Design Demonstration and Test Results

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Customer Requirements

- CR1 - Easy to carry
- CR2 - Easy to operate
- CR3 - Capture images with high resolution
- CR4 - Overall durability
- CR5 - Overall stability
- CR6 - Quick dust collection
- CR7 - Can be used in different environments

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

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 - Weight Test	1.Whole device	ER1, CR1 i

Table 1: Testing Plan

1.Flow Rate and Speed Test

Objective:

Optimizing the central channel's flow rate and making adjustments like fan speed is key to capturing fine dust particles effectively, improving data accuracy for Valley Fever research.

Procedure:

- Measure and calculate the cross-sectional area 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.
- Calculate the flow speed with channel.

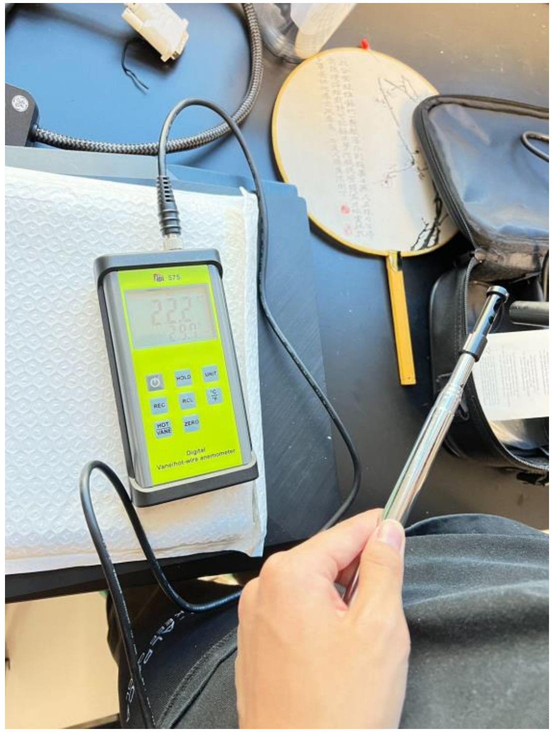

Figure 1: Test Flow Speed with Hot Wire

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:

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

$$A_0 = 0.00004128m^2$$

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

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

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.

Procedure

- Circuit Connection
- Power and Video Output Activation
- Program Monitoring
- Camera Check
- Fan Speed Verification

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%.

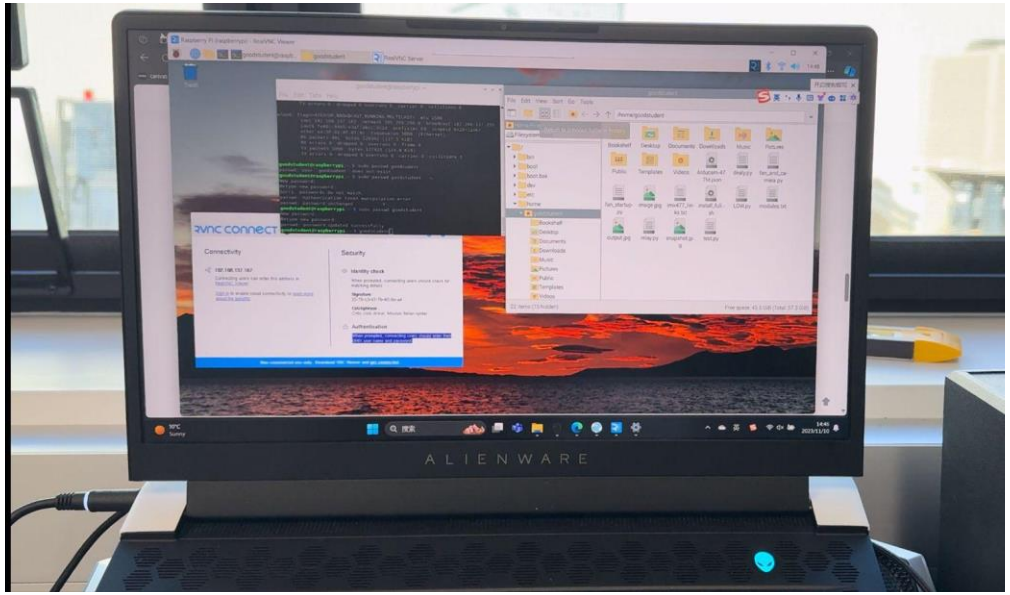

Figure 2:VNC Remote Control

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.

