Active Soil Dust Collection System with Raspberry Pi Machine Visual Characterization

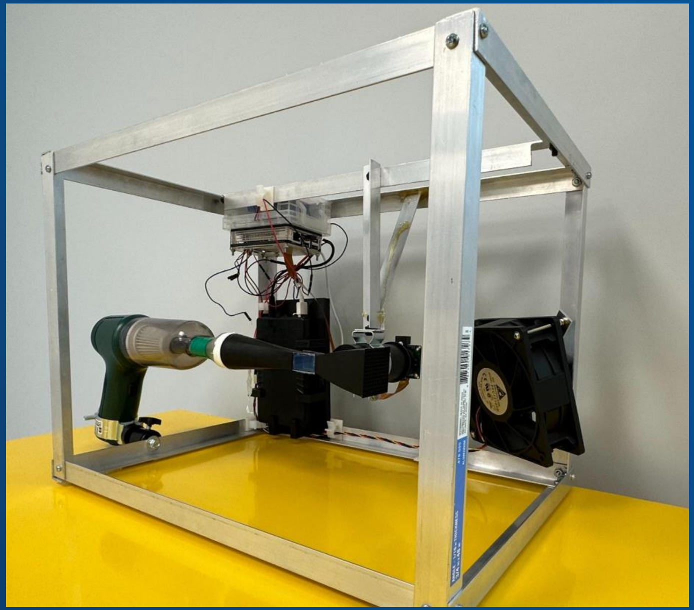
PRESENTED BY:

Jie Jin

Jun Mei

Ruihua Shi

Zhiyu Bai



NAU NORTHERN ARIZONA UNIVERSITY

Project Description

Figure 1: The primary exposure pathway

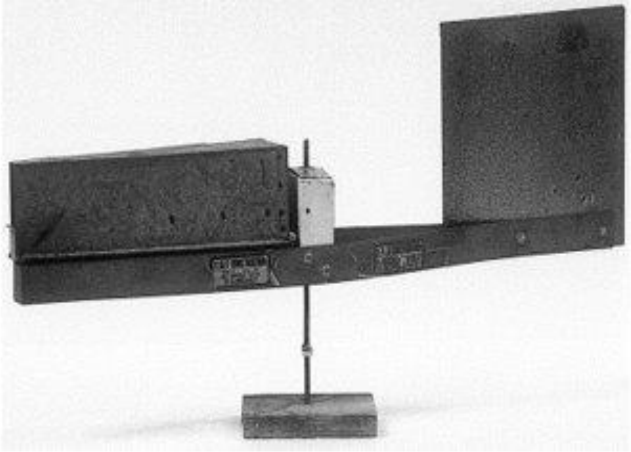


Figure 2: BSNE passive sampler

- Valley Fever is an infectious disease caused by the fungus Coccidioides.The main exposure pathway for humans is inhalation of soil dust where fungi are located. Arizona is one of the high incidence areas of Valley Fever.

- To design and implement an automatic soil dust collection and characterization system utilizing the machine vision approach.

- "Yahoo Image Search." *Yahoo.com*, 2020, images.search.yahoo.com/yhs/search. Accessed 19 June 2023.
- 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.

Clients/Stakeholders

Figure 3: Dr. Zhongwang Dou

Client/Sponsor

- Dr. Zhongwang Dou

Stakeholders

- Summer 2023 Team 3
- Researchers and Scientists
- Public Health Organizations
- Patients and the Public
- Technology Developers and Manufacturers

Consistency of Customer Requirements

Customer Requirements:

- CR1 - Easy to carry, compact and lightweight(0.04 m^3, 3kg)
- CR2 - Easy to operate
- CR3 - Capture images with high resolution(7 * 7 μm)
- CR4 - A durable design can greatly extend the life and working duration of the device(0.5h)
- CR5 - The equipment should work as steadily as possible to ensure a clear shot.
- CR6 - Fast collection(9m/s)
- CR7 - Can be used in different environments

Decomposition Model

- Provide insights into the individual components and their interactions within a larger system.
- Provide underlying logic for generating models.

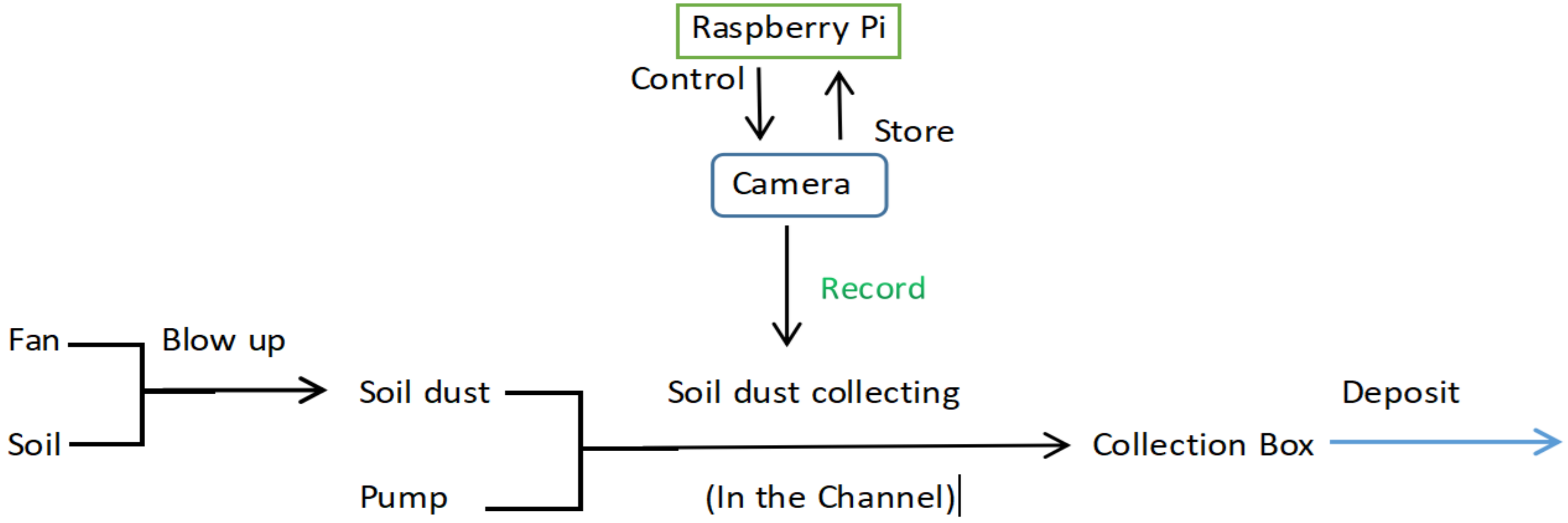


Figure 6: Decomposition Model

Engineering Requirements

Engineering Requirements:

- ER1 - Decrease weight and volume of body
- ER2 - Increase flow rate and speed
- ER3 - Increase control system automaticity
- ER4 - Decrease exposure time for shooting
- ER5 - Increase camera sharpness
- ER6 - Increase strength of material
- ER7 - Increase working duration

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
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							

