging sensor, adeptly managed by a Raspberry Pi. This sensor is capable of capturing the morphology of soil dust particles down to 2µm at a swift velocity of 8.67 m/s. The camera's specifications include an exposure time of 20 µs and sharpness of 5.21*6.94 µm, ensuring that each image captured is of the highest clarity and detail. This level of precision in imaging is paramount in accurately characterizing the soil dust and understanding its role in the transmission of Valley Fever.

In constructing this system, materials with a strength of 95 MPA were chosen to guarantee durability and robustness, essential for consistent performance under field conditions. The inclusion of a 3D printed channel, coated with indium tin oxide on the glass, not only aids in achieving clear imaging results but also contributes to the overall strength and longevity of the system. The operational efficiency of the system is optimized for extensive field use, with a working duration of up to 0.75 hours on a single charge or session. This allows for substantial data collection without the need for frequent interruptions or maintenance. The system's design includes an intelligently controlled fan, integrated with the Raspberry Pi, which agitates the air at the channel's entrance. This is complemented by a vacuum pump equipped with a HEPA filter, which is instrumental in the effective collection and filtration of airborne dust.

The implementation of this automated soil dust collection and characterization system marks a pivotal advancement in the study of Valley Fever. By automating the collection process and enhancing the quality of data through detailed soil dust morphology analysis, this system lays the groundwork for a more profound understanding of the disease's transmission dynamics. Such insights are invaluable in shaping effective prevention and control strategies for Valley Fever. Furthermore, the technological innovations and methodologies developed through this project have the potential to extend their utility to other areas of environmental and health research, driving forward a new era of technological application and development in these fields.

ACKNOWLEDGEMENTS

As we reflect on the journey of our undergraduate mechanical engineering capstone project, we recognize the invaluable contributions of our mentors and also acknowledge our own efforts and dedication that were crucial in bringing this project to fruition.

First and foremost, our deepest gratitude goes to Dr. Zhongwang Dou, our Project Sponsor and Faculty Advisor. His weekly client meetings were not just administrative check-ins but sessions of profound learning and inspiration. Dr. Dou's expert guidance, constructive feedback, and unwavering support have been instrumental in steering our project towards success. We are equally indebted to Dr. Armin Eilaghi and Dr. David Willy, our esteemed Instructors and Faculty Mentors. Their rigorous weekly staff meetings and insightful feedback post-presentation have significantly shaped the trajectory of our project. Their vast expertise and experience have not only guided us but also challenged us to delve deeper into our research and strive for excellence.

In this journey, we also take a moment to acknowledge our efforts as a team. The success of this project is a reflection of our collective hard work, dedication, and passion for engineering. We navigated challenges, embraced learning opportunities, and worked collaboratively to turn our vision into reality. This project has not only been a testament to our technical skills but also a journey of personal and professional growth.

We extend our heartfelt appreciation to our mentors for their invaluable guidance and to ourselves for the perseverance and commitment that have been pivotal in accomplishing this project. This journey has been an amalgamation of expert mentorship and our relentless pursuit of knowledge and innovation in mechanical engineering.

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1 BACKGROUND

1.1 Introduction

Valley Fever, a significant public health concern, is caused by the inhalation of Coccidioides imcites, a fungus present in soil dust. Current research methodologies for analyzing the spread and impact of this pathogen are hampered by inefficient soil dust collection techniques. Traditional manual methods are labor-intensive, time-consuming, and often yield inconsistent and limited data. These challenges underline the need for an innovative approach to enhance the accuracy and efficiency of soil sample collection, crucial for understanding and mitigating the impacts of Valley Fever.

Addressing this critical need, we propose a groundbreaking automated soil dust collection and characterization system. Utilizing advanced machine vision methods, this project is at the forefront of integrating technology and health research. The system's core comprises a portable mini-wind tunnel, which actively stirs the soil to collect dust, and a high-resolution imaging sensor operated by a Raspberry Pi. This setup not only collects soil samples more efficiently but also captures the soil dust morphology in real-time.

The system is remarkably compact and lightweight, with a total volume of only 0.038m^3 and a weight of 2.716kg, making it highly portable and field-deployable. It features a 60fps high-resolution imaging sensor, capable of capturing minute soil dust particles as small as 2µm at a velocity of 8.67 m/s. A 3D printed channel with an indium tin oxide coated glass material facilitates clear imaging, while the Raspberry Pi orchestrates a fan to agitate air at the channel's entrance. A connected vacuum pump, equipped with a HEPA filter, efficiently collects and filters airborne dust.

This project represents a significant leap in Valley Fever research. By automating the collection and characterization of soil dust, we not only improve the efficiency and quality of data collection but also enable a more profound understanding of the pathogen's transmission mechanisms. Furthermore, this system has potential applications beyond Valley Fever research, including studying the fluid properties of human inhalation of pathogen-carrying particulate matter and extending to other fields requiring precise dust analysis. The success of this project could spearhead a new era of technological innovation in environmental health research and beyond.

1.2 Project Description

Following is the original project description provided by the sponsor:

Valley Fever is an infectious disease caused by the fungus Coccidioides. The primary exposure pathway for humans is the inhalation of soil dust originating from locations in which these fungi occur in the soil. Current methods to collect soil dust samples for analyzing valley fever distribution are inefficient. We propose to design and implement an automatic soil dust collection and characterization system utilizing the machine vision approach. A portable mini wind tunnel will be used to agitate the grand for dust collection actively. A Raspberry Pi and a high-resolution imaging sensor will be employed to record the soil dust morphology in real-time. A series of validation and verification laboratory experiments will be conducted to test the accuracy of this system. Field tests in soil collection test sites are going to be scheduled to ensure the rigidity of this system. The success of implementing this apparatus will vastly improve the efficiency and accuracy of the collection of soil samples for Valley Fever studies.

2 REQUIREMENTS

This section plays a critical role in guiding the planning, execution, and evaluation of a project or task by providing customer requirements as well as engineering requirements. It helps coordinate stakeholder efforts, facilitates effective communication, and serves as a reference for measuring success.

2.1 Customer Requirements (CRs)

- CR1 - Easy to Carry

This requirement emphasizes the need for the system to be lightweight and portable. It is essential for field applications where researchers may need to transport the equipment across various terrains. Making the system easy to carry enhances its usability and accessibility in diverse research settings.

- CR2 - Easy to Operate

Simplicity in operation is a key requirement. The system should be user-friendly, allowing researchers and technicians to operate it with minimal training. This ensures efficiency and reduces the likelihood of operational errors, making the system more reliable and accessible to a wider user base.

- CR3 - Capture Images with High Resolution

High-resolution image capture is crucial for accurately analyzing soil dust morphology. This requirement ensures that the system can provide detailed and clear images, which are vital for thorough research and analysis in studies of Valley Fever and other related fields.

- CR4 - Overall Durability

Durability is a fundamental requirement as the system will be used in various outdoor environments. It needs to withstand different weather conditions and potential physical impacts. A durable system ensures longevity, reliability, and consistent performance over time.

- CR5 - Overall Stability

Stability is essential, especially when capturing high-resolution images. The system must remain steady during operation to ensure the quality of the data collected is not compromised by vibrations or movements, which is critical for accurate and reliable research outcomes.

- CR6 - Quick Dust Collection

The ability to collect dust quickly is important for efficiency and effectiveness in field research. Quick dust collection reduces the time spent in the field and increases the volume of data that can be collected in a single session, enhancing the overall productivity of the research process.

- CR7 - Can be Used in Different Environments

Versatility in different environmental conditions is a key requirement. The system should be adaptable to various soil types and weather conditions, ensuring reliable performance and accurate data collection regardless of the research location. This expands the scope and applicability of the system in diverse geographical areas.

2.2 Engineering Requirements (ERs)

- ER1 - Decrease Weight and Volume of Body

Reducing the weight and volume of the system is crucial for enhancing portability and ease of use in field applications. A lighter and more compact design facilitates transportation and deployment, especially in remote or challenging terrains, thereby increasing the system's practicality and user-friendliness.

- ER2 - Increase Flow Rate and Speed

Enhancing the flow rate and speed of the dust collection process is essential for improving the efficiency of sample collection. A higher flow rate ensures that a larger volume of soil can be processed in a shorter time, leading to more comprehensive data collection and a more effective research process.

- ER3 - Increase Control System Automaticity

Improving the automaticity of the control system is key for reducing manual intervention and increasing operational efficiency. An automated system ensures consistent performance, minimizes human error, and allows for smoother, uninterrupted data collection, making the research process more reliable and effective.

- ER4 - Decrease Exposure Time for Shooting

Minimizing the camera's exposure time is vital for capturing high-quality images of fast-moving dust particles. A shorter exposure time reduces motion blur, resulting in clearer and more precise imagery, which is essential for accurate morphological analysis of soil dust.

- ER5 - Increase Camera Sharpness

Enhancing camera sharpness is critical for capturing detailed and clear images. Higher sharpness leads to better image resolution, which is essential for accurate analysis of soil dust samples. This improvement is particularly important in research where visual data plays a central role in drawing conclusions.

- ER6 - Increase Strength of Material

Strengthening the materials used in the system's construction ensures greater durability and resilience, especially in diverse and potentially harsh environmental conditions. Stronger materials contribute to the longevity and reliability of the system, reducing the need for frequent repairs or replacements.

- ER7 - Increase Working Duration

Extending the system's working duration is crucial for maximizing field productivity. A longer operational time allows for more extensive data collection in a single session, reducing the need for multiple field trips. This not only enhances the efficiency of the research process but also makes it more cost-effective.

2.3 Functional Decomposition

This section helps stakeholders understand the system structure, facilitates effective communication, supports resource allocation, and enables targeted problem solving. It mainly introduces how to achieve an active sampler that can realize automatic dust collection and characterization.

2.3.1 Black Box Model

A black box model is often used to represent a system or process where the internal mechanics are not visible, but its functionality is understood through its inputs and outputs. In our case, the device, which is powered by electricity, incorporates a Raspberry Pi for control and is designed to gather soil dust. The inputs for this system are electrical power, soil samples, and commands from the Raspberry Pi. Its primary function, and thus its outputs, are the collection of dust and the creation of a video showing the movement of this dust. This black box representation simplifies the understanding of the device's cause-and-effect relationships, making it easier to communicate its workings to our clients. Moreover, it aids in the development of diagrams that illustrate the work process.

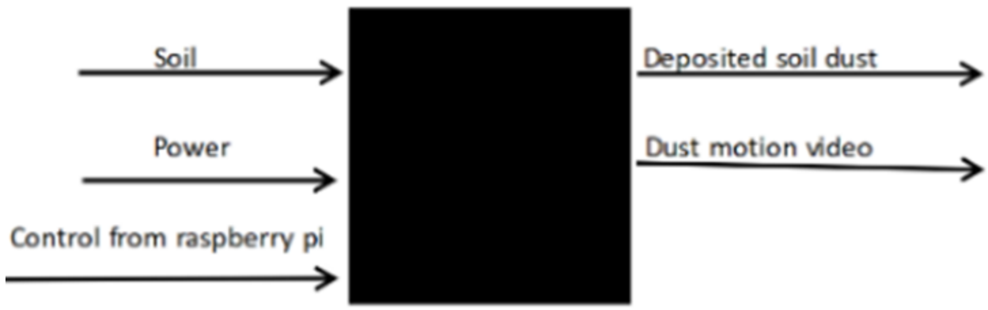


Figure 1: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The Work-Process Diagram is a visual representation that details the various steps and functions within each segment of the device's operation. Essentially, it delineates the internal logic governing the device's functioning. This diagram is instrumental in enhancing our presentation of the product to colleagues and peers. Additionally, having a well-defined Work-Process Diagram is crucial for maintaining efficiency in our design process, ensuring adherence to the fundamental logic of the device. The recent update has introduced a frame to the system, which not only serves to protect the device but also enhances its overall durability and portability.

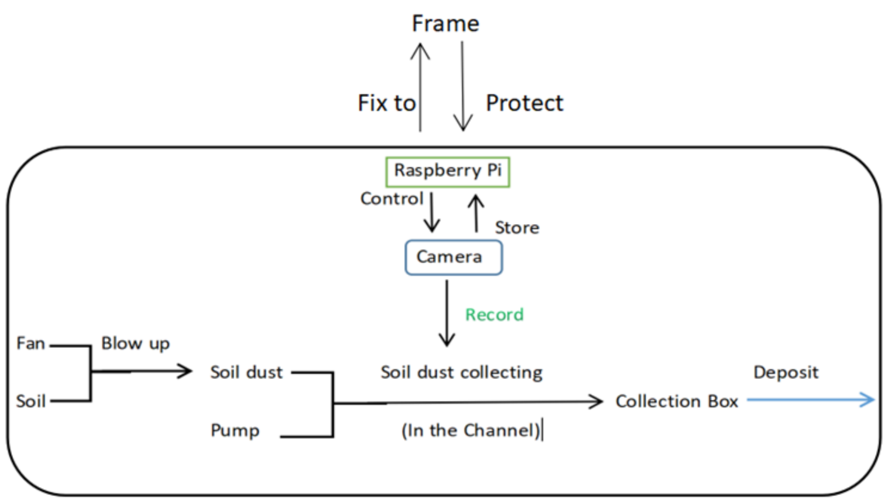


Figure 2: Work-Process Diagram

2.4 House of Quality (HoQ)

The House of Quality is a tool that effectively bridges customer needs with specific design and engineering objectives. It plays a key role in identifying and prioritizing what customers value most, such as compact design, rapid collection ability, and high clarity. This is achieved by assigning varying weights to different customer requirements. At its core, the House of Quality connects these customer needs with engineering solutions, highlighting the importance of reducing the equipment's mass, volume, and complexity for project success. Through the evaluation and weighting of different engineering approaches, we have chosen to focus primarily on simplifying the equipment's design and enhancing its collection speed. This strategic focus enables us to concentrate on essential requirements and better distribute our resources. Additionally, the House of Quality indicates that the material requirements for this project are relatively modest.

Table 1: Testing Procedures for Engineering Requirements

Experiment/Test	Relevant Components	Relevant DRs
EX1 - Flow Rate and Speed Test	1.Channel 2.Vacuum	ER2, CR6, CR7
EX2 - Control System Test	1.Raspberry Pi 2.Relay 3.Camera	ER3, CR2, CR4, CR5, CR7
EX3 - Shooting Resolution Test	1.Camera 2.Channel	ER5, CR3, CR7
EX4 - Capture Speed Test	1.Raspberry Pi 2.Fan 3.Camera	ER4, CR3, CR7
EX5 - Weight Test	1.Whole device	ER1, CR1

2.5 Standards, Codes, and Regulations

Standards and codes play an indispensable role in the field of engineering. They serve as essential benchmarks that establish uniformity, quality, safety, and operational efficiency. Adherence to these standards and codes is vital for industries to guarantee the reliability, safety, and interoperability of their products. Our team has consulted various standards and codes from numerous organizations to select the most appropriate ones for application in our project.

Table 2: Standards of Practice as Applied to this Project

Standard Number or Code	Title of Standard	How it applies to Project
ISO 12100:2010	Safety of machinery — General principles for design — Risk assessment and risk reduction	Provides safety guidelines for designing the dust collection device to ensure minimal risk to users.
AA ASD1:2017	Aluminum standards and data 2017	Associates design the structure of the aluminum frame and test it.
AWS D1.2/D1.2M: 2014	STRUCTURAL WELDING CODE - ALUMINUM	Determines the structural and safety standards for welding the aluminum frame of the dust collection device.
IEEE Std 515.1:2005	Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Commercial Applications	Helps in testing, designing, and maintaining the circuit used in our device.
ASTM E8/E8M-16a	Standard Test Methods for Tension Testing of Metallic Materials	Helps in testing the strength of the aluminum frame and other parts.
ISO 3744:2010	Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for an essentially free field over a reflecting plane	Helps in controlling the sound of our device when operating.

3 DESIGN SPACE RESEARCH

3.1 Literature Review

This section showcases the findings of each person within the team on different aspects of the technology. Each source is written up with a summary and a discussion of how it applies specifically to this project design space.

1.Goossens, Dirk, and Zvi Y Offer. "Wind Tunnel and Field Calibration of Six Aeolian Dust Samplers." Atmospheric environment (1994) 34.7 (2000): 1043–1057. Web. [1]

The study evaluated the efficiency of six aeolian dust samplers through wind tunnel experiments and field measurements. In the wind tunnel, four samplers measuring horizontal dust flux and one sampler measuring vertical dust flux were calibrated against an isokinetic reference sampler. The horizontal dust flux samplers included the BSNE, MWAC, SUSTRA, and WDFG, while the vertical deposition flux was measured using the MDCO. A SARTORIUS sampler served as the reference sampler. Field experiments replaced the WDFG with the SIERRA sampler. The most efficient samplers were found to be the MWAC and SIERRA, followed by the BSNE and SUSTRA. The collective collection of devices will be improved on passive collection devices and these examples give us the prototype of the collector.

2. Yamamoto, Naomichi et al. "A Passive Sampler for Airborne Coarse Particles." Journal of aerosol science 37.11 (2006): 1442–1454. Web. [2]

A personal aeroallergen sampler (PAAS) was developed with a gimbal-like structure that ensures continuous upward particle collection regardless of the sampler's inclination. The PAAS was evaluated for its ability to collect particles of different sizes and compared to an existing reference active sampler. The results showed a strong correlation between the two methods, indicating that the PAAS can be used effectively for long-term personal monitoring of coarse airborne particles, including aeroallergens. Also mentioned in the text is the IOS active sampler, which provides the underlying logic for manufacturing the active sampler.