Procedure

- Camera and Raspberry Pi Connection
- Camera Preview Setup
- Focus on Shooting Area
- Sensor Parameters and Resolution Calculation
- Dust Particle Size Comparison

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

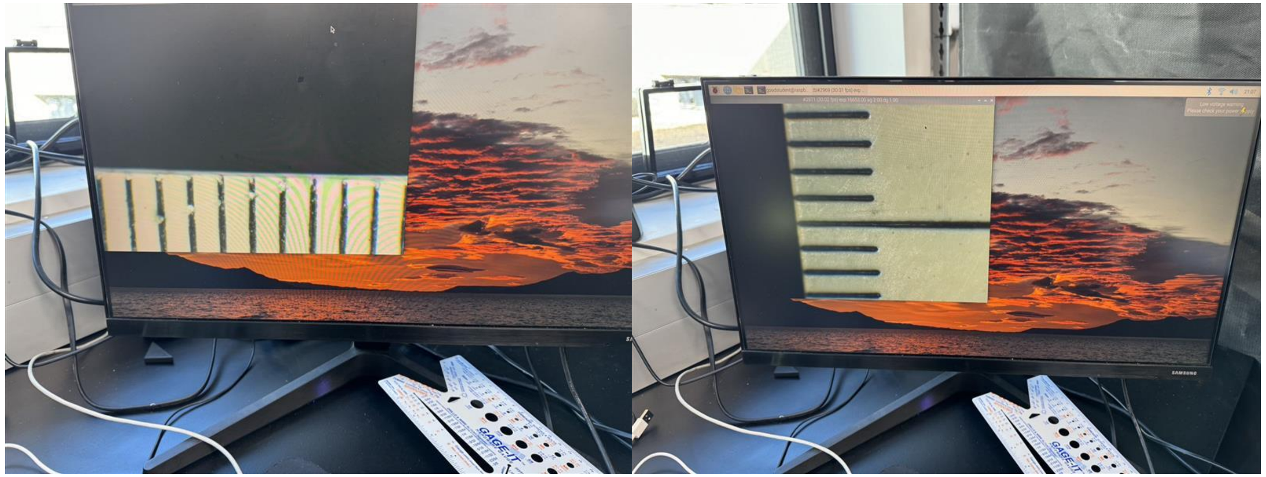

Figure 3 & 4:Shooting area in length and height

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

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

4.Capture Speed Test Results

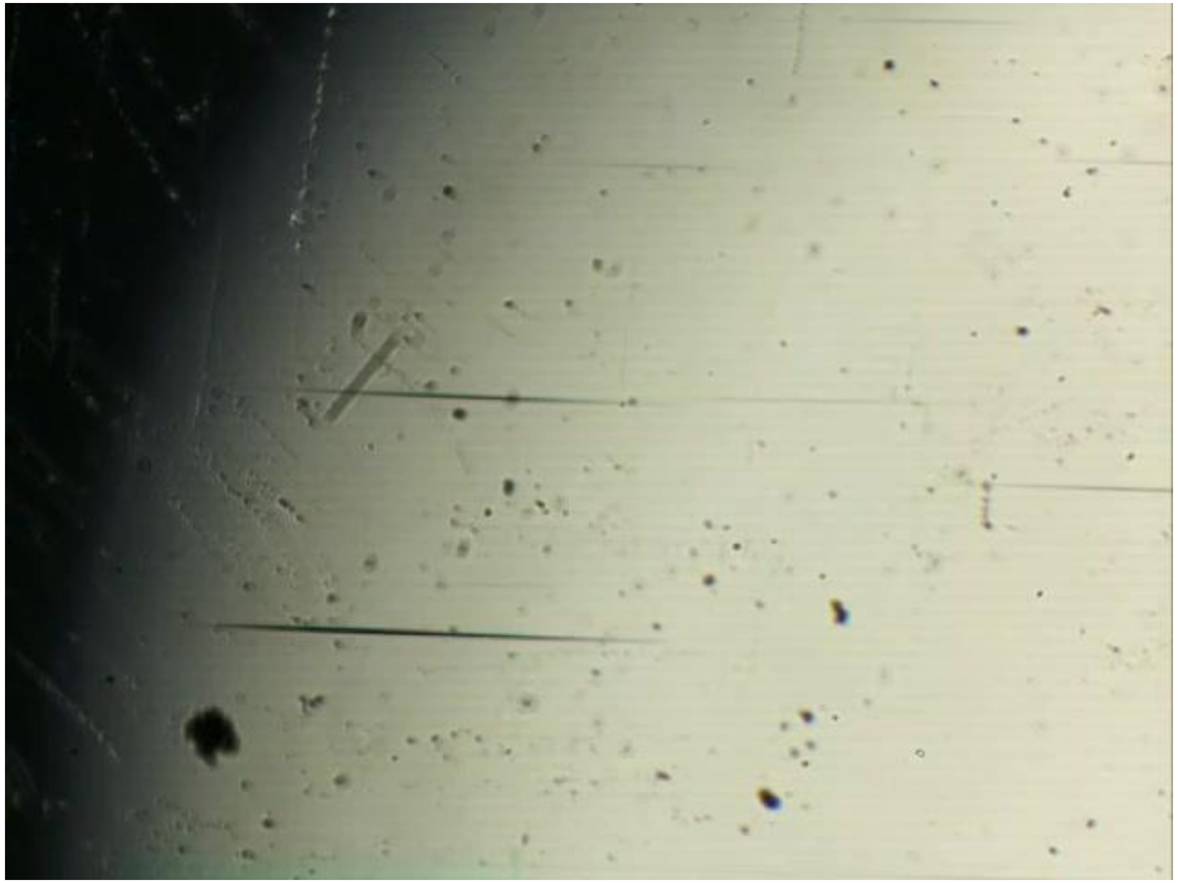

Figure 5: Resolution: 640x480 30fps

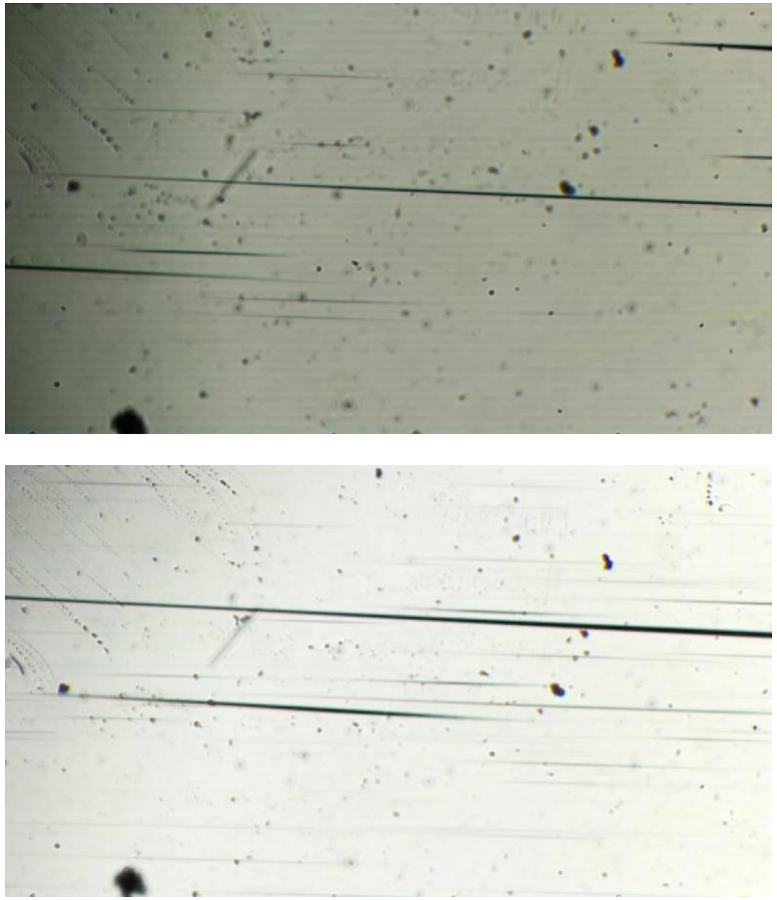