Customer Needs	Customer Weights	Technical Requirements: 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

Table 1: QFD Table

Concept Generation

- Camera - Shoot dust
- Channel - Provide air inlet and the platform for shooting window
- Fan - Blow the dust up
- Pump - Suck the dust
- Collection Box - Collect the dust

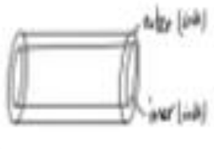
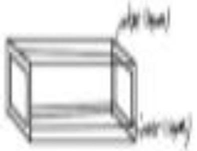
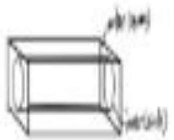
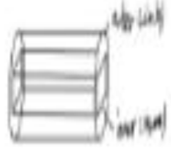
Sub-Function	1	2	3	4
Camera (A)	 5MP	 16MP	 12.3MP	 64MP
Channel (B)				
Pump (C)	 2.2kPa air pressure 300L/min wind speed	 3.5 kPa air pressure 180L/min wind speed	 3.5 kPa air pressure 180L/min wind speed	 3.4 kPa air pressure 280L/min wind speed
Fan (D)	 12V 4.8A 57.6W 5500RPM	 12V 1.32W 2000 RPM	 120V 14W 2600 RPM	 12V 0.1A 1.1W 3500RPM
Collection Box (E)				

Table 2: Morphological Matrix

Concept Selection

- Used to narrow down to 2 designs from 4
- Thought of 6 different criteria
- Had design 2 as Datum

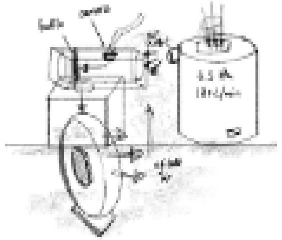
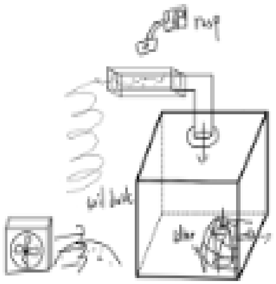
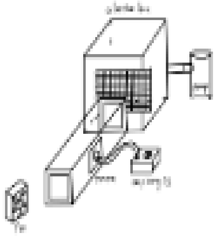
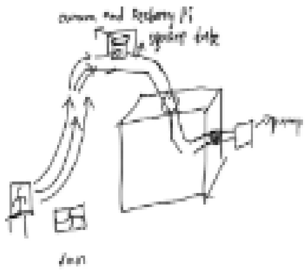
Concept → Criteria	Design 1  A2 B3 C2 D3 E1	Design 2  A4 B3 C1 D3 E2	Design 3  A2 B2 C3 D1 E3	Design 4  A4 B2 C3 D3 E5
Prime Cost	+	s	s	-
Operation	s	s	s	s
Durability	-	s	+	+
Installation	s	s	s	s
Clarity	+	s	+	+
Efficiency	+	s	+	s
∑+	3	0	3	2
∑-	1	0	0	1
∑s	2	6	3	3

Table 3: 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	0.15	94	14.1	87	13.05
Installation	0.05	97	4.85	97	4.85
Clarity	0.25	93	23.25	91	22.75
Efficiency	0.35	90	31.5	92	32.2
Total	1	Sum:	92.2	Sum:	91.65

Table 4: Decision Matrix

- Had same criteria and compared them
- Advantages/Disadvantages
- Efficiency most important
- Installation least important

First-generation Prototype

Advantages：

- Portable design
- Reduction of connecting pipes
- Guarantee the smooth flow

Disadvantages：

- Hard to move dust
- May not be able to block dust particles
- Power supply

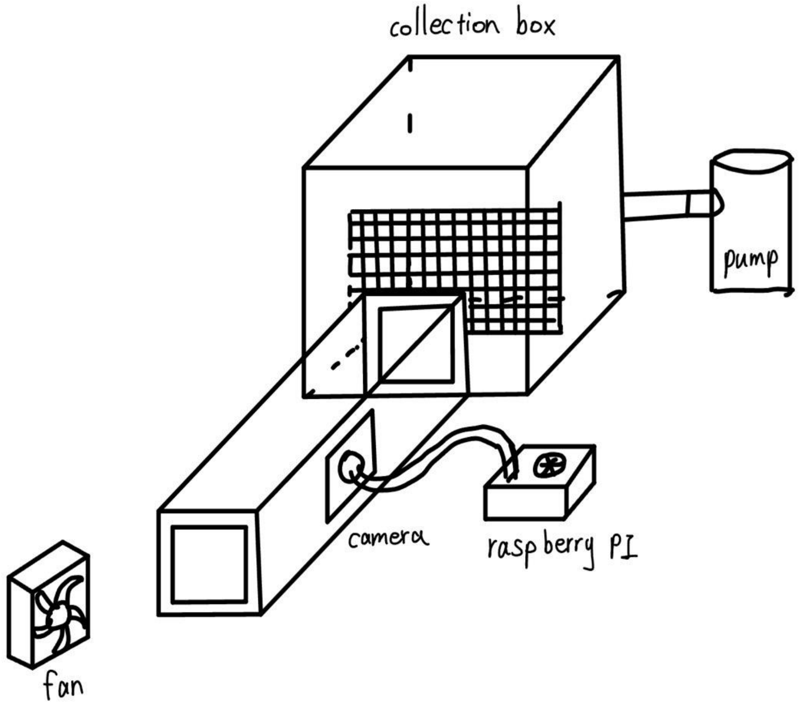
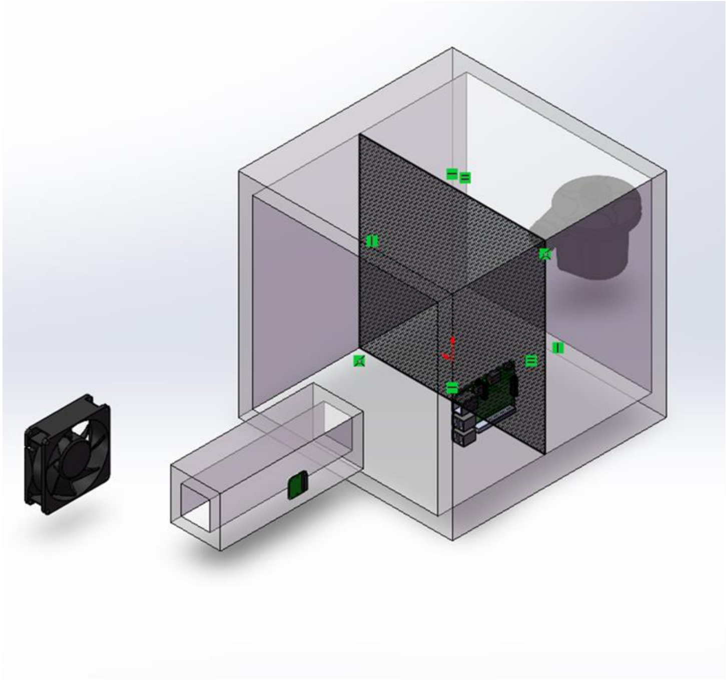
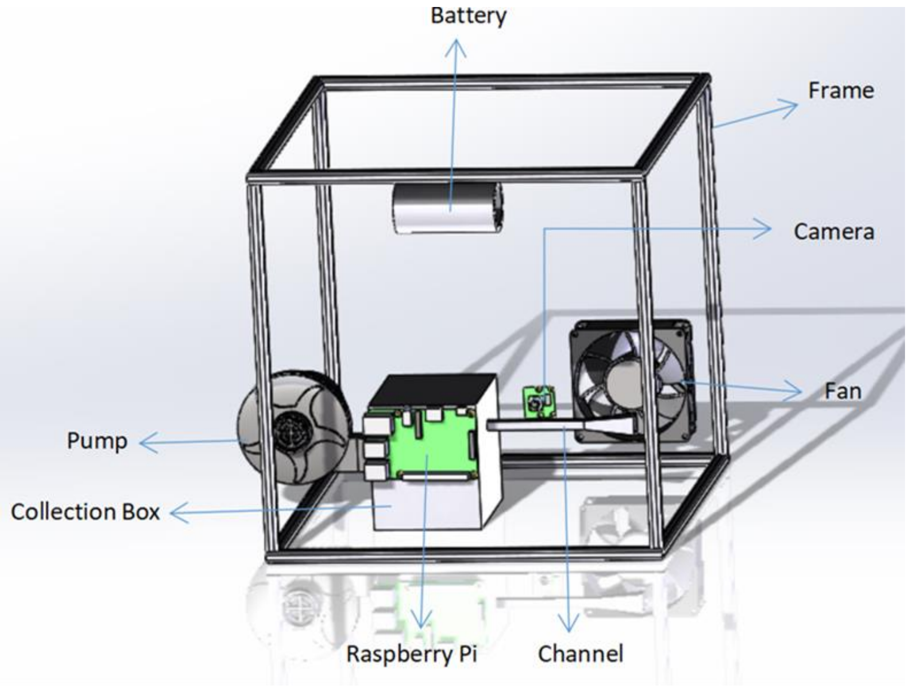