3. Verreault, Daniel, et al. "Methods for Sampling of Airborne Viruses." *Microbiology and Molecular Biology Reviews*, vol. 72, no. 3, Sept. 2008, pp. 413–444, https://doi.org/10.1128/mmbr.00002-08. [3]

The review article focuses on the importance of accurate sampling of airborne viruses in the field of aerovirology. The authors examined more than 100 papers to assess the current methods used for viral aerosol sampling. Distinguishing between infections caused by direct contact and those caused by airborne transmission can be challenging due to the various sources of viral aerosols. Air sampling provides valuable data for risk assessment, complementing epidemiological information. The review discusses different types of samplers employed, such as liquid impingers, solid impactors, filters, and electrostatic precipitators. After comparison, the filter method was adopted for this project.

4. Kalisa, Egide, et al. "A Preliminary Investigation Comparing High-Volume and Low-Volume Air Samplers for Measurement of PAHs, NPAHs and Airborne Bacterial Communities in Atmospheric Particulate Matter." *Environmental Science: Atmospheres*, vol. 2, no. 5, 2022, pp. 1120–1131, https://doi.org/10.1039/d2ea00078d. [4]

This study focused on monitoring atmospheric particulate matter (PM) in urban areas of African countries, where resources for monitoring are limited. The researchers collected PM10 using high-volume and low-volume air samplers (HVAS and LVAS) at an urban site in Rwanda. They characterized the presence of polycyclic aromatic hydrocarbons (PAHs), nitro-PAHs (NPAHs), and bacterial community structures using 16S rRNA gene sequences and compared the results between the two sampler types. HVAS and LVAS are important for air sample collection and are very helpful in the design of this project.

5. Whyte, W., et al. "Collection Efficiency and Design of Microbial Air Samplers." *Journal of Aerosol Science*, vol. 38, no. 1, 1 Jan. 2007, pp. 97–110, www.sciencedirect.com/science/article/pii/S0021850206001728, [5]

The study aimed to investigate the variables that influence the physical collection efficiency of air samplers designed to impact microbe-carrying particles onto agar surfaces. The researchers employed a simplified analytical method and computational fluid dynamics to analyze these variables. They compared the results obtained from these two techniques and examined the impact of jet velocity, nozzle size, and nozzle distance from the agar surface. The goal was to optimize these variables to design an efficient sampler. The text covers a lot of formulas on fluid dynamics, which is very helpful to help improve the efficiency of the equipment.

6. Design and development of a smart baby monitoring system ... - IEEE xplore, https://ieeexplore.ieee.org/abstract/document/8255338 (accessed Jul. 8, 2023). [6]

This article introduces a device for monitoring babies. It describes how to connect a camera to a Raspberry Pi and output its video to a display. These skills are needed for our design. We need to connect the camera to the Raspberry Pi. We can also learn from this article how to remotely output the image to the display.

7. M. A. Pagnutti et al., "Laying the foundation to use raspberry pi 3 V2 camera module imagery for Scientific and engineering purposes," SPIE Digital Library,https://www.spiedigitallibrary.org/journals/journal-of-electronic-imaging/volume-26/issue-1/013014/Laying-the-foundation-to-use-Raspberry-Pi-3-V2camera/10.1117/1.JEI.26.1.013014.full?SSO=1 (accessed Jul. 7, 2023). [7]

The paper conducted a radiometric analysis of raw data format images taken with the Raspberry Pi 3 and its V2.1 camera module. This study proves the potential of the Raspberry Pi 3 and its V2.1 camera module to generate scientific and engineering-grade imagery. It is revealed that the raw images follow a linear relationship with exposure and gain. The paper covers detailed investigations into dark frame, noise, exposure stability, flat fielding outcomes, spectral response measurements, and absolute radiometric calibration. This paper can help our team have a better idea on how our camera will take photos and how to make the photo more clear.

8. Raspberry Pi as a video server | IEEE conference publication - IEEE xplore, https://ieeexplore.ieee.org/abstract/document/8515817/ (accessed Jul. 8, 2023). [8]

This paper discusses the use of Raspberry Pi as a real-time video server for monitoring and one-sided educational conferencing applications. Utilizing Raspberry Pi's programming and control capabilities, a LAN network live real-time video/audio streaming server has been created. The video which is captured via the Raspberry Pi's camera module is compressed and transmitted over the network using a unique standard that utilizes HTTP. Similarly, audio captured through a microphone is sent using the RTP. The system addresses issues of high costs and complexity in video server systems and large storage requirements. It also recommend to extend this project to a WAN network. This article gives us a method to establish a low-cost, low-complexity video server which can reduce the customer cost.

9. Low cost real-time system monitoring using Raspberry Pi | IEEE ..., https://ieeexplore.ieee.org/abstract/document/7182665 (accessed Jul. 8, 2023). [9]

This paper outlines the design and implementation of an affordable monitoring system based on Raspberry Pi, aimed at overcoming the limitations of current CCTV surveillance systems like poor image quality, lack of automated anomaly detection, high storage requirements, and elevated costs. The proposed system uses a motion detection algorithm developed in Python. By employing this algorithm, the system significantly reduces storage needs and consequently, investment costs. The algorithm is implemented on Raspberry Pi to enable a live streaming camera that detects motion. Notably, the live video feed from the camera can be accessed from any web browser, including mobile, in real-time, enhancing the versatility of this innovative monitoring system. From this article, we can learn about a monitor system with low cost, high image quality. We can apply it to our own recording system to enhance its performance.

10. Author links open overlay panelGokulnath Anand et al., “Object detection and position tracking in real time using Raspberry Pi,” Materials Today: Proceedings, https://www.sciencedirect.com/science/article/pii/S2214785321048318?casa_token=avsI0dmy1B4AAAA
A%3ArjEhbIUd7bWU61HFqKrF6olbcsvzZ40eTONBypCIPhT7hjYOHjpww2a4unZG7u6LLiFpU9y
f-lU(accessed Jul. 7, 2023). [10]

This paper conducted a way for the Raspberry Pi to detect objects and track them. It provides an efficient shape-based object identification method and its displacement in real-time using OpenCV library. This article can help our device have a object detection and tracking system which can distinguish the required dust and implement tracking to get better recording results.

11. Heidari-Rarani, Rafiee-Afarani, M., & Zahedi, A. M. (2019). Mechanical characterization of FDM 3D printing of continuous carbon fiber reinforced PLA composites. Composites. Part B, Engineering, 175, 107147–. https://doi.org/10.1016/j.compositesb.2019.107147 [11]

This paper presents an innovative extruder technology for the production of continuous fiber-reinforced thermoplastic composites on FDM 3D printers. By overcoming challenges in the extrusion process, the researchers successfully improved the properties of the composites and provided experimental results and morphological analysis to evaluate the quality of the products. This research is of great significance for promoting the application of fiber-reinforced composites in industrial applications. The wind tunnel is a key component in an automated soil dust collection system for stirring up soil dust. In order to ensure the efficiency and stability of the wind tunnel, the internal structure needs to have sufficient strength and wear resistance. By using FDM 3D printing continuous carbon fiber-reinforced PLA composites, wind tunnel internal structures with high strength and wear resistance can be manufactured to improve the performance and life of the system.

12. Mazzanti, Malagutti, L., & Mollica, F. (2019). FDM 3D Printing of Polymers Containing Natural Fillers: A Review of their Mechanical Properties. Polymers, 11(7), 1094–. https://doi.org/10.3390/polym11071094 [12]

This paper points out the trend towards the use of natural fiber fillers in biodegradable thermoplastics and provides the results of an evaluation of the mechanical properties of common materials and a few other polymers. This shows that adding biological fillers to FDM 3D printing is feasible for improving the performance of some polymers. However, there are still many aspects that need further research, and more information about this area may be gained by modifying FDM technology and existing equipment. Polymers containing natural fillers can be used in FDM 3D printing to manufacture parts and components of the system. The mechanical properties review can provide information on the strength, rigidity, toughness and wear resistance of different materials. These performance indicators can help design suitable parts and assemblies to meet the requirements of automated soil dust collection and characterization systems.

13. Hua, Lin, Q., Qu, B., Zheng, Y., Liu, X., Li, W., Zhao, X., Chen, S., & Zhuo, D. (2021). Exceptional Mechanical Properties and Heat Resistance of Photocurable Bismaleimide Ink for 3D Printing. Materials, 14(7), 1708–. https://doi.org/10.3390/ma14071708 [13]

This paper reports a photocurable bismaleimide ink with excellent comprehensive properties for stereolithography (SLA) 3D printing. In general, photosensitive resins have the characteristics of high molding accuracy and fast processing speed in 3D printing, but their mechanical properties and heat resistance are relatively poor. These light-cured BDM inks can be used to manufacture complex structural parts and models with excellent mechanical and thermal properties. The research opens up new possibilities for developing high-performance 3D printing materials, expanding the range of materials used in SLA 3D printing. Therefore, the photocured bismaleimide ink has excellent heat resistance and can withstand the application environment at higher temperatures. In automated soil dust collection and characterization systems, parts with high temperature stability may be required, such as sensor mounts or interface parts for high temperature environments. 3D printing with this heat-resistant material can create parts that maintain stability and performance under high temperature conditions.

14. Quintana-Ruiz, & Campello, E. M. B. (2023). Discrete element modeling of selective laser sintering additive manufacturing processes. Computer Methods in Applied Mechanics and Engineering, 410, 115994–. https://doi.org/10.1016/j.cma.2023.115994 [14]

This paper presents a simple method to simulate the selective laser sintering process in advanced manufacturing. This method is based on the discrete element method (DEM) to represent the powder bed, and combined with the lumped heat transfer equation to describe the thermal phenomena that may occur in the thermomechanical active particles forming a discrete particle system. Phase transitions that may be critical in such applications are also considered. Numerical examples are provided to illustrate practical use of the method. Discrete element modeling can be used to simulate powder flow, melting and sintering process in SLS process. By simulating the effects of different process parameters, such as laser power, scanning speed, powder layer thickness, on part quality and performance, process parameters can be optimized to obtain the best print results. This helps improve the component quality and manufacturing efficiency of soil dust collection and characterization systems.

15. Kitsakis, Kechagias, J., Vaxevanidis, N., & Giagkopoulos, D. (2016). Tolerance Analysis of 3d-MJM parts according to IT grade. IOP Conference Series. Materials Science and Engineering, 161(1), 12024–. https://doi.org/10.1088/1757-899X/161/1/012024 [15]

This literature shows that the MJM 3D printing process can produce objects with IT11 level or better, classifying them into the Fits region of the IT level. This means that the printed parts have high dimensional accuracy and meet specific tolerances. These findings demonstrate the potential of the MJM process for manufacturing precise parts and provide support for achieving higher precision 3D printing. By performing tolerance analysis of 3D-MJM parts using IT grades, dimensional accuracy and consistency of geometric features in the system can be assessed. According to the design requirements and functional requirements, the appropriate tolerance range is determined to ensure the acceptability and performance of the part during the manufacturing and assembly process. This helps identify possible errors and variations in the manufacturing process and provides a basis for improving design and manufacturing methods.

16. W. Wang and M. R. Coop, "An investigation of breakage behavior of single sand particles using a high-speed microscope camera," Géotechnique, Nov. 9, 2016. doi: 10.1680/jgeot.15.P.247. [16]

This research affirms that single particle uniaxial compression tests, a standard practice in micromechanics, can illuminate the behavior of different sand particles under stress. This finding ranks sand particles within an established classification of particle breakage behavior, indicating that they exhibit high variability in their response to pressure. This shows potential for single particle uniaxial compression tests to reveal nuances in breakage behavior, contributing to the ongoing development of particle micromechanical theories. By meticulously observing and recording the breakage processes using a high-speed microscope camera, the research assesses the performance and consistency of different sand particles under stress. The method enables detailed comparison of particle strength, breakage mode, and the impact of immersion, correlating these factors with the particles' characteristics such as local roundness, size, aspect ratio, regularity, and two-dimensional sphericity. These characterization processes help a lot in calculating features of dust.

17. L. L. Ashbaugh, O. F. Carvacho, M. S. Brown, J. C. Chow, J. G. Watson, and K. C. Magliano, "Soil sample collection and analysis for the Fugitive Dust Characterization Study," Journal Name, vol., no., pp., Date. [17]

This research presents the discovery process of a distinctive collection of soil samples as part of the Fugitive Dust Characterization Study. The collection process was executed with rigorous

care, employing a methodical procedure aimed to curtail sampling bias. To preserve potential organic signatures, the samples were stored frozen. For the scope of this paper, the samples were characterized based on particle size (percent sand, silt, and clay), dry silt content (as per EPA-recommended fugitive dust emission factors), carbon and nitrogen content, and potential to emit PM10 and PM2.5. This article gives a clear standard of traditional dust characterization, Inspired our standard setting and reference.

18. F. Cai, T. Wang, W. Lu, and X. Zhang, "High-resolution mobile bio-microscope with smartphone telephoto camera lens," Optik, vol. 207, Apr. 2020, Art. no. 164449. doi: Specific DOI if available. [18]

The study explores the use of bio-microscopy, a widely established tool in clinical pathology and life science research, in a new context. Currently, bio-microscopes are sizable and mostly restricted to laboratories, limiting their accessibility and usability in different scenarios. Modifying a smartphone equipped with a telephoto camera lens into a mobile microscope by attaching an infinite correction objective in front of the lens. The experiment achieved an optical resolution of 4.4 μm with a 40x objective lens.This modification instantly gives the microscope wireless communication capabilities. This article shows a technical method of imagining transmission which is important for our project.

19. S. K. Kim, V. Mariappan, and J. S. Cha, "A Study on Environmental Micro-Dust Level Detection and Remote Monitoring of Outdoor Facilities," International Journal of Advanced Smart Convergence, vol. 9, no. 1, pp. 63-69, 2020. [Online]. Available: http://dx.doi.org/10.7236/IJASC.2020.9.1.63. [19]

This article presents a method for detecting environmental dust levels in outdoor facilities, a critical issue due to the global impact of industrial pollution on air quality and health. This method employs sensor fusion technology, using both camera sensors and commercial dust level sensors to measure and monitor micro-dust levels in real-time. The system, implemented on Raspberry Pi-based open-source hardware with an Internet of Things (IoT) framework, uses optical flow-based machine learning to detect dust levels. The system's performance has been evaluated in real-time and the experimental results demonstrate its precision and reliability. Compared to commercial sensor-based methods, this approach offers improved accuracy in detecting changes in air pollution. The article presents a similar machine learning method of our project, very helpful for our developing process.

20. W. Watanabe, R. Maruyama, H. Arimoto, and Y. Tamada, "Low-cost multi-modal microscope using Raspberry Pi," Optik, vol. 212, pp. 164713, Jun. 2020. Available: https://doi.org/10.1016/j.ijleo.2020.164713. [20]

This report describes a direction-dependent optical microscope operated with Raspberry Pi, where the LED array illumination patterns are controlled by Raspberry Pi. Images are captured using a Raspberry Pi camera module. The study demonstrates the use of Raspberry Pi-based microscopes for multimodal imaging, including bright-field microscopy, dark-field microscopy, differential phase-contrast microscopy, and polarization microscopy. The acquisition of direction-dependent dark-field and differential phase-contrast images is also demonstrated. Dark-field and differential phase-contrast images exhibit enhanced structures along the illumination axis, achieved through the use of opposite line or rectangular illumination. This report plays a significant role in our experiment for adjusting the lighting environment and light

settings.

3.2 Benchmarking

The following benchmark tests will be conducted in the automatic soil dust collection and characterization system using machine vision methods. Firstly, there is a dust collection efficiency test, which can be benchmark tested to evaluate the collection efficiency of automatic soil dust collection systems. This can include conducting collection experiments in environments with known dust concentrations and measuring the amount of dust collected by the system. By comparing with standard methods or other validated collection systems, the performance and efficiency of the system can be evaluated. Next is real-time monitoring accuracy testing, which involves real-time detection technologies such as image processing and sensors. Relevant benchmark tests can include simulating tests using known concentrations of dust and comparing them with standard concentrations to evaluate the monitoring accuracy and accuracy of the system. In addition, for the long-term use of automatic soil dust collection and characterization systems, relevant benchmark tests can include long-term stability assessment of the system. This can involve continuous testing or long-term monitoring to evaluate whether the system can maintain consistent performance and accuracy over time. Finally, after some benchmark testing, we will promptly share and seek improvement suggestions with our client to improve the final system.

3.2.1 System Level Benchmarking

The following will introduce three related existing designs. The first one is BSNE. It's a low volume particulate air sampler. It uses lower flow rates to capture particulate matter samples. It's suitable for long term sampling or the need for specific particle analysis. The second one is called SARTORIUS. It's a high volume particulate air sampler. It uses a fan or a pump to pass a large amount of air through the filter paper to capture particulate matter suspended in the air. The sampling time and flow rate can be adjusted according to needs. The third one is named MDCO. It's a settling plate sampler. It uses marbles to form a filter in the bowel to deposit particulate matter in the air. Collecting samples can be used for surface analysis or microscopic observation.