Figure 6: Resolution: 1920x1080 24fps

5. Weight Test

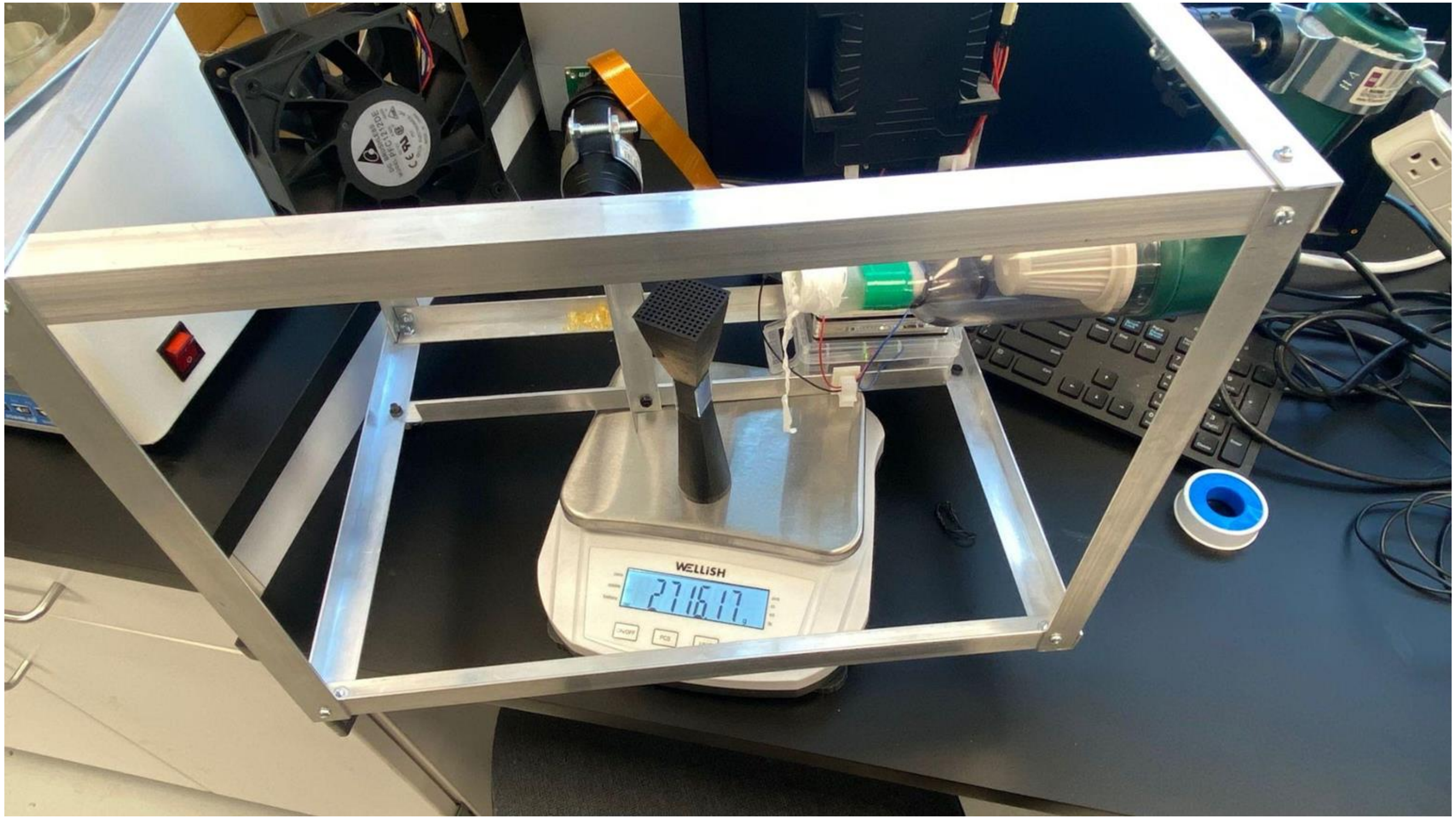

Figure 7 : Prototype Weight

Length: 16in
Width: 12in
Height: 12in

5. Weight Test

$$A = 4 * \frac{4^2}{3}\ in^2 = 7.11in^2 = 0.00459m^2$$

$$F = \frac{m * g}{2} = \frac{2716.17g * 9.81m/s^2}{2} = 133.2N$$

$$\sigma = \frac{F}{A} = 29.0kPa$$

$$\sigma_{all} = 95Mpa$$

$$f_s = \frac{\sigma_{all}}{\sigma} = 3276$$

Figure 8 : Calculation Process on Tensile Strength

6. Field Test

Figure 9: Field Test

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	29.0 kPa	5%	95 Mpa	Yes	Yes