Figure 7: Design 3

CAD Iteration





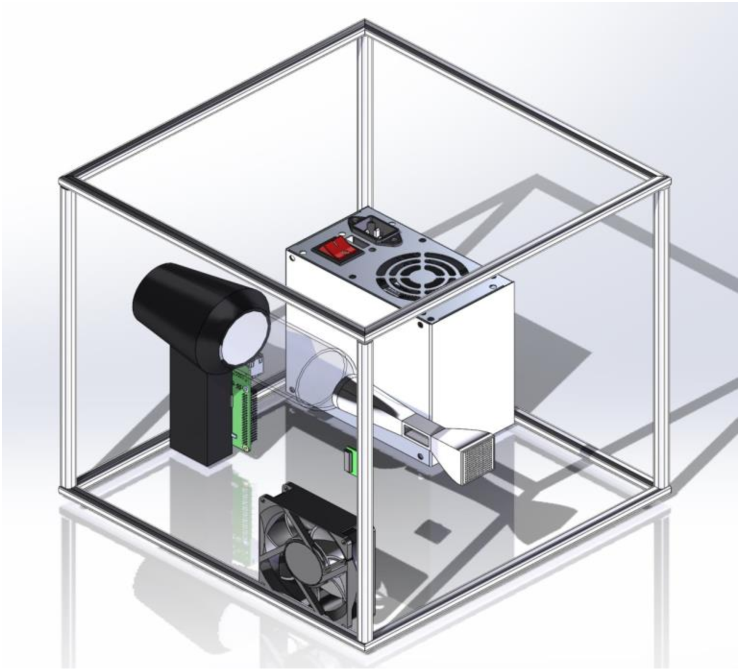


Figure 8: Previous CAD Models

Final CAD Model

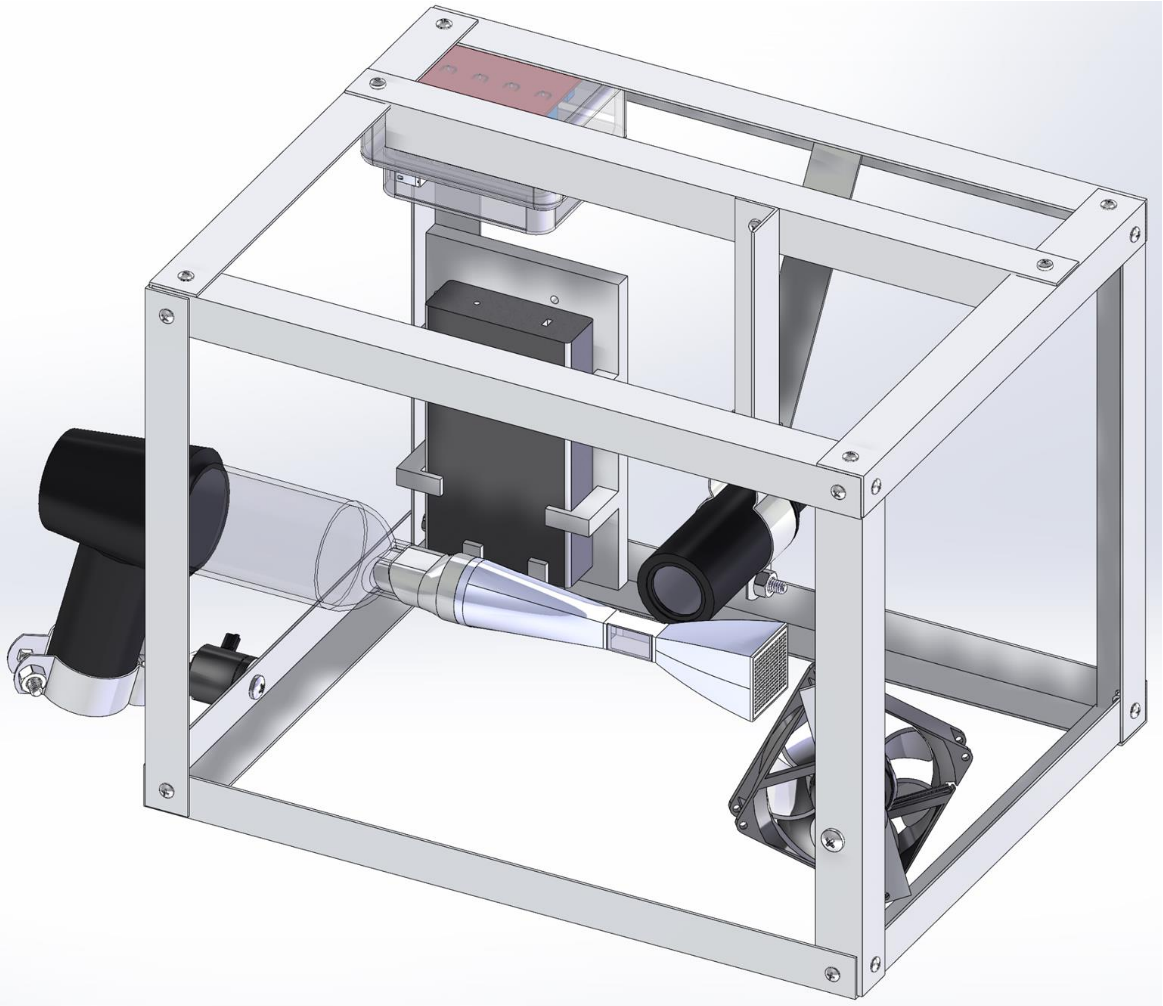


Figure 9: Final CAD Model

Manufacturing Process

Task 1	Aluminum Frame Construction	100%	8/31/23	9/7/23
Task 2	Camera driver debugging.	100%	8/31/23	9/20/23
Task 3	Pipe Printing	100%	9/13/23	9/20/23
Task 4	Joint Design and Printing	100%	9/17/23	9/22/23
Task 5	Air pump installation	100%	9/17/23	9/22/23
Task 6	Raspberry Pi Control Coding	100%	9/24/23	10/1/23
Task 7	Joint of Fan design	100%	10/8/23	10/13/23
Task 8	Fan and Raspberry Pi installation	100%	10/8/23	10/13/23
Task 9	Compact battery solution	100%	10/15/23	10/20/23
Task 10	Wire Package	100%	10/22/23	10/29/23
Task 11	Code Optimize	100%	10/29/23	11/12/23
Task 12	Future Improvement	30%	11/12/23	