3.2.1.1 Existing Design #1: BSNE

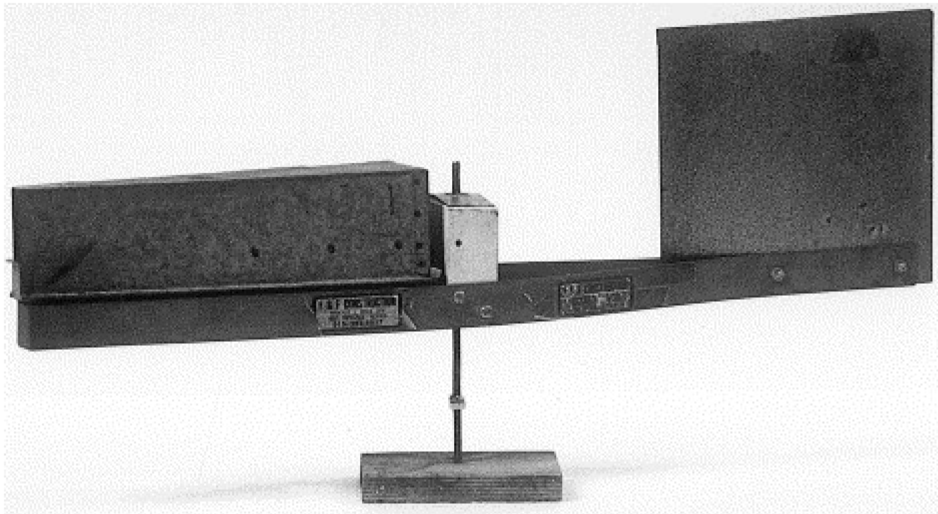


Figure 3 :BSNE sampler [1]

The BSNE sampler was developed by DW Fryrear in 1986. Although it was originally designed to collect dust from the air, it is now often used to collect soil and sand. The sampler consists of 28 gauge galvanized metal, galvanized 18 mesh sieve, and stainless steel 60 mesh sieve[1]. Dust laden air passing through a vertical 2cm × 5 cm sampler opening. Once entering the sampler, the air speed will decrease and dust will settle in the collection tray. The air is discharged through a 60 mesh sieve. The 18 mesh sieve reduces the movement of sedimentary materials, preventing the decomposition of collected sediment and the possibility of very fine particles losing from the top of the sieve. The rubber retainer seals all small holes behind or in front of the assembled sampler. The Weather vane at the rear ensures that the sampler rotates downwind. This information provides reference for the design and development of automated collection and characterization systems. A device with similar functions can be designed based on the principle and structure of the BSNE sampler, combined with machine vision methods for automatic soil dust collection and characterization. Machine vision methods can be used to analyze and identify particle characteristics, morphology, and composition in collected soil dust samples. Such a system can provide efficient, accurate, and automated soil dust analysis, which helps to research and monitor soil environmental quality, plant health, and other related applications.

3.2.1.2 Existing Design #2: SARTORIUS

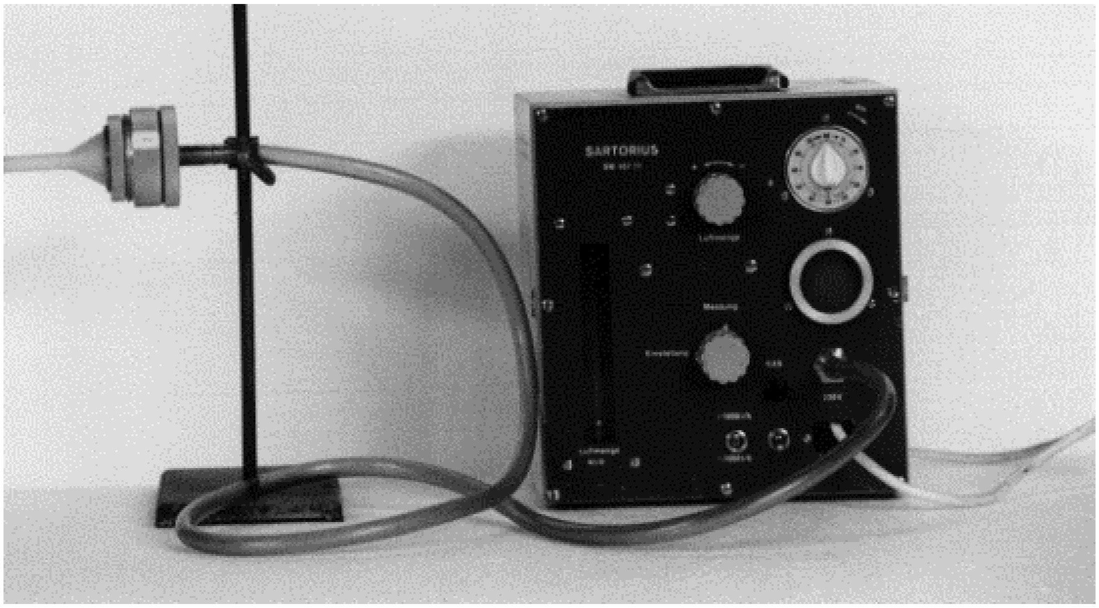


Figure 4:Sartorius Membranfilter SM 16711 [1]

This is a commercially available active sampler registered as Sartorius Membranfilter SM 16711.

The sampler sucks in dusty air at an adjustable rate and is connected to the filter holder. By adjusting the flow controller, the flow can be adjusted within the range of 200 to 1800 l/h and the actual flow can be read from the instrument[1]. To measure at a specific wind speed, the diameter of the suction tank inlet is reduced by attaching an extension cover to the filter bracket, and all holes are sealed with silicone paste. This information provides reference and guidance when associated with automatic soil dust collection and characterization systems using machine vision methods. The active sampler can be used as a part of the system to control the collection rate and particle input conditions of soil dust. Machine vision methods can be combined with this system to perform image analysis, morphological feature extraction, and composition analysis on collected soil dust. By combining these technologies, automated, efficient, and accurate soil dust collection and characterization can be achieved.

3.2.1.3 Existing Design #3: MDCO

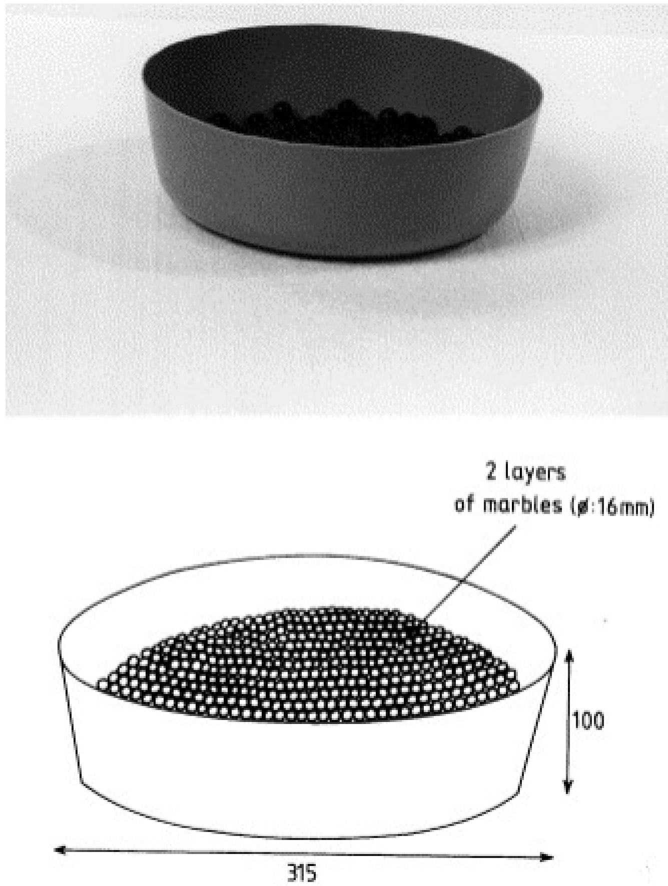


Figure 5: Marble Dust Collector [1]

This is a vertical flux sampler, namely the marble dust collector (MDCO), as well as its composition and usage. MDCO is a commonly used sampler, especially in desert research. It consists of a plastic tray and one or two layers of marble, which can be installed on the ground or connected to a vertical mast. The shape of the tray is usually circular, with a diameter of 31.5 centimeters and a height of 10 centimeters[1]. Standard glass marbles are used as tracers in the sampler. When associated with the automatic soil dust collection and characterization system using machine vision methods, the vertical flux sampler can be used as part of the system to measure the ratio of vertical deposition flux to horizontal dust flux. Machine vision methods can be combined with this system to perform image analysis, morphological feature extraction, and composition analysis on collected soil dust samples. By combining these technologies, automated, efficient, and accurate soil dust collection and characterization can be achieved, and further research on soil environmental quality and other related applications can be conducted.

3.2.2 Subsystem Level Benchmarking

The following will introduce three types of existing related subsystem designs. The first one is the lens, which is used for optical focusing and changing field of view angle. The second one is fan, which is mainly used to agitate the air and to blow up the dust. The third one is air pump, which is mainly used for blowing or absorbing the dust suspended in the air. These will become valuable references for the final subsystems.

3.2.2.1 Subsystem #1: Lens

The lens is a device installed at the front of the camera in this project, which can effectively expand the functions of the camera. Different lenses include ultra-wide-angle lenses, macro lenses, microscope lenses, etc. These optical lenses can greatly expand the applicable range of the camera without sacrificing clarity.

3.2.2.1.1 Existing Design #1: Dino-Lite Pro AM4113Ts

Figure 6: Lens Choice #1

Pros:

- Low cost,
- compact structure,
- high optical magnification.
- It has seven light-emitting diodes, which can produce clearer images.

Cons:

- The cost is relatively high.
- The pixel is only 1.3MP, which is relatively low.

3.2.2.1.2 Existing Design #2: Raspberry Pi HQ Camera Fitted with C/CS-Mount

Figure 7: Lens Choice #2

Pros:

- With a magnification of 100 times, it is highly suitable for observing tiny dust particles. compact structure.
- It is waterproof and sufficiently robust and durable to ensure no deformation under certain pressure.

Cons:

- The length is quite long, and in order to install the lens, modifications to the interface section are required.

3.2.2.2 Subsystem #2: Fan

The fan in this project is a tool for raising dust. It helps the project simulate the scenario of wind in nature, where light surface dust is blown up and rotates within the area. The fan greatly improves the efficiency of this active collection device and is more in line with reality.

3.2.2.2.1 Existing Design #1: 12V 4.8A 57.6W 5500RPM

Figure 8: Fan Choice #1

Pros:

- It has an extremely high power output, capable of providing strong wind force.

- It is waterproof and sufficiently robust and durable to ensure no deformation under certain pressure.

Cons:
- The price is relatively expensive.
- High power consumption will result in shorter battery life, and it requires a high-capacity power source.

3.2.2.2.2 Existing Design #2: 120V 14W 2600 RPM

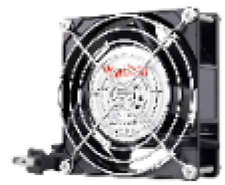


Figure 9: Fan Choice #2

Pros:
- Moderate power output provides sufficient wind force.
- It has low noise levels.

Cons:
- The price is relatively expensive.
- It is not easy to carry or find a high-voltage power source.

3.2.2.2.3 Existing Design #3: 12V 0.1A 1.1W 3500RPM

Figure 10: Fan Choice #3

Pros:
- A 12V power supply is more widely used and easier to find for power sourcing.
- It has low noise levels.

Cons:
- The total power output is relatively low, which may not be sufficient to provide enough wind force.
- There is a lack of compatible connecting components.

3.2.2.3 Subsystem #3: Air Pump

The air pump in this project is a device used to provide suction power, drawing the raised dust particles from the passage into the collection chamber, simulating the condition of humans inhaling dusty particles carrying bacteria during the breathing process. The air pump is the source of power for active collection, and an indispensable part of the entire device.

3.2.2.3.1 Existing Design #1: 2.2kPa air pressure 300L/min wind speed

Figure 11: Pump Choice #1

Pros:

- The lower working pressure and higher flow rate make it suitable for applications that require a large amount of gas flow without requiring excessive pressure.
- High flow rate can provide faster gas supply, suitable for certain applications that require rapid inflation or exhaust.

Cons:

- The pressure is relatively low and may not meet certain high pressure requirements for applications.
- If higher pressure is required, additional compression equipment may be required to increase the output pressure.

3.2.2.3.2 Existing Design #2: 3.5 kPa air pressure 180L/min wind speed

Figure 12: Pump Choice #2

Pros:

- The high working pressure makes it suitable for applications that require a certain amount of pressure, while still having moderate flow rates.
- Applications that can meet certain moderate pressure requirements.

Cons:

- Low flow rate may not be suitable for applications that require a large amount of gas flow.
- If higher flow rates are required, it may be necessary to choose another model of air pump.

3.2.2.3.3 Existing Design #3: 3.4 kPa air pressure 280L/min wind speed

Figure 13: Pump Choice #3

Pros:

- The high working pressure and moderate flow make it a relatively comprehensive choice, suitable for various applications.

- Applications that can meet certain pressure and flow requirements.

Cons:

- For certain special requirements, higher pressure or flow may be required.
- In certain specific application scenarios, other models with higher pressure or flow rates may be more suitable.

4 CONCEPT GENERATION

This section provides different full-system designs and sub-system designs based on the results of benchmarking, each design listing the advantages and disadvantages as a brief technical analysis for a quick review. The four different full-system designs each have five different components which are camera, channel, pump, fan and collection box. The section also provides four different designs for each subsystem design together with a brief introduction.

4.1 Full System Concepts

This design includes three different types of complete system designs, namely the Intermittently Settling Soil Dust Collection System, All-in-one Rapid Response Dust Collection System, and Partition Filtering Dust Collection System. They differ in their methods of dust collection.

The Intermittently Settling Soil Dust Collection System uses an air pump that switches on and off intermittently to inhale dust. This method allows the dust to not stick to the filter plate when the air pump is off and to fall for collection.

The All-in-one Rapid Response Dust Collection System wraps the entire air pump in a net, preventing dust particles from entering the air pump and causing damage.

The Partition Filtering Dust Collection System uses a filter partition to divide the entire collection space into two parts. The dust sucked into the collection box will fall due to gravity after touching the partition, and is collected in the slot under the partition. The partition also separates the pump into a separate space for easy replacement and adjustment.

4.1.1 Full System Design #1: Intermittently Settling Soil Dust Collection System

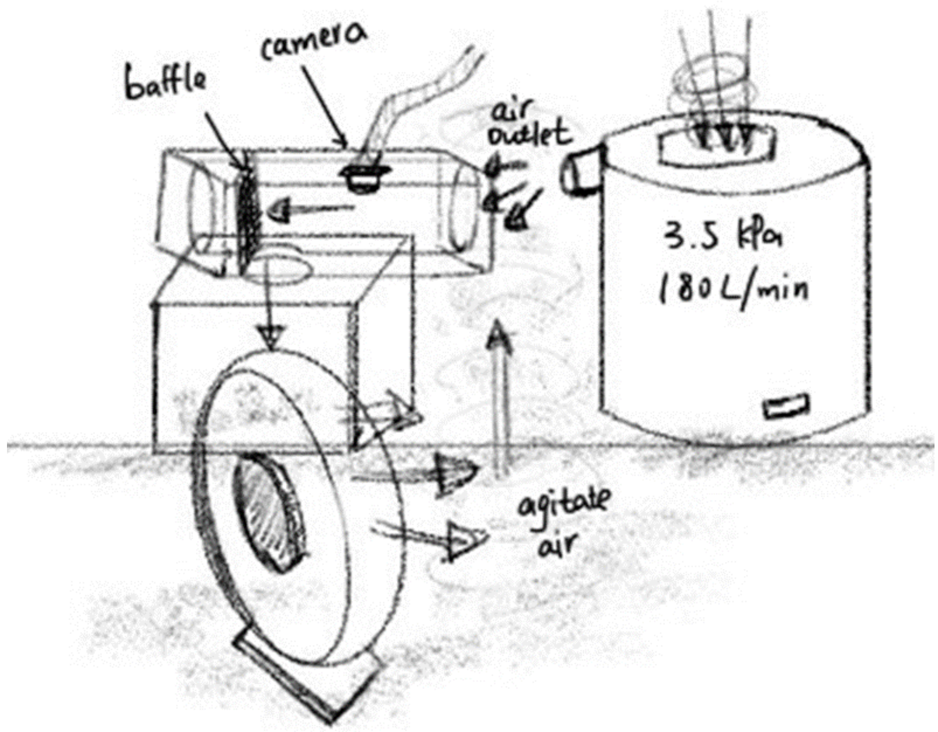


Figure 14: Full System Design #1

This design uses a 120V 14W 2600 RPM fan placed near the dust inlet to agitate the air and make the soil dust carrying Coccidioides bacteria float up as much as possible. The dust in the air is then blown into the channel with an air pump of 3.5kPa 180 L/min. A 16MP camera is then mounted above the channel and connected to a Raspberry Pi to record dust motion. Finally, a baffle is set up at the end of the channel; and the pump blows intermittently, so that the dust entering the pipe has time to free fall into the collection box after hitting the baffle.

Pros:

- High dust collection efficiency.
- Low cost.

Cons:

- Particles may be easily sucked into the pump, resulting in reduced service life.
- Failure to set a filter may cause large particles to enter the collection box together.