ER7-Increase working duration	0.5 h	10%	0.75h	Yes	Yes

Table 2 : 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 3 : CR summary table

Future Work / LED Test

Speed : 8.67 m/s

Resolution 1: 1920*1080

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

Exposure time:

2*0.000521cm / (867 cm/s) = 0.0000012 s = 1.2 us

Resolution 1: 640*480

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

Exposure time:

2*0.00156cm / (867 cm/s) = 0.0000036 s = 3.6 us

Future Work / LED Test

Objective:

Get the minimum pulse width of the PP 600 LED light controller to determine if it can help the camera freeze the target within two pixels.

Figure 10: Pulse width Test

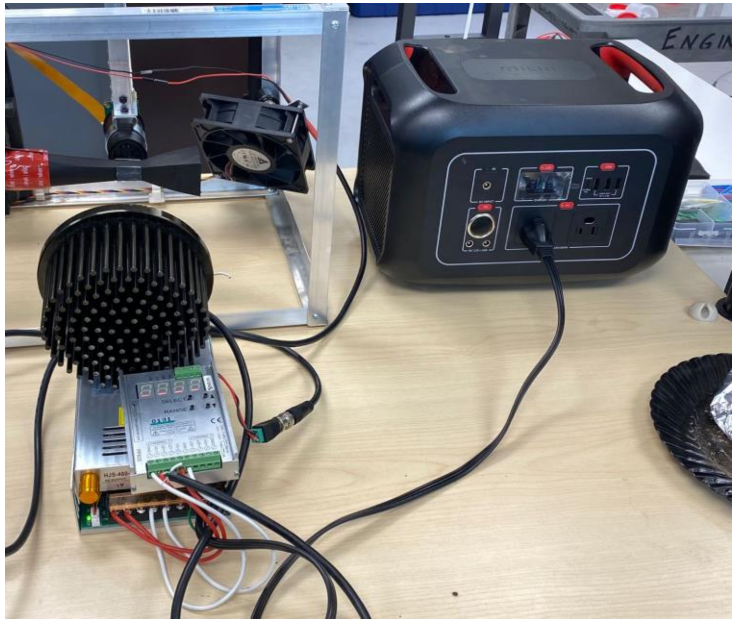

Figure 11: LED light back

Procedure:

Use an oscilloscope to test pulse wavelength.

Figure 12: LED light front

Result:

Minimum pulse width: 20 µs.

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
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	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						
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 4: QFD Table

Thanks!

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