Table 5: Manufacturing Process

Manufacturing

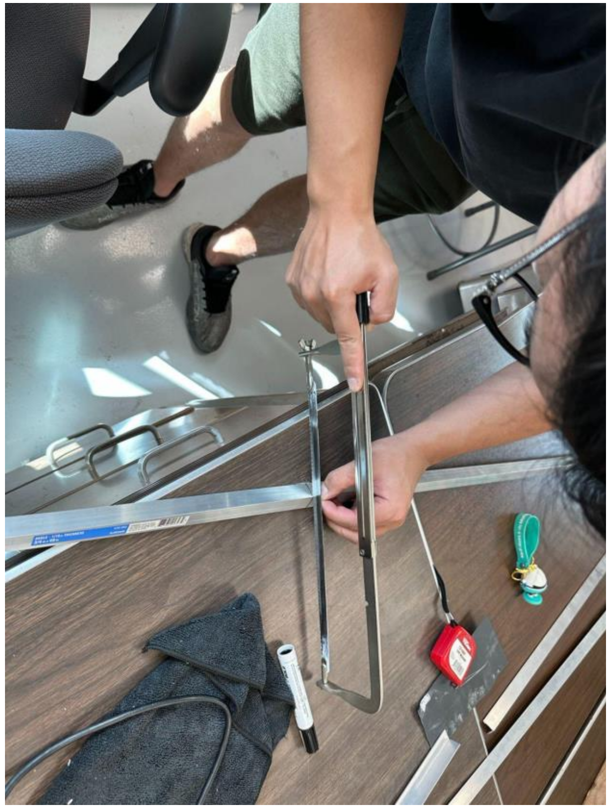


Figure 10: Cutting of aluminum rods

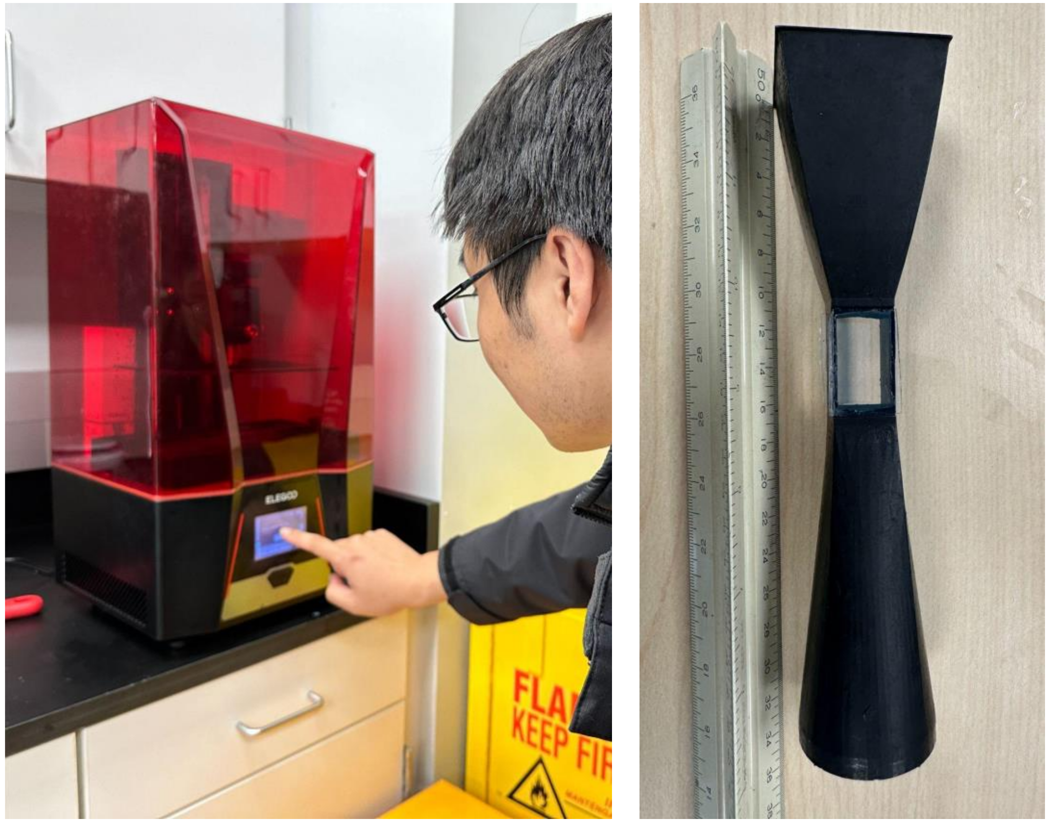


Figure 11&12: Making conductive channels

Manufacturing

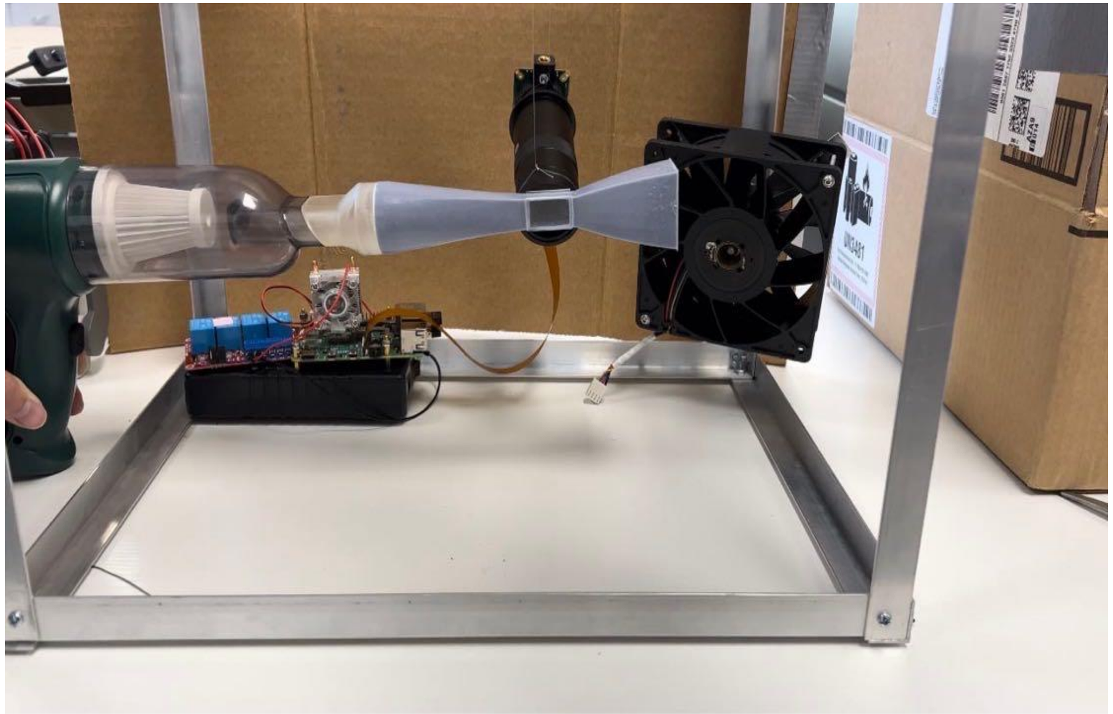


Figure 13: Device Prototype

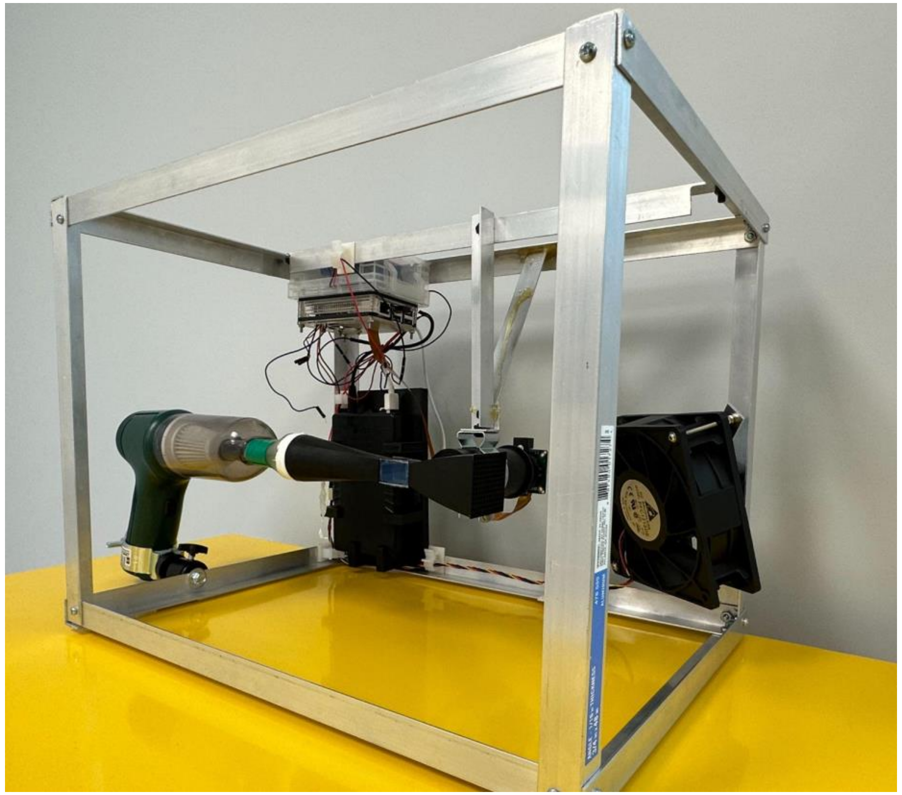


Figure 14: Final Design

Testing Plan

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-Working Duration Test	1.Battery 2.Fan 3.Raspberry Pi	ER7,CR4,CR7

Table 6: Testing Plan

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:

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