4.1.2 Full System Design #2: All-in-one rapid response dust collection system

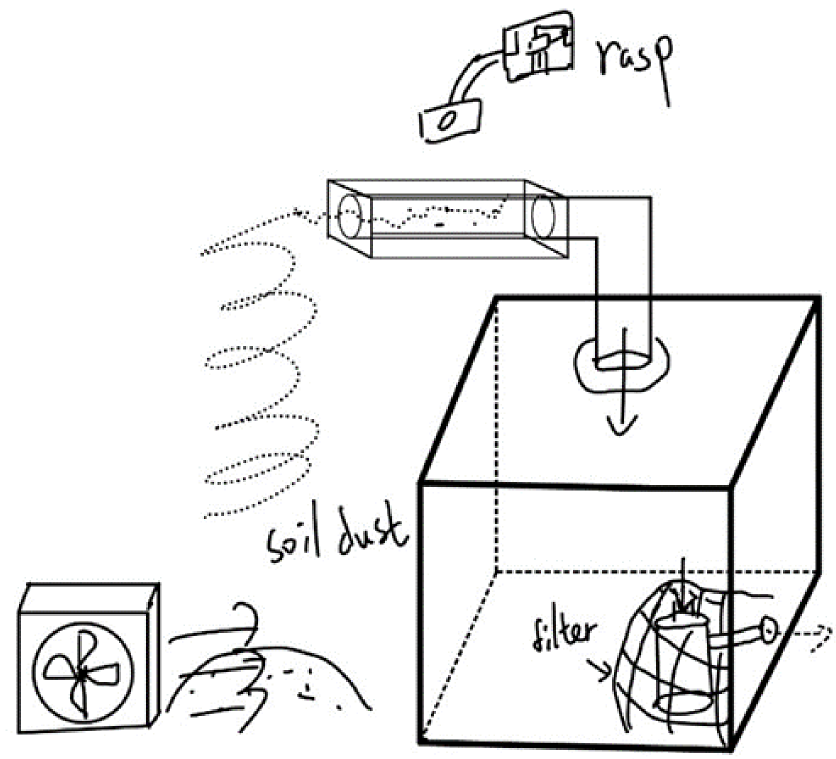


Figure 15: Full System Design #2

This design uses a 120V 14W 2600 RPM fan to blow up the dust and a 300L/min high flow rate air pump to draw the dust into the collection box. A 64MP camera is then mounted above the channel and connected to a Raspberry Pi to record dust movement. The unit is designed as an integrated unit with the pump placed inside the collection box and a filter to isolate the dust from entering the pump. Because the pump is inside the collection box, the aspiration process will become efficient.

Pros:

- Easy to carry
- Fast response time

Cons:

- Dust may enter the pump
- The camera is too sharp, and the Raspberry Pi may not be able to handle it

4.1.3 Full System Design #3: Partition filtering dust collection system.

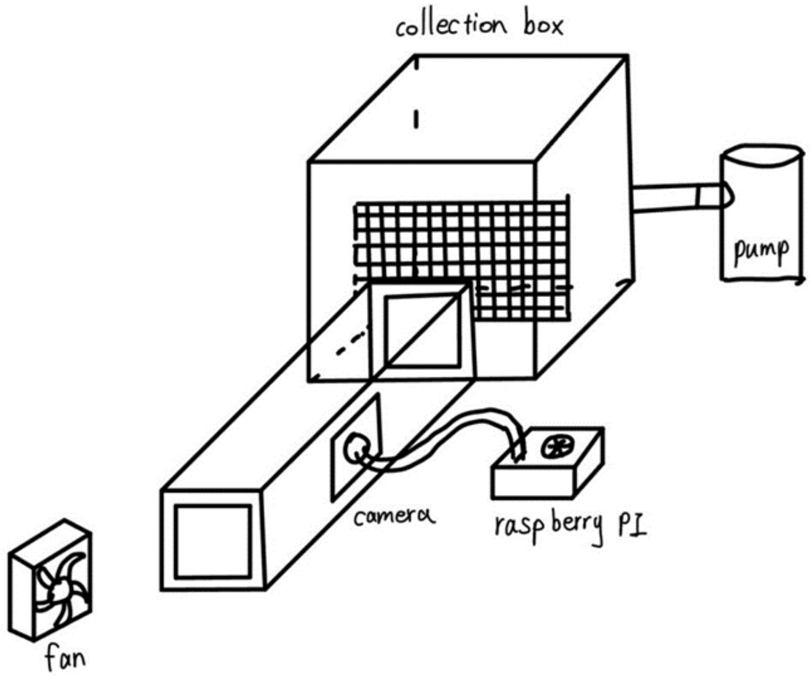


Figure 16: Full System Design #3

This design uses a high-power 12V, 48W, 5500 RPM blower to stir up dust, and a 180 L/min pump to collect it. A Raspberry Pi camera with a resolution of 16MP and a 100x magnification is housed in a rectangular tube with a 4cm edge length at the front, taking pictures of the dust. The collection box at the back is responsible for storing the dust samples.The collection box is divided into a storage part and a pump part by a partition. The inhaled dust is blocked by the partition and falls into the front part. The pump is located in the back part of the collection box and can be taken out from the back part for power adjustment and replacement.

Pros:

- Modular design, for easy operation of each part.
- A powerful fan effectively raises dust.

Cons:

- It's inconvenient to remove dust samples from the collection box.
- The overall volume is large and inconvenient to carry

4.1.4 Full System Design #4: Precision Strike Dust Collection System

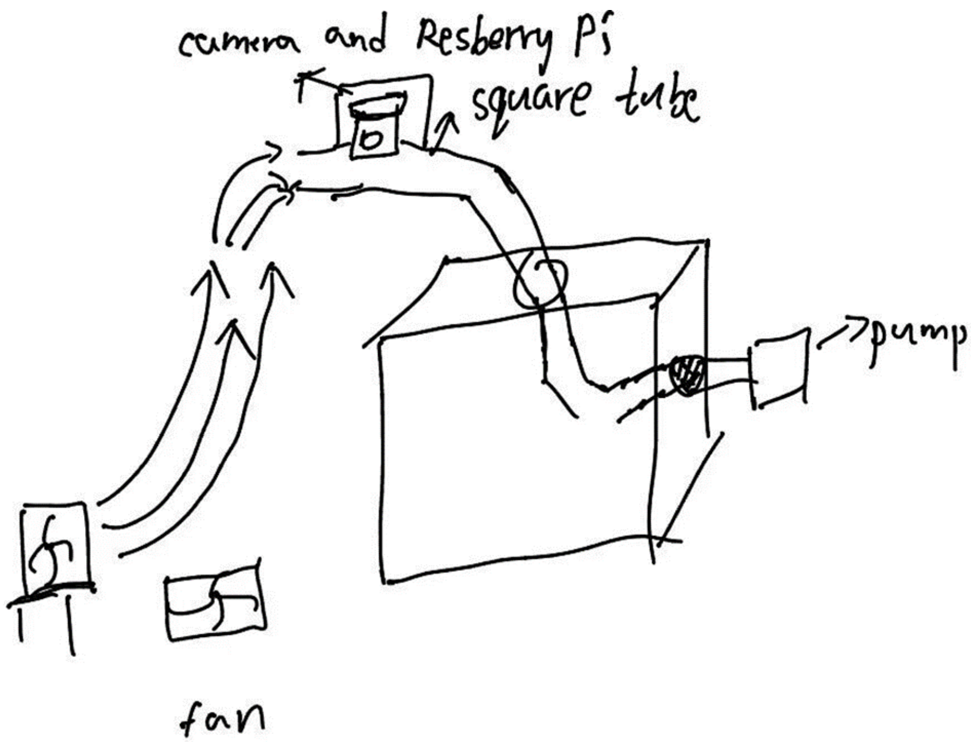


Figure 17: Full System Design #4

This design uses two 12V, 0.1A, 1.1W, 3500 RPM fans to raise the dust to the channel. Then the dust will be s by a 3.5-kpa air pump which has 180 L/min wind speed. The dust will fall in the collection box through the hole on the channel. There is a 16MP camera connected with Raspberry Pi on the channel to record the collection process.

Pros:

- High efficiency of raising the dust.
- Dust hardly enters the pump.

Cons:

- It's inconvenient to carry.
- Dust may enter the fan which causes device damage.

4.2 Subsystem Concepts

This project's subsystem also consists of three distinct parts: the pipe, collection box, and camera. The pipe is the channel through which dust flows during collection. Most existing designs do not include a pipe, with the collection box completely exposed, which is not conducive to analysis and adjustment. The collection box is a device for storing samples, and its capacity determines the amount of dust collected. The collection box also has different collection methods due to different structures. The camera is a standard interface for Raspberry

Pi and is compatible with the Raspberry Pi 4B we use, for recording the dust collection process and conducting feature analysis.

4.2.1 Subsystem #1: Channel

4.2.1.1 Design #1: cylinder-shaped pipe

The pipe is the channel through which the dust passes during the collection process, and it is also the carrier where the camera is mounted. A good pipe must have sufficient strength and appropriate length, and should be made as simple as possible for easy production without affecting portability.

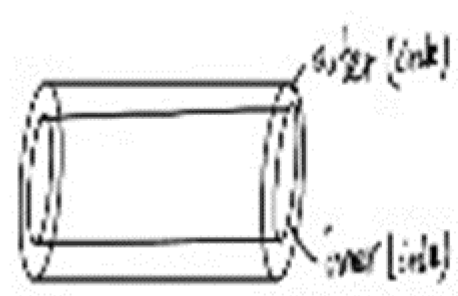


Figure 18: Channel Design #1

Pros:

- Cost-effective.
- It is widely available on the market and easy to purchase.
- Strong structure

Cons:

- It is not convenient to fix or secure.
- A circular-shaped pipe will create a vortex inside the pipe.

4.2.1.2 Design #2: square-shaped pipe

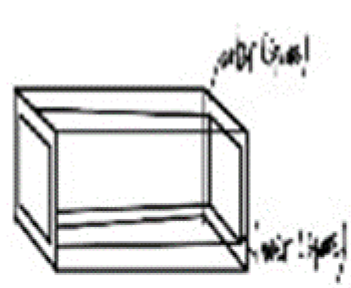


Figure 19: Channel Design #2

Pros:

- Cost-effective.
- It is widely available on the market and easy to purchase.
- It has good compatibility and allows for easy installation of cameras.

Cons:

- It is not as sturdy as a circular structure.

4.2.1.3 Design #3: outer rectangular shape and an inner circular shape

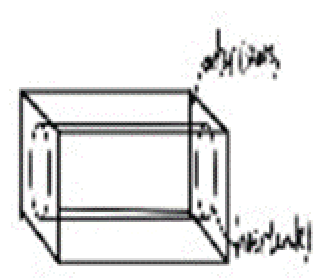


Figure 20: Channel Design #3

Pros:

- It is designed to balance both scalability and stability.
- A thicker inner wall provides greater strength and can withstand higher pressures.

Cons:

- It is relatively difficult to find in the market and may require customization.
- It has a higher cost.

4.2.2 Subsystem #2: Collection Box

The collection box is the part for storing dust and particles. It's an independent box linking the pipe and the air pump. The volume of the collection box determines the capacity of the sample, and the size of its opening determines the efficiency of the collection process. At the same time, the collection box must also have enough strength for support and must remain stable under certain air pressure and dust collision. The collection box also serves the role of connecting all parts, being the terminal of all other parts.

4.2.2.1 Design #1: Top Filter version

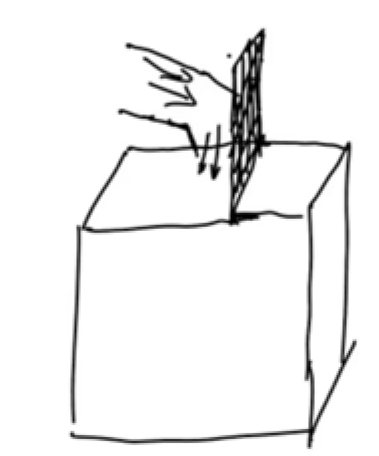


Figure 21: Collection Box Design #1

Pros:

- The pump is at the right side of the filter, so the dust can hardly enter the pump.
- It can collect most of the dust.

Cons:

- The filter will be hard to fix.
- It's hard to install.

4.2.2.2 Design #2: Bottom Filter version

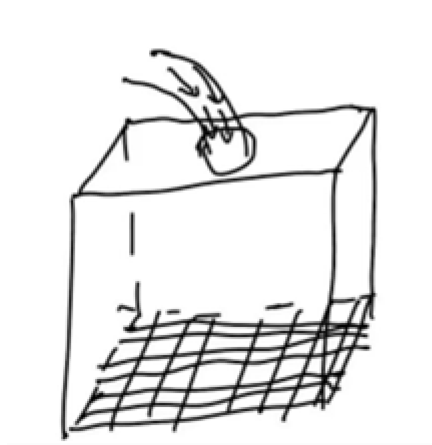


Figure 22: Collection Box Design #2

Pros:

- All the dust will enter the box.
- Easy to install.

Cons:

- Dust may go through the filter.
- When dust is on the filter, it will be difficult to collect more.

4.2.2.3 Design #3: Back Filter version

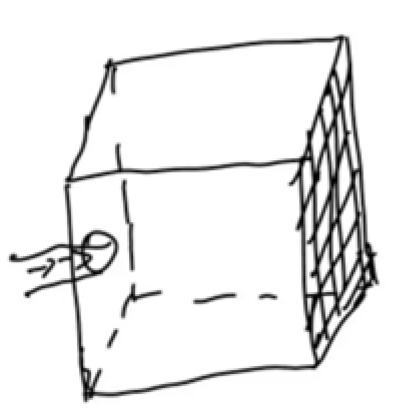


Figure 23: Collection Box Design #3

Pros:

- Easy to install.
- It can collect more dust.

Cons:

- Dust may enter the pump.
- Dust may leak through the filter.

4.2.3 Subsystem #3: Camera

The camera is an indispensable part of the entire project, its main function is to capture the flow of dust particles and record the diameter of dust particles. The camera must have a sufficient frame rate and clarity to meet the requirement for accurate feature analysis.

4.2.3.1 Design #1: 5MP Raspberry Pi camera

Figure 24: Camera Choice #1

Pros:

- The price is very cheap, and the component is easily replaceable.

Cons:

- The resolution is low, making it difficult to capture clear dust images.

4.2.3.2 Design #2: 16MP Raspberry Pi camera

Figure 25: Camera Choice #2

Pros:

- The price is moderate and within budget.
- The frame rate is high, meeting the shooting requirements.

Cons:

- There is a non-removable protective casing, which affects compatibility to some extent.

4.2.3.3 Design #3: 64MP Raspberry Pi camera

Figure 26: Camera Choice #3

Pros:

- The captured image is very clear.

Cons:

- The price is relatively expensive.
- The version is very outdated, and the compatibility is poor.

5 DESIGN SELECTED – First Semester

In section 5.1, the technical selection criteria will be determined. In section 5.2, we will discuss how technical criteria are applied to the Pugh chart and Decision Matrix. After that, we will explain how the best decision is made.

5.1 Technical Selection Criteria

Pugh Chart

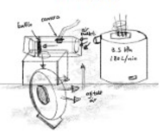
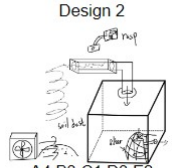
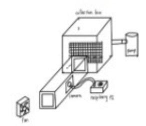
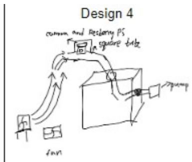
Concept → Criteria	Design 1  A1 B3 C2 D3 E1	Design 2  A4 B3 C1 D3 E2	Design 3  A2 B2 C3 D1 E3	Design 4  A4 B2 C3 D3 E5
Prime Cost	+	s	s	-
Operation	s	s	s	s
Durability	-	s	+	+
Installation	s	s	s	s
Clarity	+	s	+	+
Efficiency	+	s	+	s
∑+	3	0	3	2
∑-	1	0	0	1
∑s	2	6	3	3

Figure 27: Pugh Chart

Decision Matrix

Criterion	Weight	Design 3		Design 1	
		Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Prime Cost	0.1	90	9	93	9.3
Operation	0.1	95	9.5	95	9.5
Durability	0.1	93	9.3	89	8.9
Installation	0.05	97	4.85	97	4.85
Clarity	0.3	93	27.9	90	27
Efficiency	0.35	90	31.5	92	32.2
Total	1	Sum:	92.05	Sum:	91.75

Figure 28: Decision Matrix

The criteria we chose are prime cost, operation, durability, installation, clarify and efficiency.

1. Prime Cost: This refers to the material cost and the components cost need to assemble the product. This is crucial because a low-cost product will have a more affordable price for the consumers.
2. Operation: This reflects the design's ease of use and how it will work. It's important for a product to be user friendly and work normally.
3. Durability: Durability represents the life span and reliability of the design under normal usage conditions. This is significant because a more durable design will require fewer replacements or repairs which will lead to higher customer satisfaction and reduced costs in the long term.
4. Installation: Installation criteria refer to the ease and cost of installing the design. A design that is easy to install and does not require specialized skills or equipment will be more desirable to customers.
5. Clarity: This criterion is about how understandable the design is. This can be quantified in terms of the number of user instructions, or the time taken for a user to understand how to use the design.
6. Efficiency: Efficiency refers to how fast our device will collect the dust which is a

main advantage of our product.

These criteria will be used differently in the Pugh Chart and Decision Matrix.

In the Pugh Chart, these criteria are used as a basis for comparing alternative designs against the datum which is design 2 in our Pugh chart. For each criterion, a design will be scored as +(better), -(worse), or s(the same) compared to the datum. The scores are then summed to get an overall performance score for each design.

In the Decision Matrix, the same criteria are used but are given weights according to their importance. The 2 designs chosen by Pugh chart are then scored against each criterion, and the score is multiplied by the weight to get a weighted score. The weighted scores are summed to get an overall score for each design.

In conclusion, these criteria were chosen for both methods because they represent key quantifiable aspects of the design that are important to both customers and engineers. The difference is in how the criteria are used in each method, with the Pugh Chart using a relative comparison and the Decision Matrix using a weighted sum.

5.2 Rationale for Design Selection

In the Pugh Chart, we selected Design 1 and Design 3 as our 2 top designs.

Design 1:

Design 1 has an advantage of high efficiency. As a dust collector, high efficiency has to be the first thing to consider.

Regarding Prime Cost, Design 1 components are cheaper than the datum's which is more user friendly.

On the downside, Design 1 has drawbacks such as the potential for dust to be sucked into the pump, which may reduce its service life and the failure to set a filter which may cause large particles to enter the collection box together.

Design 3:

Design 3's operation criterion is notably enhanced due to its modular design.

The powerful fan adds to the efficiency score which is very important as mentioned before.

However, Design 3's limitations include the inconvenience in removing dust samples from the collection box and the large overall volume, which could limit its portability and cause issues with installation.

Pugh Chart and Decision Matrix Applications:

Both designs were initially evaluated through a Pugh Chart, allowing us to compare them qualitatively against a datum design based on the chosen criteria. This helped narrow down the options, with Designs 1 and 3 showing the most advantages over the datum.

For a more granular analysis, a Decision Matrix was employed. Design 3 has a higher score according to the matrix. Although Design 1 has a higher score in efficiency and prime cost criteria, Design 3 has higher scores in operation,durability, installation and clarity. As a result, Design 3 was selected to be our final design.

In summary, both Design 1 and Design 3 exhibit considerable potential. They were selected as the top designs based on their ability to satisfy most of the chosen criteria to a significant extent although they have some disadvantages. Despite Design 1 is more efficient, Design 3 has a better balance among all the criteria. Therefore, Design 3 is chosen as our final design.

6 Project Management – Second Semester

6.1 Gantt Chart

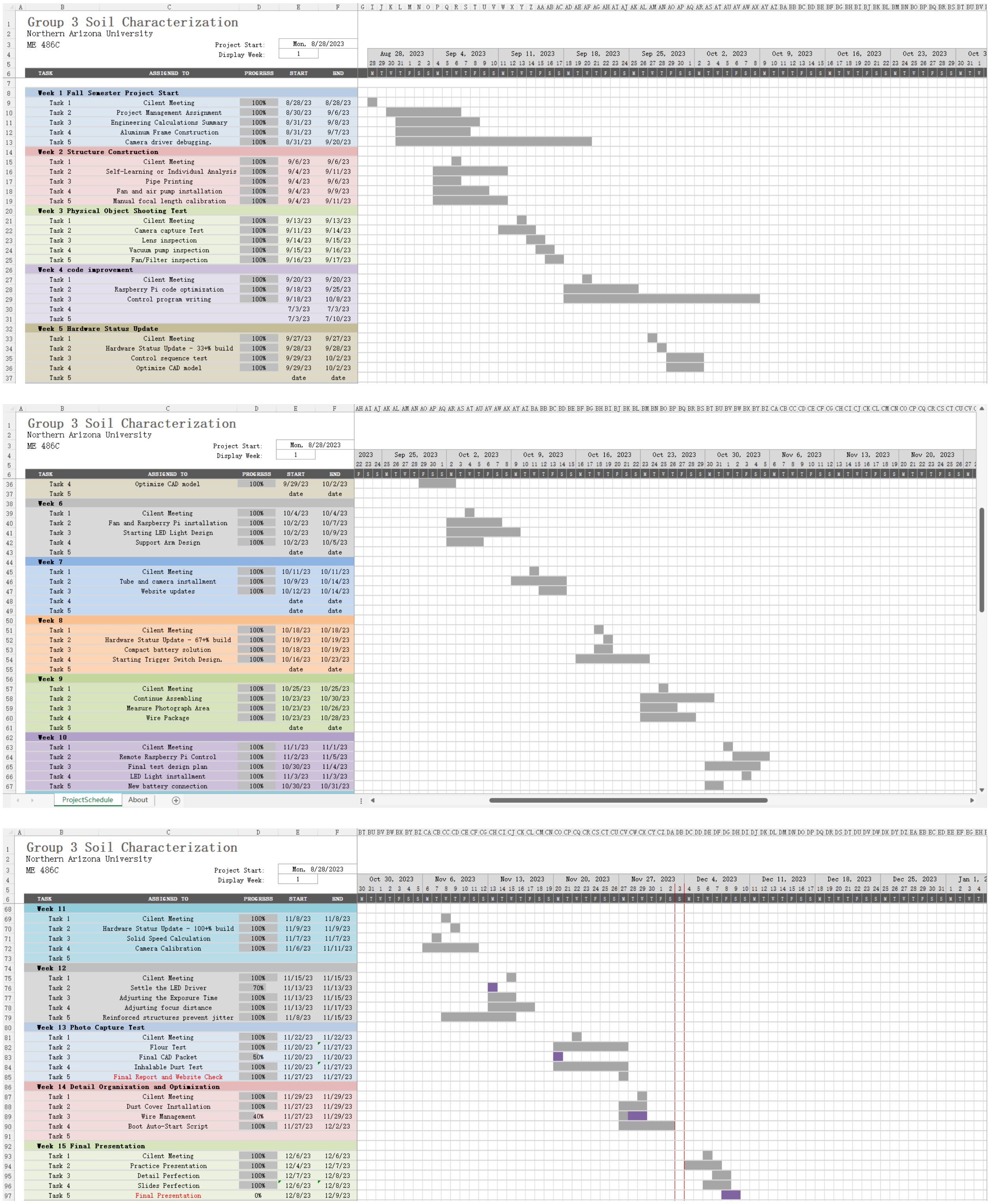


Figure 29: Gantt Chart

From the Gantt chart, it can be seen that the vast majority of the set goals have been completed and have met the expected objectives. However, two sub-tasks were not completed: organizing wire connections and initializing the LED lights. The wire organization includes creating protective casings for the wiring and tidying the wires, as well as making a dust cover for the Raspberry Pi's camera module. The LED light tasks involve setting very short flashing durations, connecting an external power source, a control box, and the Raspberry Pi. Due to the project's budget constraints, we couldn't purchase a control box capable of transmitting very short pulses, hence the LED could not provide the exposure duration required by the Raspberry Pi camera.

6.2 Purchasing Plan

Bill of Materials										
Team				Soil Characterization						
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost ($)	Link to Cost Estimate	Part Status	Date
1	Fan	1	12V 57.6W 5500RPM	Agitate the air	N/A	120mm*120mm*38mm	24.99	https://www.amazon.com/PFC1212DE-252-85CFM-6	Assembled	7/5/2023
2	Carbon Conductive Paint	1	N/A	To make the wind tunnel conductive	N/A	12 mL	33.13	https://www.amazon.com/MG-Chemicals/dp/B01MQ4	Assembled	9/4/2023
3	Camera	1	12.3PM	Shoot and record dust	N/A	2.5in	29.99	https://www.amazon.com/Arducam-Autofocus-Raspbe	Assembled	7/21/2023
4	Battery	1	11.1V/6Ah (66.6Wh)	Power supply to the control system	Lithium Ion	28mm*85mm*145mm	N/A	N/A	Assembled	10/18/2023
5	Raspberry Pi 4B	1	N/A	Control the camera and fan	N/A	N/A	N/A	N/A	Assembled	7/21/2023
6	Plant-Based UV Resin	3	3kg in total	Used for 3d printng	UV Resin	N/A	29	https://www.anycubic.com/collections/plant-based-uv-	In house	7/5/2023
7	Vacuum Pump	1	60W with HEPA filter	Absorb and store the dust	N/A	8.27in*6.30in	17.26	https://www.temu.com/wireless-mini-car-vacuum-clea	Assembled	9/4/2023
8	Shooting Window on Channel	1	Clear, conductive film	Camera window to capture dust	ITO Coated Glass	1in*0.4in	N/A	N/A	Assembled	10/9/2023
9	HEPA Filter	12	N/A	Replace filter in vacuum to store dust	Plastic	2"L*1"W*4"H	38.97	https://www.amazon.com/Hand-Held-Cleaner-Replace	In house	9/4/2023
10	Nut	10	N/A	Fix components with mount	Zinc	1/4in	1.1	Homedepo	Assembled	7/5/2023
11	Screw	10	N/A	Fix components with mount	Zinc	1/4in*1/2in	1.38	Homedepo	Assembled	7/5/2023
12	Ball Head Screw Tripod Mount	4	360 degree rotating mount base	Fix fan and channel	Aluminum Alloy	N/A	13.98	https://www.amazon.com/dp/B08M47S5CW?ref=ppx_	Assembled	9/9/2023
14	Frame	1	Cuboid	Make the entire system easy to transfer	Aluminum	12in*12in*16in	63.81	https://www.homedepot.com/p/Everbilt-1-1-2-in-x-96-	Assembled	8/31/2023
						Total Spent	253.61	Total Parts Needed	14	
								Total Parts Received	14	
								Parts Required (%)	100%	
								Assembled (%)	100%	

Figure 30: Actual Purchasing Plan

Bill of Materials									
Team				Soil Characterization					
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost ($)	Link to Cost estimate	Part Status
1	Fan	1	12V 57.6W 5500RPM	Agitate the air	N/A	120*120*38mm	24.99	https://www.amazon.com/PFC1212DE-252-	Ready to assemble
2	Channel	1	Trumpet tube	Provide air inlet,outlet and camera window	Polylactic Acid	Inlet: 33mm*33mm Outlet: r = 17.5mm	49.99	https://www.amazon.com/dp/B00X8BQYVM	Being manufactured
3	Camera	1	12.3PM	Shoot and record dust	N/A	2.5 inches	29.99	https://www.amazon.com/Arducam-Autofocu	Being debugged
4	Raspberry Pi 4B	1		Control the camera and fan	N/A	N/A		N/A	Being debugged
5	Plant-Based UV Resin	3	3kg in total	Used for 3d printng	UV Resin	N.A	29	https://www.anycubic.com/collections/plant-	In house
6	Vacuum Pump	1	60W with HEPA filter	Absorb and store the dust	N/A	8.27in*6.30in	17.26	https://www.temu.com/wireless-mini-car-vac	Ready to assemble
7	Shooting Window on Channel	1	Clear, conductive film	Camera window to capture dust	ITO Coated Glass	1in*0.4in			Yet to be purchased
8	Frame	1	Cuboid	Make the entire system easy to transfer	Aluminum	12in*12in*16in	63.81	https://www.homedepot.com/p/Everbilt-1-1-	Has been manufactured
Total Cost Estimate:							215.04		

Figure 30: Original Purchasing Plan

Compared to our bill of materials from the beginning of the semester, our current BOM has many differences. Firstly, we have already got all the parts we need for the project, and the dates of acquisition have been updated. Secondly, some items in the original BOM have been replaced due to changes in our project design.

6.3 Manufacturing Plan

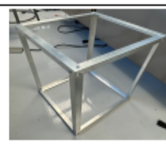
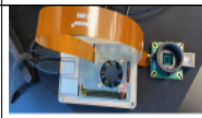
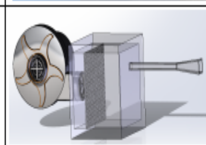
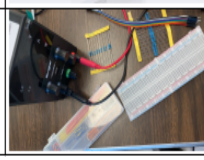
No	Part Name	Picture	Who	When and Time	Raw Material	Where
1	Frame		Jie Jin Ruihua Shi	8/31/2023-9/7/2023 5 hours	Aluminum	The Machine Shop
2	Automatic shooting system		Ruihua Shi Jie Jin	8/31/2023-9/20/2023 25 hours	Raspberry Pi Autofocus Camera	Biofluids Lab
3	Collection system		Jun Mei	9/4/2023-9/16/2023 7 hours	ITO Coated Glass Acrylic sheet Engineering plastics filter	Biofluids Lab
4	Energy supply system		Zhiyu Bai	25/9/2023-5/10/2023 7 hours	Electric power source Wire	Biofluids Lab

Figure 31: Original Manufacturing Plan

NO	Task	System	Time to Start	Place
1	Aluminum Frame Construction	Manufacturing Framework	8/31/23	Biofluids Lab
2	Camera driver debugging.	Automatic Camera System	8/31/23	Biofluids Lab
3	Pipe Printing	Collection System	9/4/23	Biofluids Lab
4	Vacuum installation	Automatic Camera System Collection Systems	9/15/23	Biofluids Lab
5	Fan and Raspberry Pi installation	Collection System	10/2/23	Biofluids Lab
6	Tube and camera installment	Collection System	10/9/23	Biofluids Lab
7	Battery Installation	Power Supply System	10/30/23	Biofluids Lab

Figure 32: Actual Manufacturing Plan

Figure 31 shows our manufacturing plan at the beginning of the semester and figure 32 shows the actual manufacturing plan. The new manufacturing plan is more closely related to the actual progress of our project. Moreover, following the new plan for installation and production can maximize our team's efficiency. For instance, building the frame and debugging the camera driver can be done simultaneously, as these two tasks do not interfere with each other. Then, after the frame construction is completed, we can seamlessly transition to the vacuum installation work. This is more rationalized and efficient compared to the original plan.

7 Final Hardware

7.1 Final Hardware Images and Descriptions

Our project includes four systems, which are Manufacturing Framework, Automatic Camera System, Dust Collection System, Power Supply System. In this section, I will detail the function of each system.

7.1.1 Manufacturing Framework

The frame is mainly made up of 12 one-foot long aluminum beams fitted together, and holes will be drilled in the frame in order to allow the other parts to be secured to the frame. In this way can we meet the customer requirement on the portability of the device.

7.1.2 Dust Collection System

The dust collection system consists of a channel, a vacuum and a fan. The channel is 3D printed with resin and painted with conductive paint. Two holes are cut in on the channel and two ITO glass which is a kind of conductive material will be installed on them hence the camera can capture pictures through the glass. The glass can also ensure its transparency. The reason we need to use conductive paint and glass is to prevent the static influencing the track of the soil dust while flowing in the wind tunnel. The vacuum is equipped with a replaceable HEPA filter which can protect the pump in the vacuum from small particles.

7.1.3 Automatic Camera System

The system consists of a Raspberry Pi and an Autofocus Camera. The Raspberry Pi is used to control the camera and the fan, and the images captured by the camera will be temporarily stored in the Raspberry Pi. This system is used to capture particles moving at high speeds. So this is extremely demanding on the characteristics of the camera, and a lot of time will be spent on tuning the camera's frame rate as well as the exposure rate. The camera will be constantly calibrated through multiple tests. Thus, the sharpest image can be obtained under limited conditions.

7.1.4 Power Supply System

The power supply system will power the fan and Raspberry Pi. The main part of this system is a power bank which transmits 12V voltage to the fan and 5V voltage to Raspberry Pi. Besides, a relay is used to control the disconnection and connection of the fan.

Figure 33: Final Hardware Image

7.2 Design Changes in Second Semester

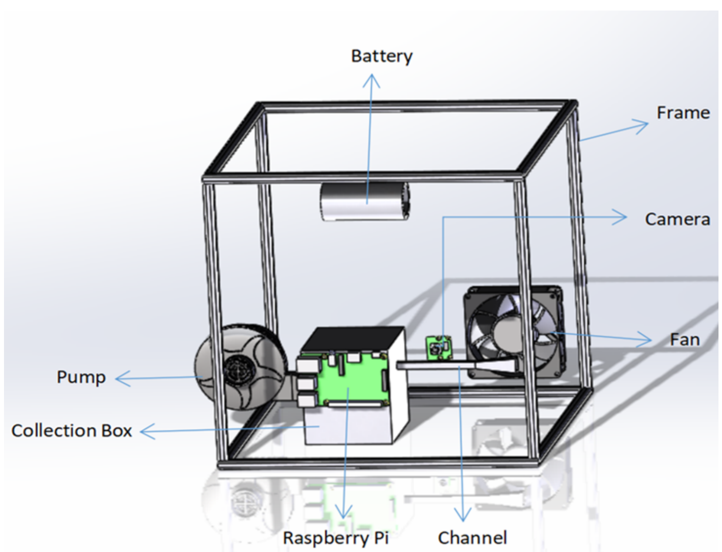


Figure 34: Original CAD Model

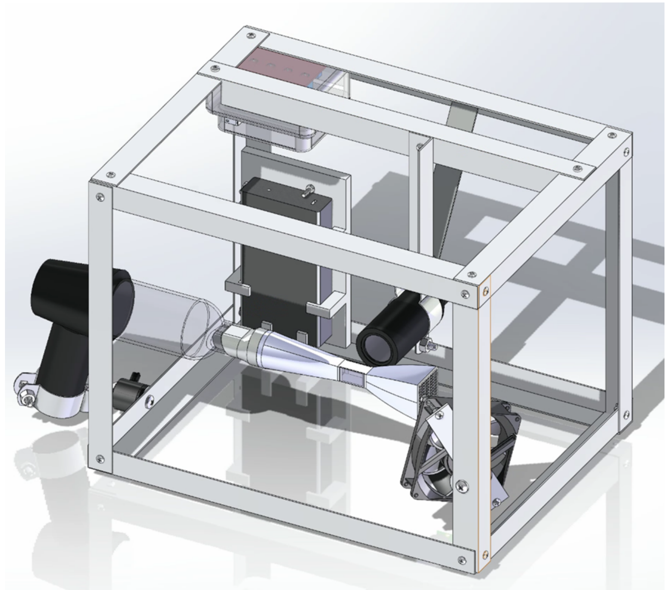


Figure 35: Final CAD Model

Figure 34 is the CAD model at the beginning of this semester and figure 35 is our current CAD model. During this semester, our team has made significant changes to our capstone project according to the requirements put forth by the client which can be directly displayed by the two CAD models.

7.2.1 Design Iteration 1: Change in Dust Collection System

The most significant change in our project was our collection system. Firstly, we removed the originally planned pump, collection box, and the filter inside the collection box which was used to prevent particles from entering the pump. This was because our client, Dr. Dou Zhongwang, felt that we did not need to collect so much dust and the installation and removal of the filter would become very troublesome. Therefore, we decided to use a vacuum with a HEPA filter to replace the aforementioned equipment.

We also changed the shape of the air channel. We widened the diameter of the channel to ensure that the efficiency of soil dust collection would not be compromised by the channel being too narrow when the vacuum sucks in soil dust. We also added some curvature inside the channel to reduce the occurrence of turbulence. At the beginning of the semester, we planned to use a kind of conductive 3D printing filament to print the channel to prevent the static influencing the track of the soil dust in the channel while taking photos. Later we changed our idea due to the high price of that material and decided to spray a kind of conductive paint inside and outside the channel.