$$A_0 = 0.00004128m^2$$

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

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

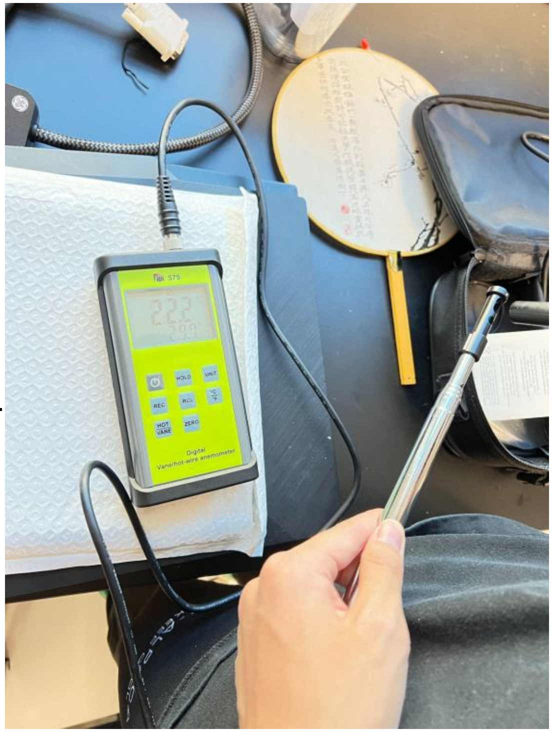


Figure 15. Test Flow Speed with Hot Wire

2. Control System Test Results

Results

- Successfully set up remote connection for Raspberry Pi using RealVNC software.
- Raspberry Pi connected to laptop hotspot for WLAN-based remote desktop and file transfer.
- Set the fan speed limit to 50%, with the actual speed around 2100 rpm.
- The fan speed is approximately 38% of the maximum speed, which is within the acceptable range of 30%-40%.