7.2.2 Design Iteration 2: Change in Manufacturing Framework

Initially, our team wanted to use T-slotted Profile beams to make the frame, but later considering the cost and processing difficulty, we changed it to L-slotted beams. To assemble the beams into a frame, we drilled three holes at each end of the beams and connected them with screws and nuts.

7.2.3 Design Iteration 2: Change in Power Supply System

We also replaced the power supply, we originally wanted to use the one below in figure 36. But since it conflicted with our customer requirement which requires the whole device be portable, we replaced it with the power supply in the red circle in figure 36. In order to attach the power supply to the frame, we also designed a container for it that would mount to the frame which is shown in figure 37.

Figure 36: Power Supply

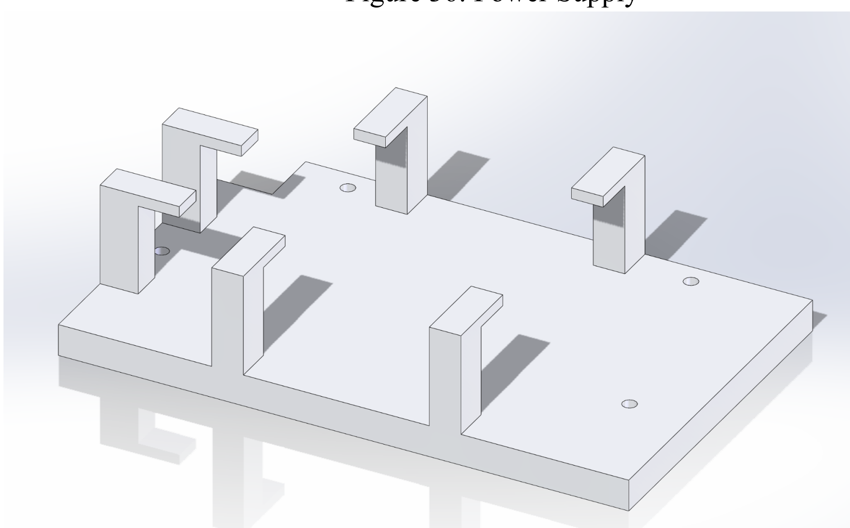


Figure 37: Power Supply Fixer

7.3 Hardware Challenges Bested

Discuss the challenges that your team faces to get 100% hardware on time and how your team overcame/bested those challenges.

During the manufacturing process, our team encountered many challenges. Among them, how to fix all the parts onto our frame became our biggest problem. First, we needed to think about how to firmly fix all the components to the frame to ensure our entire device was portable. Second, we had to make our vacuum and fan movable, so that during actual use, we could adjust the position of the vacuum to focus the camera on the center of the ITO glass which is installed on our channel and adjust the position of the fan to ensure the fan can blow up the most soil dust. Eventually, our team found a 360 degree rotating mount base adapter to attach the vacuum and the fan on the frame. For the camera, we cut a shorter beam and use a screw and nut to fix it. Then we put the relay into a small box and glued it to the frame, and the Raspberry Pi was secured on the small box using screws and nuts.

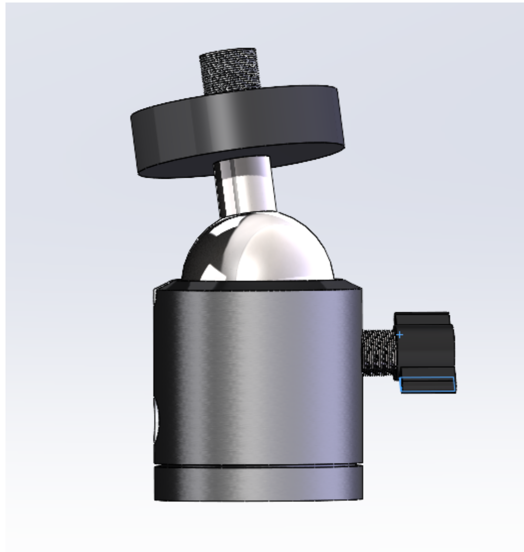


Figure 38: 360 Degrees Rotation Mount Base

After we successfully fixed all the parts, we found that due to the low bending modulus of the aluminum, the beam used to fix the camera would shake during operation and affect the capture of images. Considering that triangles are the most stable structures, we solved this problem by gluing another beam with rosin between the beam and frame as shown in figure 39.

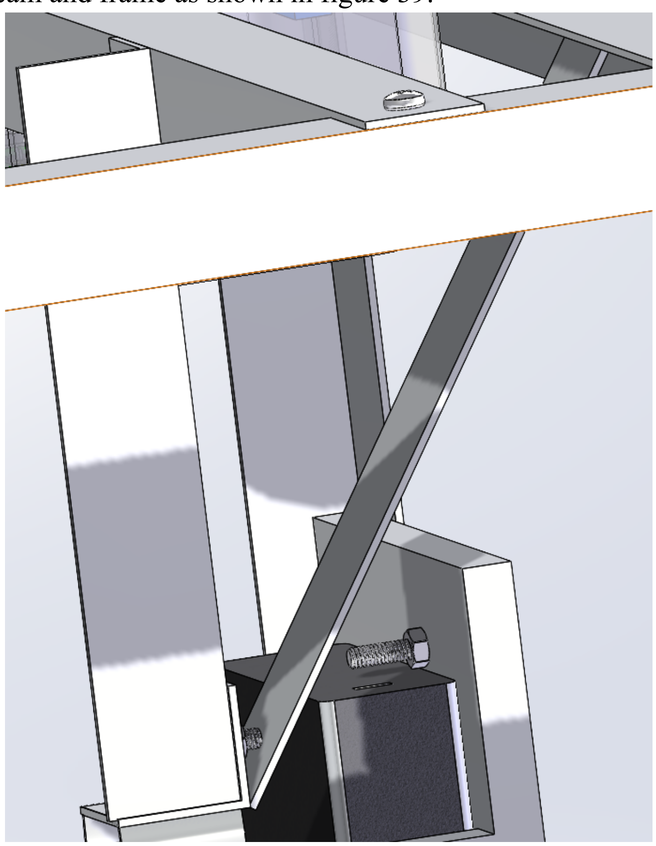


Figure 39: Camera Fixer

8 Testing

8.1 Testing Plan

8.1.1 Flow Rate and Speed Test

Objective

The purpose of calculating the flow rate in the central channel with a vacuum pump is to optimize the system for effectively suspending and capturing soil dust particles. Ensuring a suitable flow rate is crucial for the high-resolution imaging sensor to accurately capture and characterize 2μm-sized dust particles in real time. To effectively optimize the system, considerations such as adjusting the fan speed, fine-tuning the channel dimensions, and selecting an appropriate filter can be made. These adjustments ensure consistent and efficient dust agitation and collection, thereby enhancing the quality and reliability of data collected for Valley Fever research.

Procedure

Steps:

- Measure and calculate the cross-sectional area, A, at the vacuum pump inlet and outlet, respectively.
- Set up the flow meter with Hot Wire for flow speed measurement mode.
- Measure the flow speed at the vacuum pump inlet and outlet, respectively.
- Calculate the flow rate at inlet and outlet.
- Calculate the cross-sectional area in the middle of the channel.
- The two flow rate values in the middle of the channel are calculated and then average to get the final result.

8.1.2 Control System Test

Objective

The objective of this test is to ensure the correct connection of the entire system and the stable operation of the control system, as well as to check if the code still runs properly after changing the power source. This includes the signal control of the Raspberry Pi, the correct operation of the relay, the normal operation of the fan, and the photo shooting of the camera. During the experiment, the only parameter that needs to be measured is the fan's rotation speed, to check whether it aligns with the expected operation of PWM. Based on the measurement results, adjustments might be required in the control code for the fan speed and the high-level duration of the relay.

Procedure

Step 1: Circuit Connection

- Properly connect the circuits between the devices, linking the Raspberry Pi's ground interface to the negative terminal of the power supply.
- Use heat shrink tubing to reinforce the connections at each circuit junction.

Step 2: Power and Video Output Activation

- Turn on the power switch and connect the video output.
- Check if the relay and Raspberry Pi indicator lights are correctly lit.
- Launch the command window and execute the file with python3.

Step 3: Program Monitoring

- Wait for the program to run and use auditory cues to determine if the relay is functioning properly.
- Record the operation time of the fan and compare it with the time set in the control code.

Step 4: Camera Check

- Verify that the camera is operational and save the captured images locally.

Step 5: Fan Speed Verification

- Compare the fan speed returned by the program with the set speed percentage.

8.1.3 Shooting Resolution Test

Objective

The purpose of this test is to measure the equivalent resolution of the Raspberry Pi under a fixed magnification lens, so as to roughly estimate the size of dust particles in the captured field of view and the expected image blurriness after shooting. The equipment required for this test includes a Raspberry Pi and a Raspberry Pi camera lens. Variables that need to be controlled in this test are the magnification of the lens, the size of a single pixel of the Raspberry Pi sensor, the focusing distance, and the size of the shooting range. Based on the test results, adjustments may need to be made to the lens magnification and focusing distance.

Procedure

Step 1: Camera and Raspberry Pi Connection

- Connect the camera to the Raspberry Pi, power on the Raspberry Pi, and ensure the power supply is functioning properly.

Step 2: Camera Preview Setup

- Enter the camera preview code into the Raspberry Pi's console, set it for 300 seconds, and adjust the lens magnification for focusing. The Raspberry Pi's output image should be visible on the display screen.

Step 3: Focus on Shooting Area

- Focus the Raspberry Pi's camera on a section of the desktop and use a marker to delineate the shooting area.

Step 4: Sensor Parameters and Resolution Calculation

- Using the Raspberry Pi's sensor parameters, focus distance, and the marked shooting area, calculate the equivalent resolution.

Step 5: Dust Particle Size Comparison

- Compare the calculated resolution with the size of dust particles. If necessary, adjust the lens magnification to ensure the particles are clearly visible.

8.1.4 Capture Speed Test

Objective

The capture speed test is also a test taken to ensure that clear images are captured. When equipment is used to capture high-speed particles, the combination of shutter speed and light source is especially critical, as it directly affects the ability to clearly capture these fast-moving objects. If the shutter time is long it will result in the motion of the particles being captured. In order to freeze the motion of high-speed particles, it is necessary to use an extremely fast shutter speed, such as 1 μs second or faster. This reduces motion blur and captures the instantaneous position of the particles. Since fast shutter speeds greatly reduce the amount of light coming in, the shutter speed allows the option of adding varying degrees of light sources to supplement the shutter speed to achieve the best results.

Procedure

Step 1 : Shooting particles with the shutter time set to 1 μs.
Step 2 : Shooting particles with the shutter time set to 0.1 μs.
Step 3 : Shooting particles with the shutter time set to 0.01 μs.
Step 4 : Set up different light sources at different shutter times to see which one is the sharpest.

8.1.5 Working Duration Test

Objective

The purpose of this test is to measure the endurance time of the device. As the device uses a 10000mAh lithium battery for power supply and needs to be tested externally, and it will experience a significant instantaneous power consumption in a single operation cycle, it is necessary to test the number of cycles the device can run stably. The equipment needed for this test is the entire device, and an additional multimeter is used to measure the current and voltage during the operation process. Variables to control during the test include a constant power source, changes in current during operation, and instantaneous power at each moment. Since the power source can be removed and replaced at any time, there are no parameters or equipment that need to be adjusted. The test results will serve as a reference for the number of batteries we carry.

Procedure

Step 1: Voltage and Current Measurement Setup

- Connect a voltmeter and ammeter to both ends of the power supply to prepare for recording the voltage and current during operation. If possible, use sensors to record data over time.

Step 2: Power Supply Activation

- Turn on the power switch, which will boot up the Raspberry Pi. Record the voltage and current at this moment.

Step 3: Fan Activation and Monitoring

- Execute the code to start the fan and observe the changes in voltage and current. Theoretically, the current should resemble an inverted parabola, similar to a downward-opening quadratic function.

Step 4: Energy Consumption Calculation

- Calculate the electrical energy consumed during a working cycle. This can be done by integrating the product of voltage and current over time to calculate the total energy. The theoretical number of operation cycles can be determined by dividing the battery capacity by this energy consumption value.

8.2 Testing Results

1.Flow Rate and Speed Test

Results

Cross sectional area of inlet:

$A_i = length \times width = 0.01748m \times 0.00794m = 1.387 \times 10^{-4} m^2$

Cross sectional area of outlet:

$A_o = \pi r^2 = \pi 0.003625^2 = 0.00004128m^2$

Flow speed at inlet:

$v_i = 12.1 \frac{m}{s}$

Flow speed at outlet:

$v_o = 37.6 \frac{m}{s}$

Flow rate at inlet:

$Q_i = A_i \times V_i = 1.387 \times 10^{-4} m^2 \times 12.1 \frac{m}{s} = 0.001678 \frac{m^3}{s}$

Flow rate at outlet:

$Q_o = A_o \times V_o = 0.00004128m^2 \times 37.6 \frac{m}{s} = 0.001552 \frac{m^3}{s}$

Cross sectional area of middle of the channel:

$A_m = length_m \times width_m = 0.013m \times 0.0013m = 0.000169m^2$

Calculate the flow speed at the middle of the channel:

$v_1 = \frac{Q_i}{A_m} = \frac{0.001678 \frac{m^3}{s}}{0.000169m^2} = 9.93 \frac{m}{s}$

$v_2 = \frac{Q_o}{A_m} = \frac{0.001552 \frac{m^3}{s}}{0.000169m^2} = 9.18 \frac{m}{s}$

Average to get the final result:

$v = \frac{v_1 + v_2}{2} = \frac{9.93 \frac{m}{s} + 9.18 \frac{m}{s}}{2} = 9.555 \frac{m}{s}$

Flow speed with channel:

$v_o = 35.5 \frac{m}{s}$

$A_0 = 0.00004128m^2$

$Q = 1.4654 \times 10^{-3} \frac{m^3}{s}$

$v_{middle} = \frac{Q}{A_m} = 8.67 \frac{m}{s}$

So in the end we will choose 8.67m/s.

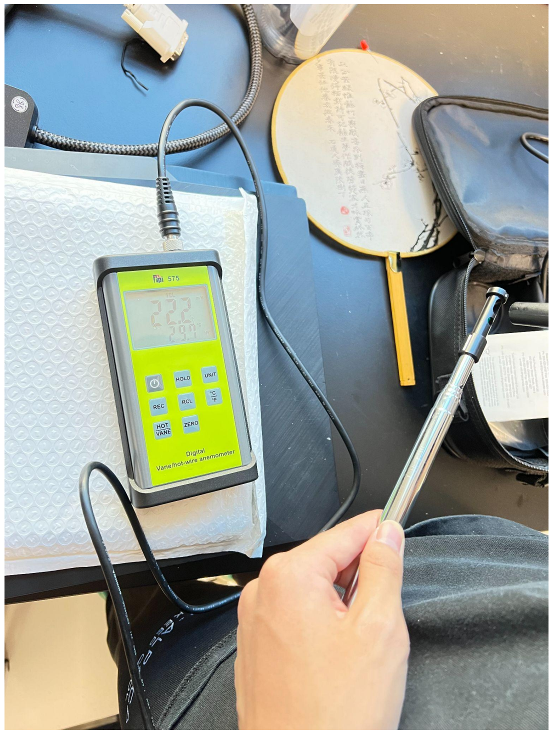


Figure 39: Anemometer

2.Control System Test

Results

The test successfully utilized RealVNC software for remote control of a Raspberry Pi, achieving remote desktop, display, file transfer, and control functionalities. The remote control script enabled the fan to operate for 8 seconds, with the camera starting to record a 5-second video at the fifth second, and the recording was stored in a local folder. Tests showed that when using PWM to adjust the fan to 50% of its speed, the maximum speed reached was around 2150 rpm, which is approximately 38% of its maximum speed. These test results are within our expectations and are acceptable.

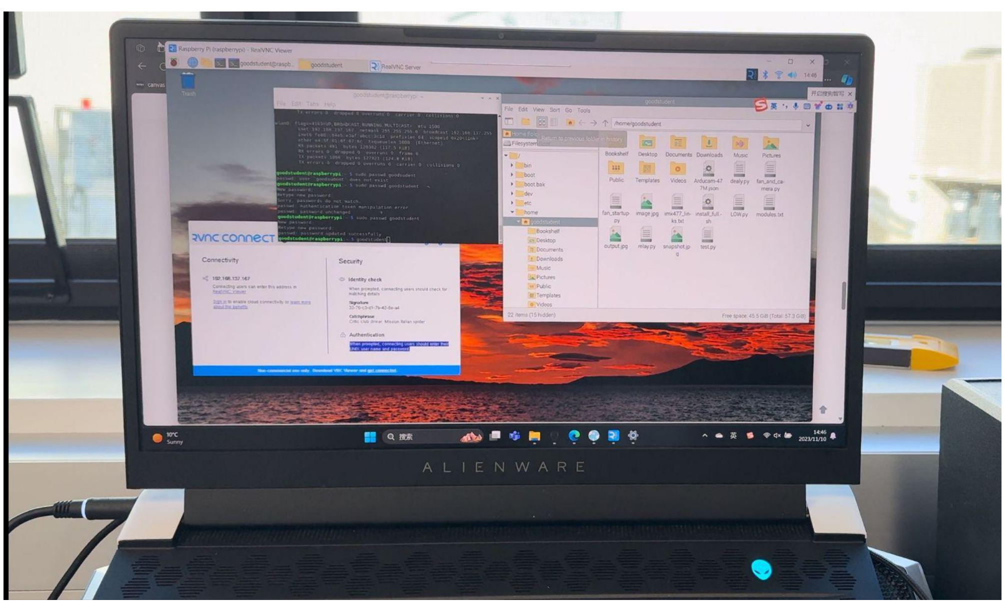


Figure 40: Raspberry Pi Command Prompt

3.Shooting Resolution Test

Results

The field of view (FoV) can be calculated using the lens's focal length and the sensor size. The formula for the horizontal FoV is:

$$FoV_{horizontal} = 2 \times arctan(\frac{sensor\ width}{2 \times focal\ length})$$

The sensor width can be calculated from the sensor diagonal and pixel size. With the diagonal and aspect ratio, you can calculate the sensor's width and height.