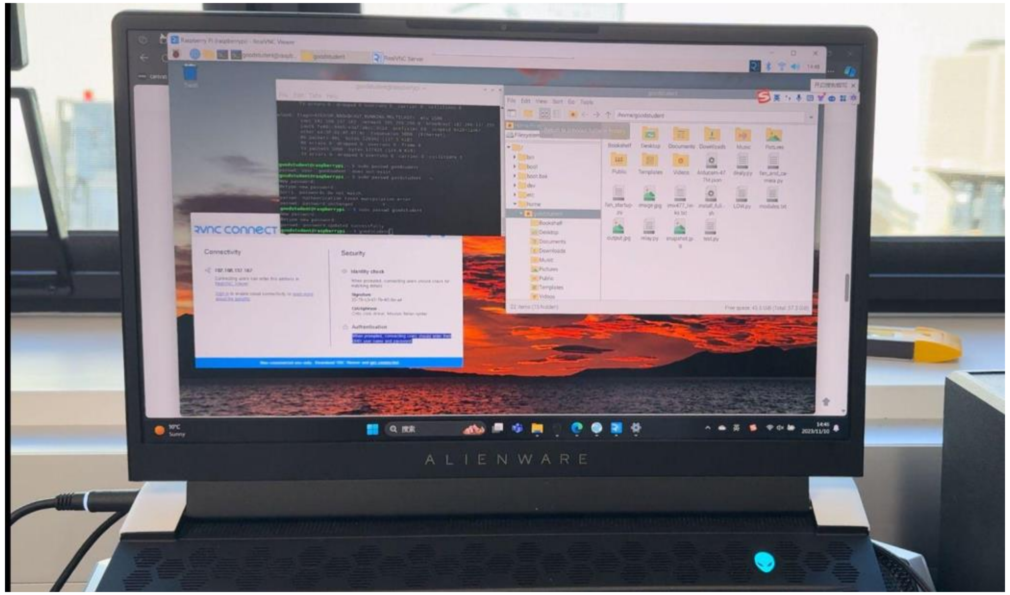


Figure 16:VNC Remote Control

3.Shooting Resolution Test Results

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

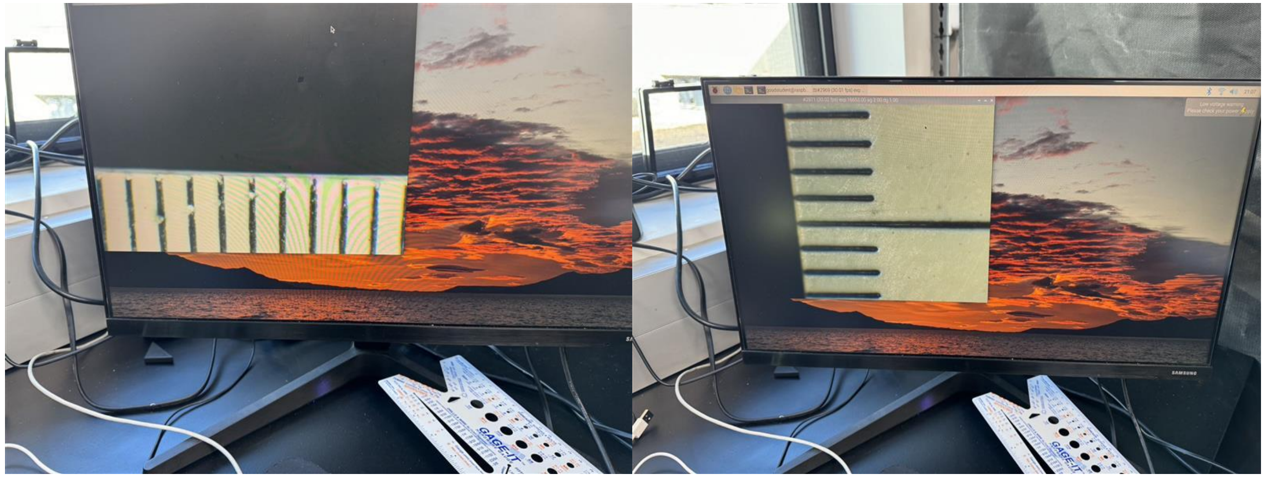


Figure 17 & 18:Shooting area in length and height

4. Capture Speed Test Results

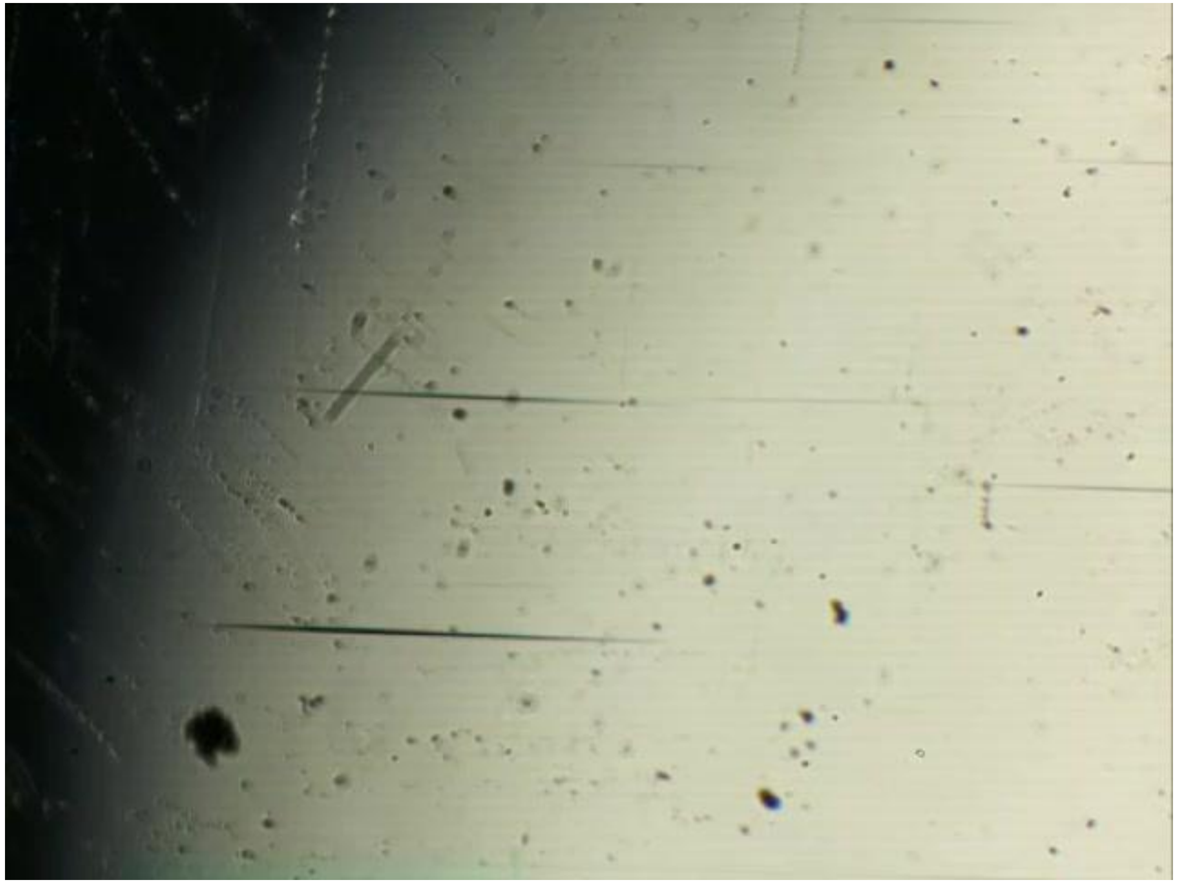


Figure 19: Resolution: 640x480 30fps

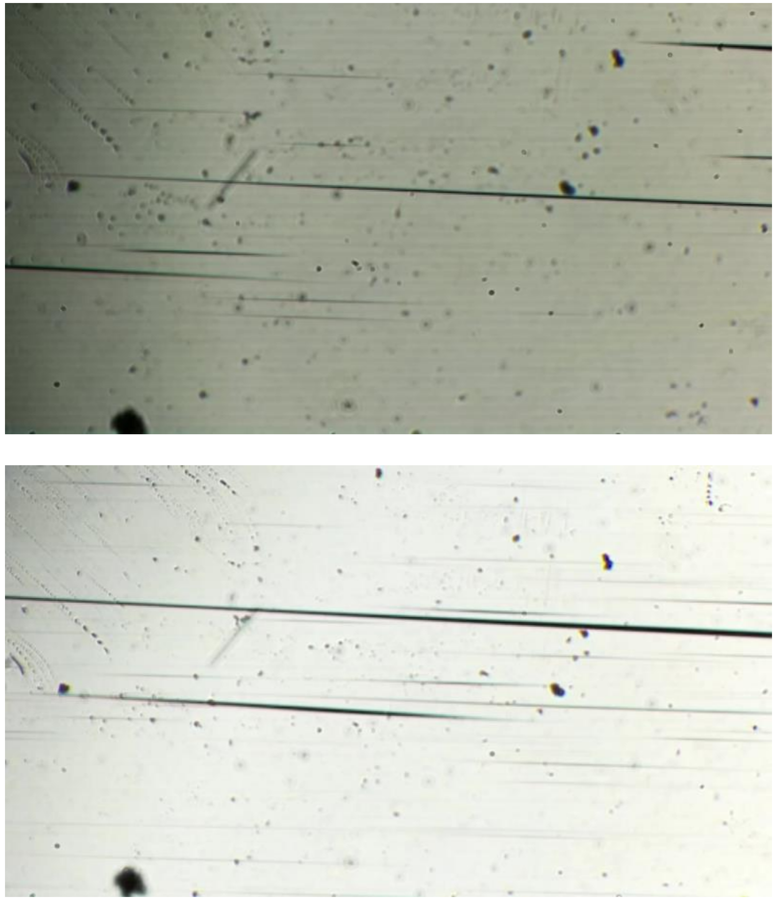
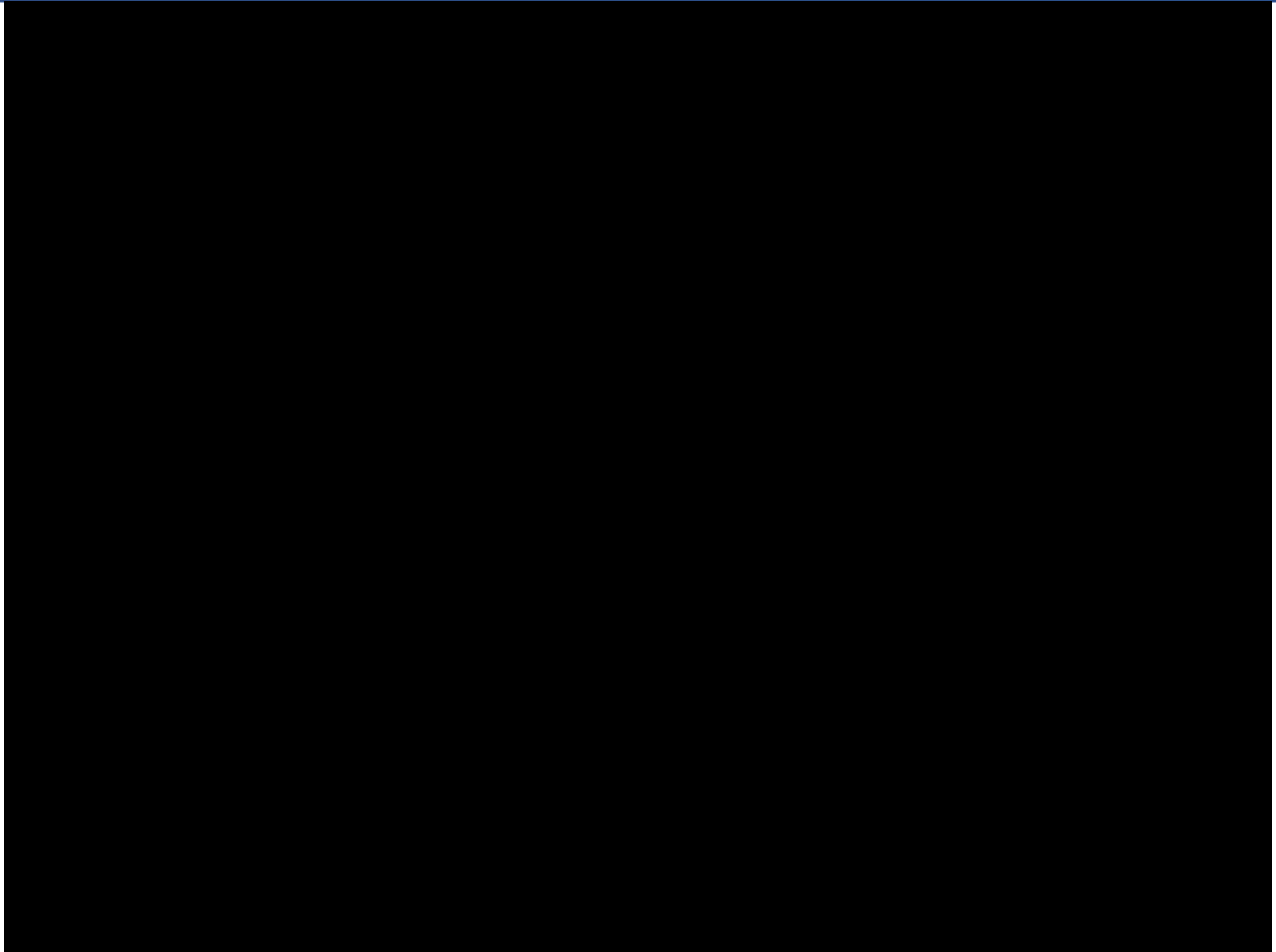