Calculate the size of the area that the camera will capture at a particular distance using the following formula:

$$Width\ of\ area = 2 \times distance\ to\ subject \times tan(\frac{FoV_{horizontal}}{2})$$

$$Height\ of\ area = 2 \times distance\ to\ subject \times tan(\frac{FoV_{vertical}}{2})$$

knowing the actual width and height of the area captured, equivalent resolution can be calculated as follows:

$$Equivalent\ resolution\ width = \frac{Width\ of\ area}{Pixel\ size\ width}$$

$$Equivalent\ resolution\ height = \frac{Height\ of\ area}{Pixel\ size\ width}$$

Under ideal circumstances, the calculated equivalent pixel size should be smaller than the size of the dust particles. This means that each dust particle will occupy several pixel grids, making it observable.

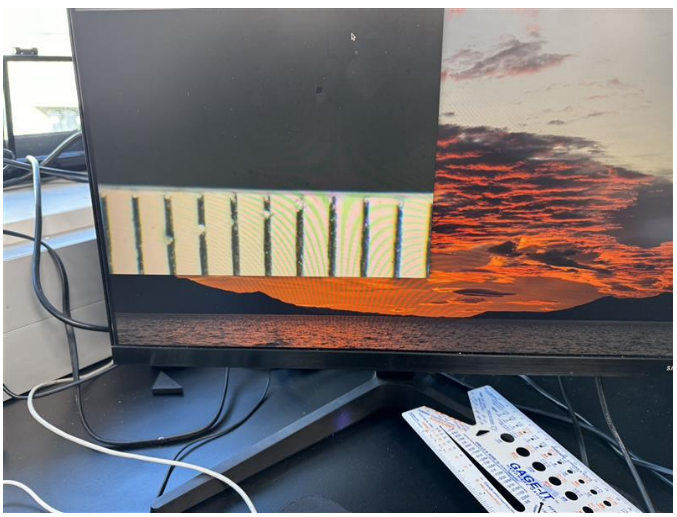


Figure 41: Horizontal Camera Calibration

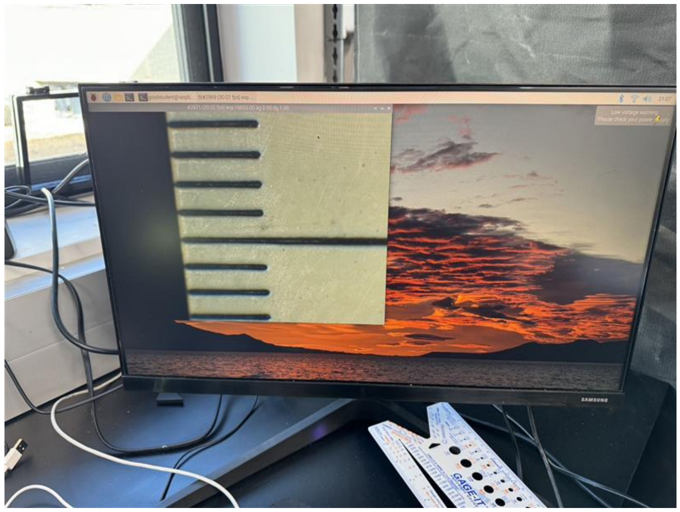


Figure 42: VerticalCamera Calibration

Table 3: Camera Calibration Results

Speed : 8.67 m/s

Shutter time : 1/8772 s

Resolution 1: 1920*1080

Direction	Pixel	Length (cm)	Length per pixel(cm)
Horizontal	1920	1	0.000521
Vertical	1080	0.75	0.000694

Image length:

867cm/s*(1/8772)s/0.000521=189.7 pixel

Resolution 1: 640*480

Direction	Pixel	Length (cm)	Length per pixel(cm)
Horizontal	640	1	0.00156
Vertical	480	0.75	0.00156

Image length:

Image length: 867cm/s*(1/8772)s/0.00156=63.3 pixel

4.Capture Speed Test

Results

After calculations and testing, it was found that dust particles leave a significant number of pixel traces within the camera's field of view during motion. At the highest resolution of 1920x1080, the image of the dust particles has a tail of approximately 190 pixel particles. When calculated at a resolution of 640x480, the tail length is about 63 pixel particles.

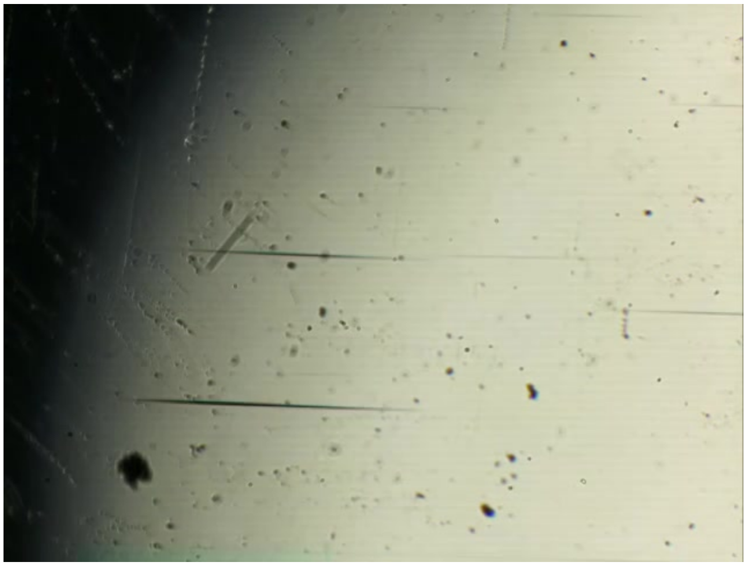


Figure 43: Resolution: 640x480 30fps

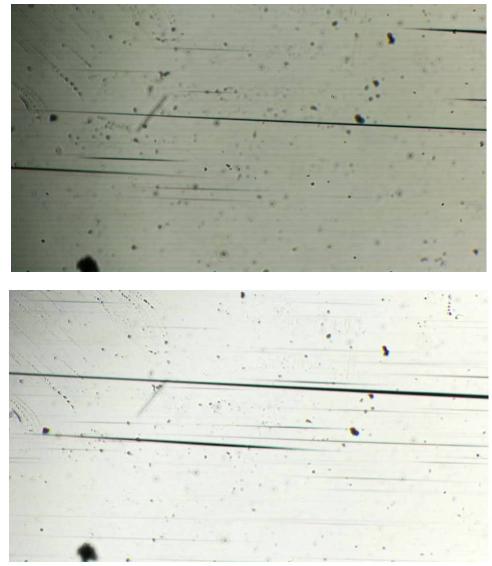


Figure 44: Resolution: 1920x1080 24fps

As observed in the image, under high resolution, the tail is longer, allowing for a clear depiction of the dust particles' motion trajectory. This also confirms that there is no turbulent effect in the fluid within the Channel. Given that the minimum exposure time of the Raspberry Pi camera used is 1/8772 seconds, achieving shorter tail images would require setting the exposure time very low during capture. Tests showed that the shortest exposure time supported by the budget-friendly LED light source equipment is 20 µs, whereas the exposure time needed to capture images with no tail is 1 µs, which is significantly shorter than what we can currently achieve. Therefore, capturing clear images of dust particles without tails will be an area for future improvement. However, the primary goal of this project, capturing the motion trajectory of particles, has been successfully achieved.

5.Working Duration Test

Results

Record the initial voltage (V_0) and current (I_0) when the Raspberry Pi is turned on. The power (P) can be calculated as:

$$P = V \times I$$

To calculate the energy (E) consumed over a working cycle, integrating the power over time. If P(t) is the power as a function of time, then energy is:

$$E = \int P(t)dt$$

To calculate the theoretical number of operation cycles (N) that a battery can support, use the battery's capacity (C) , in watt-hours or milliampere-hours) and the energy consumed per cycle (E):

$$N = \frac{C}{E}$$

Based on the power ratings of each component and the capacity of the battery, and assuming an ideal battery efficiency of 80%, the battery used in the project can support approximately 371 cycles of the entire system. This includes inputting commands into the Raspberry Pi, the Pi initiating its operations, driving the fan, and completing image capture. In actual tests, the lithium battery voltage decreases as the charge depletes, and once the 12V output falls below 10.1V or the 5V output falls below 4.2V, the Raspberry Pi fails to drive the relay or respond to input commands. Practically, the whole system managed to run for about 84 cycles or work continuously for approximately 45 minutes. Although there is a significant discrepancy between the theoretical and practical results, the operational duration and cycle count meet our ERS and Current CRS. Moreover, since our batteries can be quickly removed and replaced, the experimental results are acceptable.

Table 4: CR summary table

Customer Requirement	CR met? (Yes or No)	Client Acceptable (Yes or No)
CR1-Easy to carry, compact and lightweight	Yes	Yes
CR2-Easy to operate	Yes	Yes
CR3-High resolution	NO	NO
CR4-durable	Yes	Yes
CR5-Stable	Yes	Yes
CR6-Fast collection	Yes	Yes
CR7-Can be used in different environments	Yes	Yes

Table 5: ER summary table

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER met? (Yes or No)	Client Acceptable (Yes or No)
ER1-Decrease weight and volume of body	0.04 m^3 3 kg	5%	0.038 m^3 2.716 kg	Yes	Yes
ER2-increase flow rate and speed	9 m/s	2%	8.671 m/s	Yes	Yes
ER3-Increase control system automaticity	Most parts in the device can be controlled by Raspberry Pi		Raspberry Pi can control the camera and fan	Yes	Yes
ER4-Decrease exposure time for shooting	1.5 µs	5%	20 µs	No	Yes
ER5-Increase camera sharpness	7 * 7 µm	5%	5.21 * 6.94 µm	Yes	Yes
ER6-Increase strength of material	29.0 kPa	5%	95 Mpa	Yes	Yes
ER7-Increase working duration	0.5 h	10%	0.75h	Yes	Yes

8.3 Testing Challenges Bested

During each testing phase of the project, some issues were encountered, and efforts were made to find possible solutions.

Test 1: During the testing process, it was identified that the calculated flow rate was based on the air passing through the Channel, not the actual flow rate of dust particles. To obtain more accurate results, we utilized an anemometer for real-time flow rate calculation. Multiple measurements were taken to derive an average value, aiming to get as close as possible to the true flow rate and volumetric flow rate of the particles.

Test 2: Multiple issues were encountered during the remote control setup. Firstly, a connection could only be established when the Raspberry Pi and the control system were on the same local network. However, the Raspberry Pi could not connect to the NAU public network. To resolve this, we used a laptop's hotspot to set up a network and configured the Raspberry Pi to automatically connect to the previously connected network configuration at startup, thus achieving automatic connection to the laptop's hotspot.

Additionally, the Raspberry Pi would not display the desktop when not connected to a screen output. In such a case, using remote control would not show any operational interface. To overcome this, we connected the Raspberry Pi's HDMI output to a screen before booting up and then unplugged it after startup. With this approach, the remote desktop could display the Raspberry Pi's operating system, and video output was maintained even after rebooting.

Test 3: When measuring the camera range and calculating the resolution of the Raspberry Pi camera, the main issue encountered was camera shake. Since the camera does not have an autofocus feature, activating the fan and vacuum during operation caused vibrations, leading to unclear preview images. To address this issue, we added a stabilizing rod to the camera module and used expanding adhesive to form a triangular structure, significantly enhancing its stability.

Test 4: As the most critical and complex part of the testing, the first issue we faced in capturing the flow of dust particles was inadequate lighting. The natural outdoor light was insufficient for capturing enough light within extremely short shutter speeds, so we used a high-frequency flashing flashlight as an external light source to illuminate the Channel. Furthermore, we divided the inhalation test and the image capture test into two separate phases. Since we couldn't raise dust particles in the lab, we placed the particles in a disposable plastic cup. We also cut off the power supply to the fan, so that when the program ran, the fan wouldn't work, and the vacuum would directly inhale the dust particles from the cup for filming. Test personnel provided a flickering light source using the high-frequency flashlight.

In later stages of the experiment, we used an external LED light as the light source, providing stronger illumination. Due to the high cost of LED light controllers, we couldn't provide a pulse duration as short as 1μs. Therefore, we attempted to use 20μs pulses for the LED lights to flicker. The main focus of the subsequent work was on synchronizing the LED light flickering with the camera. By adjusting the delay, we aimed to start the LED light flickering simultaneously with the camera capturing the images.

9 RISK ANALYSIS AND MITIGATION

[Use this section to discuss how the team mitigated potential failures in the system based on their design decisions. Provide an introduction to the section here.]

9.1 Potential Failures Identified First Semester

Failures can be divided into three broad categories: material failure, electronic component failure, and connection or operational failure.

- Material failure: This type of failure includes the damage to the 3D printed resin, the damage to the fan blades, and the corrosion of the frame. Mitigating these failures requires using more durable materials or regularly replacing parts. However, this might increase the cost and complexity of the project.
- Electronic component failure: Failures like the battery bloating and leakage, pump overheating, and the Raspberry Pi software or hardware malfunction fall under this category. While it's essential to ensure proper operation of these components, some solutions might conflict with one another. For instance, adding a heat sink to the pump to avoid overheating could add extra weight to the system, which might affect the frame's durability and overall efficiency.
- Connection or Operational failure: Failures like the blockage of the filter and connection issues with the Raspberry Pi come under this. While it's possible to address these issues separately, mitigating connection failures might require extra redundancy measures that add to the system's complexity.

9.2 Potential Failures Identified This Semester

There were three main potential failures for the team this semester: wobbly shooting parts, creation of eddy currents in the collection channel, unstable power supply, and damage to the electronics from soil dust.

- Wobbly shooting parts: The soil dust collection channel is fixed to the vacuum which is fixed to the frame. A ball joint is added between the vacuum and the frame in order to make the angle of the collection device adjustable. However, the moments of the collection system are too long, resulting in a susceptibility to wobbling. The wobbling of the collection passband will cause the captured image to be blurred.
- Creation of eddy currents in the collection channel: The slope of the inner wall of the collection channel and the height difference of the structure on the inner wall can easily make the soil dust fluid turbulent and affect the original fluid properties. This can result in the original trajectory of the particles not being captured.
- Unstable power supply: To reduce weight and improve space utilization, a smaller battery is used to power the camera, the fan, and the Raspberry Pi. However, because of the limitations of a small battery, the stability of the power supply may not be high, which may cause the Raspberry Pi to disconnect and paralyze the system.
- Damage to the electronics from soil dust: During the collection of soil dust, the soil dust is raised by the fan, and the spreading soil dust particles may enter the Raspberry Pi, as well as the camera, and ultimately damage the electronics.

9.3 Risk Mitigation

9.3.1 *Potential Failures Identified First Semester*

- Material Failure: For the brittle fracture of the 3D printing resin, we used a high strength resin and improved printing technology, and verified its robustness through pressure and impact tests. For damage to fan blades, we used impact-resistant blades that were specially designed and tested for durability. Using stronger materials may increase cost and weight. For this reason, we balanced strength and weight and chose the best combination of materials. New risks in the design process include increased cost and complexity.

- Electronic Component Failure: For battery expansion and leakage, we chose a high-quality battery with an intelligent charge/discharge system to avoid overcharging and discharging. For software errors in the Raspberry Pi, we conducted an in-depth code review and testing. Incorporating additional monitoring and protection circuitry increases the complexity and energy consumption of the design. We weighed complexity and safety and chose the optimal solution. New risks introduced may include over-complexity of the system, leading to maintenance difficulties.
- Connection or Operational Failure: To solve the networking problem of the Raspberry Pi, we designed a dual connection system (wireless and wired) and conducted network stability tests. For filter clogging, we designed an easy-to-replace filter system and adjusted the filter size according to the actual dust size. The dual connection system adds complexity to the design, but it improves the reliability of the system. We found a balance between complexity and reliability. New risks introduced include the complexity of maintaining the dual network system.

9.3.2 *Potential Failures Identified This Semester*

- Wobbly shooting parts: Add additional support structures to minimize vibration. Design a vibration damping mechanism, such as the use of shock-absorbing materials or a spring system. Structural stability tests and vibration analysis are performed to ensure that the modified design is able to withstand the additional loads without oscillating, ensuring image quality. Adding support structures or vibration dampening systems may add weight and complexity, but it is critical to ensure image stability and accuracy. New risks may include increased structural complexity and maintenance requirements. At the same time the flexibility of the collection system will be reduced.
- Creation of eddy currents in the collection channel: Optimize the design of the collection channel by using the wind tunnel structure as a whole and chamfering the inner surface where there is a height difference to reduce turbulence generation. Use computational fluid dynamics (CFD) simulations to optimize the channel design. Practical tests verified the effectiveness of the improved channel in reducing eddy currents by observing the trajectory of the particles. The optimized channel requires a thinner wall thickness, which may increase the cost of the design and the likelihood of breakage, but this is essential to ensure the effectiveness and accuracy of the dust collection.
- Unstable power supply: Use more efficient batteries or add a small backup power system. Tests have verified that a new battery or backup power system can provide a more stable power supply. Choosing a more efficient battery or adding a backup power source may add weight and cost, but it is critical to system stability and reliability. New risks may include the added weight affecting overall system portability and maneuverability, as well as placing a greater burden on the overall frame.
- Damage to the electronics from soil dust: Add a dustproof enclosure for the Raspberry Pi and camera to prevent soil dust from entering. Tests verified that the dustproof enclosure was effective in preventing dust from damaging electronic equipment. Dust protection measures may increase costs and maintenance requirements, but they are critical to protecting critical electronic components. New risks may include damage to electronic components from dust enclosures affecting their heat dissipation.