Figure 20: Resolution: 1920x1080 24fps

4. Capture Speed Demonstration



5. Duration Test

$$Cross\ section\ A = 0.002m * 0.0254m * 0.0254m = 0.0000508m^2$$

$$F = m * g = 2716.17g * \frac{9.81m}{s^2} = 25.6N$$

$$\sigma = \frac{F}{A} = 50.3kPa$$

$$\sigma_{all} = 65Mpa$$

$$f_s = \frac{\sigma_{all}}{\sigma} = 129$$

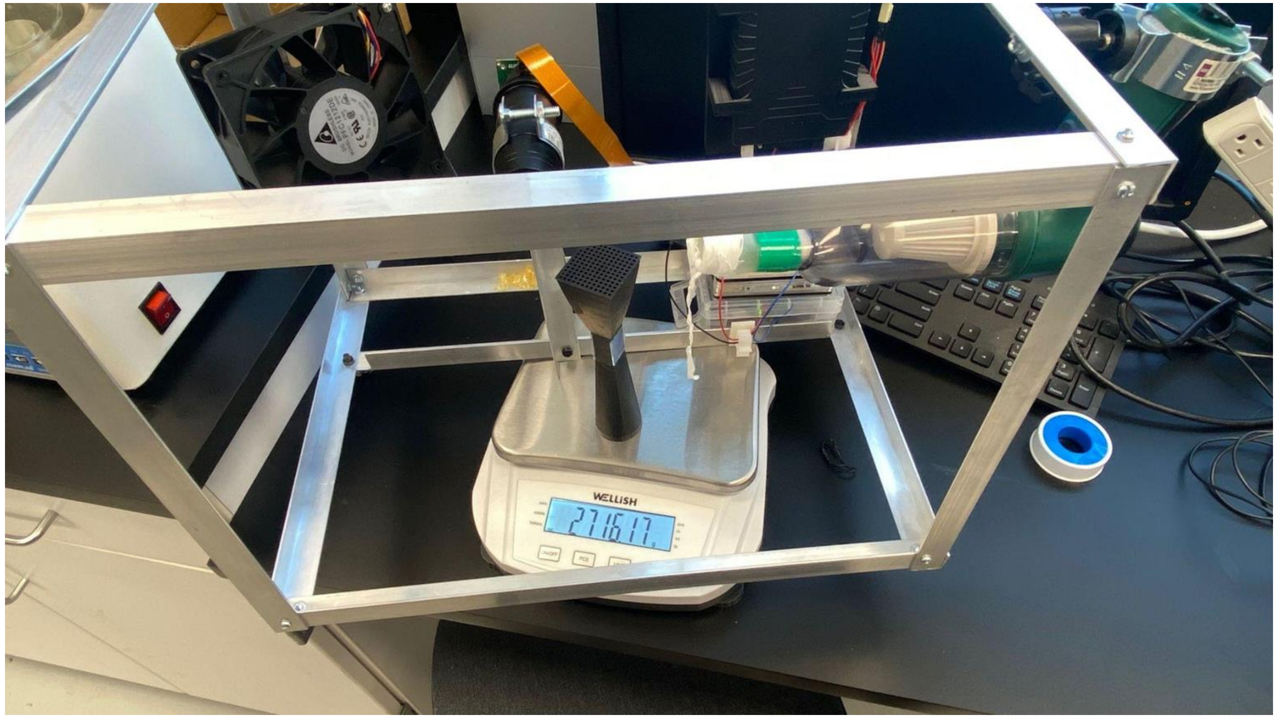


Figure 21 : Prototype Weight

Testing Result

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	<65 Mpa	5%	0.503 Mpa	Yes	Yes
ER7-Increase working duration	0.5 h	10%	0.75h	Yes	Yes

Table 7 : ER summary table

Testing Result

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 8 : CR summary table

Purchasing Plan

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
2	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
3	Camera	1	12.3PM	Shoot and record dust	N/A	2.5in	29.99	https://www.amazon.com/Arducam-Autofocus-Raspbe	Assembled
4	Battery	1	11.1V/6Ah (66.6Wh)	Power supply to the control system	Lithium Ion	28mm*85mm*145mm	N/A	N/A	Assembled
5	Raspberry Pi 4B	1	N/A	Control the camera and fan	N/A	N/A	N/A	N/A	Assembled
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	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
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
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
10	Nut	10	N/A	Fix components with mount	Zinc	1/4in	1.1	Homedepo	Assembled
11	Screw	10	N/A	Fix components with mount	Zinc	1/4in*1/2in	1.38	Homedepo	Assembled
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
13	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
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

Table 9: Bill of Materials

NORTHERN ARIZONA UNIVERSITY

Purchasing Plan

Total Spent	293.37	Total Parts Needed	14
		Total Parts Received	14
		Parts Required (%)	100%
		Assembled (%)	100%

Table 10 : Bill of Materials

Future Work / LED Test

Objective:

To get 2 microsecond pulses of light to help the camera freeze the target within two pixels.

Procedure:

Use an oscilloscope to test pulse wavelength.

Result:

Minimum pulse width: 20 µs.

Figure 21: Pulse width Test

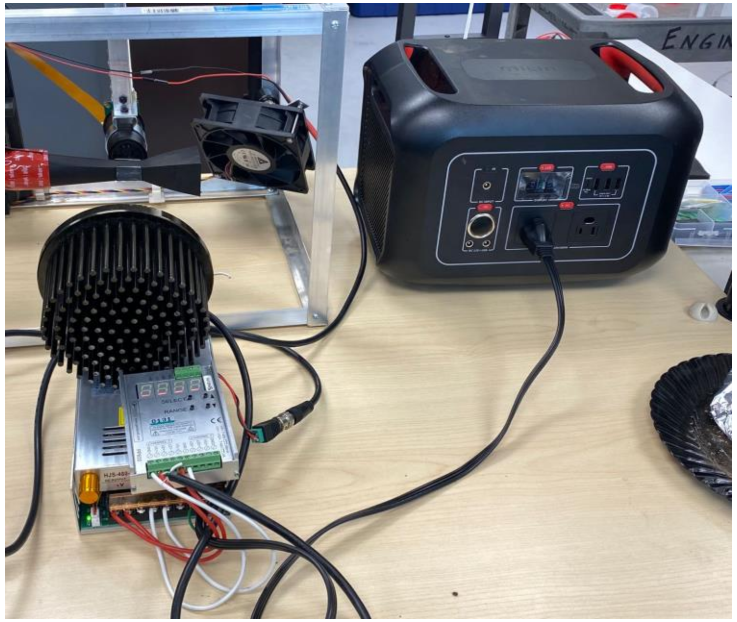


Figure 22: LED light back

Figure 23: LED light front

Future Plan

- Change the material for the frame
- Change to a new lighting controller with shorter pulse
- Achieve synchronization of LED light and the camera

Conclusion

- The device can actively collect soil dust as well as photograph the trajectory of particles.
- Generally meets all customer requirements.
- Future work will focus on improving the ability to freeze particle images

Reference

[1] Tong, Gill, T. E., Sprigg, W. A., Van Pelt, R. S., Baklanov, A. A., Barker, B. M., Bell, J. E., Castillo, J., Gassó, S., Gaston, C. J., Griffin, D. W., Huneeus, N., Kahn, R. A., Kuciauskas, A. P., Ladino, L. A., Li, J., Mayol-Bracero, O. L., McCotter, O. Z., Méndez-Lázaro, P. A., & Mudu, P. (2023). Health and Safety Effects of Airborne Soil Dust in the Americas and Beyond. Reviews of Geophysics., 61(2). https://doi.org/10.1029/2021RG000763

[2] 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.

[3] VERREAULT, MOINEAU, S., & DUCHAINE, C. (2008). Methods for Sampling of Airborne Viruses. Microbiology and Molecular Biology Reviews, 72(3), 413–444. https://doi.org/10.1128/MMBR.00002-08

[4] E. Kalisa, V. Kuuire, and M. Adams, "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, pp. 1120–1131, 2022, doi: https://doi.org/10.1039/d2ea00078d.

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

Thanks!

Questions?

NAU NORTHERN ARIZONA UNIVERSITY