This risk analysis directly influenced the design of our project. We opted for a compromise between durability and efficiency. This trade-off risk study was vital in shaping the design decisions in our project. The choices we made were driven by a thorough understanding of how these risks interact and how mitigating one could exacerbate another. It provided us with a roadmap to a design that balances efficiency, durability, and maintainability.

10 LOOKING FORWARD

This section of the report details future testing efforts that will be conducted on the system to improve and modify it.

10.1 Future Testing Procedures

10.1.1 Supply Stability Test

Objective

Ensure the stable operation of electronic components in the device during operation。

Procedure

1.Connecting the multimeter and powered components to the power supply

2.Observe that the voltage and current remain within specified limits under different load conditions. Large fluctuations may indicate instability.

10.2 Future Iterations

10.2.1 Future Iteration 1: Frame

For future framing work, the team prefers to use a square T-slot profile instead of the current L-shaped aluminum frame. The current L-shaped aluminum frame is lightweight and strong enough, but has a slight wobble due to its structure, which is solved by the square T-slot profile. The square T-slot profile also makes it easier to install components on the frame.

10.2.2 Future Iteration 2: LED System

The team wanted to add a pulsed LED system to the system. Because the shutter time was not short enough, the resulting images of dust were lines representing the movement of particles rather than points. So using a short exposure time to capture a freeze frame image of the particles was proposed. First of all it is necessary to select an LED controller, an LED lamp and a suitable power supply that allows the LED lamp to produce a pulsed light source. Because high power LED lamps require a higher power supply, a higher power supply needs to be replaced. The LED controller will then be used to output a 2 microsecond pulsed signal, and very short exposure times can be achieved by placing the LED lamp on one side of the viewing window and turning on the led while the soil dust flow process is being photographed.

10.2.3 Future Iteration 3: Synchronous Setting

After setting up the pulsed LED system, you need to set up the synchronization between the LED pulses and the camera shots. Using the XVS pin (vertical synchronization), the camera is allowed to pulse when frame capture is initiated.The LEDs can listen to this synchronization pulse and capture a frame at the same time as another camera. This allows the LEDs to be synchronized with the camera.

11 CONCLUSIONS

As we conclude this project report, it is evident that the development of the automated soil dust collection and characterization system represents a significant advancement in the field of environmental health research, particularly in the study of Valley Fever. This project, born from the necessity to improve the efficiency and accuracy of soil sample collection, has successfully integrated innovative machine vision technology with a user-friendly, portable design.

The project team set forth with clear goals: to create a system that is not only effective in dust collection but also robust, adaptable, and efficient in various field conditions. These objectives were met through meticulous planning, design, and execution, resulting in a system that significantly decreases the weight and volume of the body for ease of transport, increases flow rate and speed for efficient sample collection, and enhances control system automaticity for reliability. Additionally, the improvements in camera sharpness and the reduction in exposure time for shooting have been instrumental in achieving high-resolution imaging of soil dust, crucial for detailed morphological analysis.

The strength of materials used in the construction of the system has been increased, ensuring durability and stability in diverse environmental conditions, while the extended working duration has maximized field productivity. The results of this project not only meet the set engineering requirements but also align seamlessly with the customer requirements, underscoring the project's success in addressing the needs of both researchers and the broader scientific community.

In summary, this project has not only achieved its specific goals but has also set a precedent for future research and development in this field. The team's dedication, combined with the guidance of our mentors, has culminated in the creation of a system that stands as a testament to the possibilities of technological innovation in addressing environmental health challenges. The successful completion of this project paves the way for more efficient, accurate, and comprehensive research into Valley Fever, with potential applications extending beyond this specific field.

11.1 Reflection

Reflecting on our project, the automated soil dust collection and characterization system, it's clear that our design process is deeply rooted in engineering principles, with a strong emphasis on public health, safety, environmental considerations, and economic factors. These elements are integral to our project, given its direct impact on health research, specifically in studying Valley Fever.

- Public Health and Safety

The primary driver of our project is public health. Valley Fever, caused by soil-borne fungi, poses significant health risks. Our system aims to facilitate more efficient and accurate research into this disease. By automating and improving the soil dust collection process, our design contributes to a deeper understanding of Valley Fever, ultimately aiding in the development of better prevention and treatment methods. In terms of safety, we ensure that our system is safe to operate in various environmental conditions. The use of robust materials and the incorporation of safety features in the design minimize the risk of accidents or malfunctions during operation.

- Environmental Considerations

Environmental factors play a crucial role in our design process. The system's ability to function effectively in different environmental conditions is paramount. We achieve this by selecting materials and components that can withstand various weather conditions and by ensuring that the system's operation does not negatively impact the environments in which it is used. Additionally, the portability and durability of our design minimize the ecological footprint by reducing the need for frequent replacements or repairs.

- Economic Factors

Economically, it is important to create a cost-effective solution. We achieve this by optimizing the design for manufacturing ease and selecting cost-efficient materials without compromising quality. This approach ensures that our system is accessible to a wider range of researchers and institutions, making it a viable tool for Valley Fever research across different regions.

- Cultural and Global Factors

While our project is primarily focused on public health and environmental aspects, we also consider cultural and global factors. Valley Fever is a concern in various parts of the world, and our system is designed to be adaptable and easy to use, regardless of the user's cultural background or geographical location. This universality in design ensures that our system can be deployed globally, contributing to international research efforts.

In conclusion, our project's design process is a careful balancing act of various factors, with a strong emphasis on public health, safety, environmental sustainability, and economic viability. Through thoughtful design choices, rigorous testing, and continuous iteration, we develop a system that not only meets the specified needs but also addresses broader considerations, making it a valuable tool in the fight against Valley Fever.

11.2 Project Applicability

As we conclude our project on the automated soil dust collection and characterization system, we reflect on how this experience has been a vital preparatory phase for our future careers. The project has not only sharpened our technical skills but also developed our proficiency in various essential soft skills.

Throughout the project, we delved deep into the realms of engineering design and problem-solving, tackling complex challenges that honed our technical expertise. This hands-on experience in managing a project from concept to completion has been invaluable, fostering an innovative mindset crucial in engineering. Simultaneously, the project demanded effective teamwork and project management skills. Our collaborative efforts in planning, execution, and problem-solving underlined the importance of communication, teamwork, and the ability to work under pressure. These experiences have prepared us to work efficiently in professional settings, where collaboration and adaptability are key.

Moreover, the focus on public health in our project instilled a strong sense of social responsibility and ethical considerations in us. We learned the importance of creating solutions that are not only effective but also socially and environmentally responsible. Additionally, engaging with various stakeholders has significantly improved our professional communication and presentation skills, equipping us to convey complex technical information effectively.

In summary, this project has been an enriching journey, equipping us with a broad spectrum of skills. As we transition into our professional careers, we carry forward the technical knowledge, collaborative experience, ethical insights, and communication skills gained from this project. This experience has been more than an academic endeavor; it has been an essential stepping stone into our professional lives.

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13 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report. These can contain engineering calculations, engineering drawings, bills of materials, current system analyses, and surveys or questionnaires. Letter the Appendices and provide descriptive titles. For example: Appendix A-House of Quality, Appendix B- Budget Analysis, etc. All Appendices should start on a new page.]

13.1 Appendix A: QFD

Decrease weight and volume of body						
increase flow rate and speed	+					
Increase control system automaticity	+	+				
Decrease exposure time for shooting						
Increase camera sharpness						
Increase strength of material						
Increase working duration						

		Technical Requirements						
Customer Needs	Customer Weights	Decrease weight and volume of body	increase flow rate and speed	Increase control system automaticity	Decrease exposure time for shooting	Increase camera sharpness	Increase strength of material	Increase working duration
Easy to carry, compact and lightweight	5	9						
Easy to operate	4	3		9				
High resolution	4				9	9		
durable	2			1			9	9
Stable	3			1			3	
Fast collection	5		9					
Affordable	4	1						
Can be used in different environments	2	1	1	3	3	3	3	3
Technical Requirement Units		kg , m^3	L/min	N/A	μs	μm	Mpa	hour
Technical Requirement Targets		60	45	45	30	40	35	20
Importance rating		63	47	47	40	42	33	24

13.2 Appendix B: Bill of Materials

Fan	1	12V 57.6W 5500RPM	Agitate the air	N/A	120mm*120mm*38mm	24.99	https://www.amazon.com/PFC1212DE-252-85CFM-6	Assembled
Channel	1	Trumpet tube	Provide air inlet,outlet and camera window	Conductive Filamen	Inlet: 33mm*33mm Outlet: r = 17.5mm	49.99	https://www.amazon.com/dp/B00X8BQYVM?ref_=cm	Assembled
Camera	1	12.3PM	Shoot and record dust	N/A	2.5in	29.99	https://www.amazon.com/Arducam-Autofocus-Raspbe	Assembled
Battery	1	11.1V/6Ah (66.6Wh)	Power supply to the control system	Lithium Ion	28mm*85mm*145mm	N/A	N/A	Assembled
Raspberry Pi 4B	1	N/A	Control the camera and fan	N/A	N/A	N/A	N/A	Assembled
Plant-Based UV Resin	3	3kg in total	Used for 3d printng	UV Resin	N/A	29	https://www.anycubic.com/collections/plant-based-uv-	In house
Vacuum Pump	1	60W with HEPA filter	Absorb and store the dust	N/A	8.27in*6.30in	17.26	https://www.temu.com/wireless-mini-car-vacuum-clear	Assembled
Shooting Window on Channel	1	Clear, conductive film	Camera window to capture dust	ITO Coated Glass	1in*0.4in	N/A	N/A	Assembled
HEPA Filter	12	N/A	Replace filter in vacuum to store dust	Plastic	2"L*1"W*4"H	38.97	https://www.amazon.com/Hand-Held-Cleaner-Replace	In house
Nut	10	N/A	Fix components with mount	Zinc	1/4in	1.1	Homedepo	Assembled
Screw	10	N/A	Fix components with mount	Zinc	1/4in*1/2in	1.38	Homedepo	Assembled
Ball Head Screw Tripod Mount	4	360 degree rotating mount base	Fix fan and channel	Aluminum Alloy	N/A	13.98	https://www.amazon.com/dp/B08M4785CW?ref=ppx_	Assembled
Woven Wire 10 Mesh	2	2mm hole	N/A	Stainless Steel 304L	11.4"*23.6"	22.9	https://www.amazon.com/Woven-Wire-Mesh-Stainles	Assembled
Frame	1	Cuboid	Make the entire system easy to transfer	Aluminum	12in*12in*16in	63.81	https://www.homedepot.com/p/Everbilt-1-1-2-in-x-96	Assembled

13.3 Appendix C: Potential Failures Identified

Potential Critical Failure 1: (Channel) Mechanical Failure: Brittle Fracture

This failure is due to the insufficient strength of the 3D printed resin. Due to the limitations of transparent 3D printing materials, the material often shows cracks, deformation, and fractures under pressure and stress. This failure will cause dust splashes during the collection process, affecting the surrounding environment and causing damage to other equipment. There are several ways to solve this problem, including printing multiple models for selection, designing better mechanical models, or testing new resins

Potential Critical Failure 2: (Battery) Swelling

This failure is caused by overcharging, over discharging, or abnormal environmental temperatures of the battery. A swollen battery can increase in volume, putting pressure on the casing, and may also have the potential for explosion or combustion due to the release of internal gases, posing a threat to equipment and human safety. When a battery swells, it should be immediately stopped from use and replaced. Meanwhile, during daily use, it is necessary to control the charging and discharging currents and use the battery correctly to extend its lifespan and avoid swelling.

Potential Critical Failure 3: (Battery) Leakage

"This failure is caused by abnormal environmental temperatures of the battery, physical collision and destruction, and improper storage. Battery leakage can produce corrosive chemicals, which can react with the metal casing and equipment, causing them to become brittle or even generate heat and burn. Battery leakage is a very dangerous failure. It is necessary to replace the battery promptly and check for equipment damage. You can also use lithium batteries instead of lead-acid batteries or zinc-manganese batteries to avoid this kind of failure.

Potential Critical Failure 4: (Fans) Electrical Failures: Blade blockage

This failure is caused by foreign objects entering the fan blades during operation, obstructing the rotation of the blades. This fault can cause the fan to shake, make noise, or even burn out the motor, and the smell and toxic substances produced can pose a threat to the health of people around. Fan blockage is a serious fault. Possible mitigation strategies include arranging a dust cover around the fan for maintenance, or using fans specifically designed for dusty environments to enhance the fan's tolerance to the environment.

Potential Critical Failure 5: (Fans) Blade Damage

This failure is caused by foreign objects entering the fan blades during operation, causing collision and friction that damage the blades. If the blades of a high-speed rotating fan are damaged, it can cause splashing of fragments and collision, further increasing the hazard and instability of the fan. Once fan blade damage occurs, it's essential to replace the blades or the whole fan promptly to ensure safety. To mitigate this fault, durability testing and collision testing of the fan should be conducted to ensure that the dust in the experimental field will not cause damage to the blades

Potential Critical Failure 6: (Raspberry Pi) Software Errors

This failure is caused by driver incompatibility, code syntax errors, hardware failure, or software crashes when the Raspberry Pi is running software. Given the Raspberry Pi serves as the control center, any fault can lead to abnormal operation of the entire device, including overworking, shutdown, burning circuits, etc., posing a significant safety hazard. To prevent the occurrence of faults, all equipment must be thoroughly tested before the experiment, the software must be run multiple times to check its stability, and pre-experiments must be conducted in indoor test sites. Backup plans should also be prepared, with computer control as an alternative when the Raspberry Pi stops working.

Potential Critical Failure 7: (Raspberry Pi) Network issues

This failure is caused by unstable connections, disconnection, and other related problems. When the Raspberry Pi experiences a connection failure, it loses its remote-control capabilities and will continue to operate under its current program, leading to damage due to prolonged operation and loss of transmission capabilities causing the process to halt. To avoid connection failures, we must employ both wireless and wired connection solutions, switching to the alternative when one encounters a problem.

Potential Critical Failure 8: (Filter) Blockage

This failure is caused by issues such as prolonged use of the filter, aging, sizing problems, and high dust adhesion. When the filter is blocked, the efficiency of the pump is reduced, the airflow is slowed down, and the pores of the filter are enlarged, leading to some dust particles passing through and damaging the pump. To avoid this failure, regular replacement of the filter is necessary. Also, adjustments should be made to the filter selection based on the actual size of the dust in the field, to ensure maximum efficiency.

Potential Critical Failure 9: (Frame) Corrosion or Oxidation

This failure is caused by battery leakage, contact with chemicals, and natural aging. When the frame comes into contact with different types of corrosive chemicals, it can become brittle or soft. Eventually, the frame may deform or break, leading to the collapse of the entire structure. If the structure breaks, the resulting fragments could cause injury to people nearby. The solution to this problem lies in the selection of frame materials, such as choosing between aluminum alloy and stainless steel. While ensuring safety, it's necessary to maximize durability and minimize weight as much as possible.

Potential Critical Failure 10: (Pump) Overheating

This failure is caused by poor heat dissipation of the pump, long-term use, and internal damage. When the pump overheats, its voltage and current will decrease, reducing its operational efficiency. Meanwhile, prolonged overheating can burn out internal electronic components like capacitors and wires, causing irreversible damage to the pump. In severe cases, the pump may burn out, producing toxic fumes and high temperatures. To avoid this problem, the position of the pump can be included in the fan's air duct to assist in cooling, or a sunshade can be created for the pump to avoid direct sunlight. At the same time, the pump should be tested to gauge its tolerance, to prevent failures during the experiment.

New potential failures are highlighted

Potential Critical Failure 11: Wobbly shooting parts

The soil dust collection channel is fixed to the vacuum which is fixed to the frame. A ball joint is added between the vacuum and the frame in order to make the angle of the collection device adjustable. However, the moments of the collection system are too long, resulting in a susceptibility to wobbling. The wobbling of the collection passband will cause the captured image to be blurred. At the same time the wobbly collection channel may be deflected and not aligned with the direction of soil dust flow, resulting in less efficient collection.

Potential Critical Failure 12: Creation of eddy currents in the collection channel

Ideally the inner wall of the collection channel should be streamlined and not significantly affect the original properties of the fluid. The slope of the inner wall of the collection channel and the height difference of the structure on the inner wall can easily make the soil dust fluid turbulent and affect the original fluid properties. This can result in the original trajectory of the particles not being captured. In the original fluid situation, the photographed particle trajectory map is supposed to be a straight line, whereas in the presence of turbulence, the trajectory map will change to an arc.

Potential Critical Failure 13: Unstable power supply

To reduce weight and improve space utilization, a smaller battery is used to power the camera, the fan, and the Raspberry Pi. However, because of the limitations of a small battery, the stability of the power supply may not be high, which may cause the Raspberry Pi to disconnect and paralyze the system. Especially under remote control, there is no wire connection between the computer and the Raspberry Pi, when the stability of the power supply is required.

Potential Critical Failure 14: Damage to the electronics from soil dust

Considering the heat dissipation of the Raspberry Pi, the original skeletonized case is now used. As well as the camera's circuit board is naked and exposed to the air. During the collection of soil dust, the soil dust is raised by the fan, and the spreading soil dust particles may enter the Raspberry Pi, as well as the camera, and ultimately damage the electronics.