Engineering Design and Innovation - Final Report (Spring 2022)

Clean it– Disinfects Surfaces!

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Project Objective:

A way to address transmission of diseases in hospitals, and other public places so that there is a 99.999% decrease in overall pathogen count hence leading to a low risk for contagion.

Project Significance:

Most surfaces have particles deeply embedded in them because no surface is completely smooth and contains crevasses. Hence the ridges stop particles. Also, the particles may be stuck due to inter-molecular forces. It could also be a biofilm, which don't easily be removed. Hence no amount of cleaning or scrubbing would be able to remove these particles. Our device uses resonance which dislodges particles that can then be removed with vacuum features.[4]

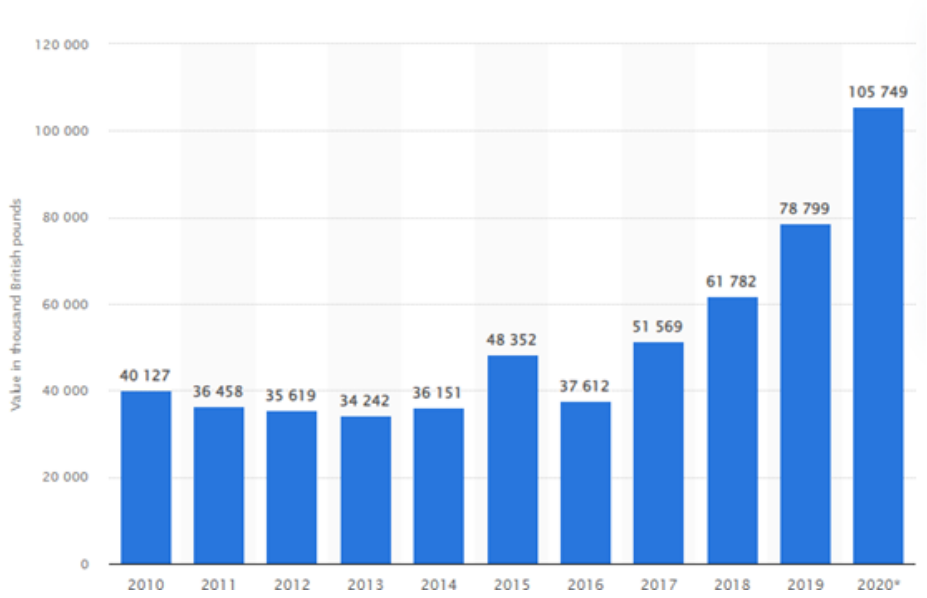


Figure: shows the sales of disinfectant based quaternary ammonium salts in the United Kingdom between 2010 and 2020.

The above graph shows an increase in demand for disinfectants. The requirement has doubled from the initial demand in 2018. The requirement is still rising as people have been educated about the potential risk and it has become a requirement of crowded spaces to be disinfectant regularly.

Chemical disinfectants cause a lot of pollution in the manufacturing process. Alcohols damage equipment, bleach Ruber, it dissolves glue, it evaporates rapidly, making extended exposure time difficult to achieve unless the items are immersed. Elevated levels of glutaraldehyde vapor when equipment is processed in poorly ventilated rooms or spills occur, Acute or chronic exposure can result in skin irritation or dermatitis, mucous membrane irritation (eye, nose, mouth), or pulmonary symptoms. Allergic reactions have also been reported. All these conditions show the environmental impact of disinfectants.

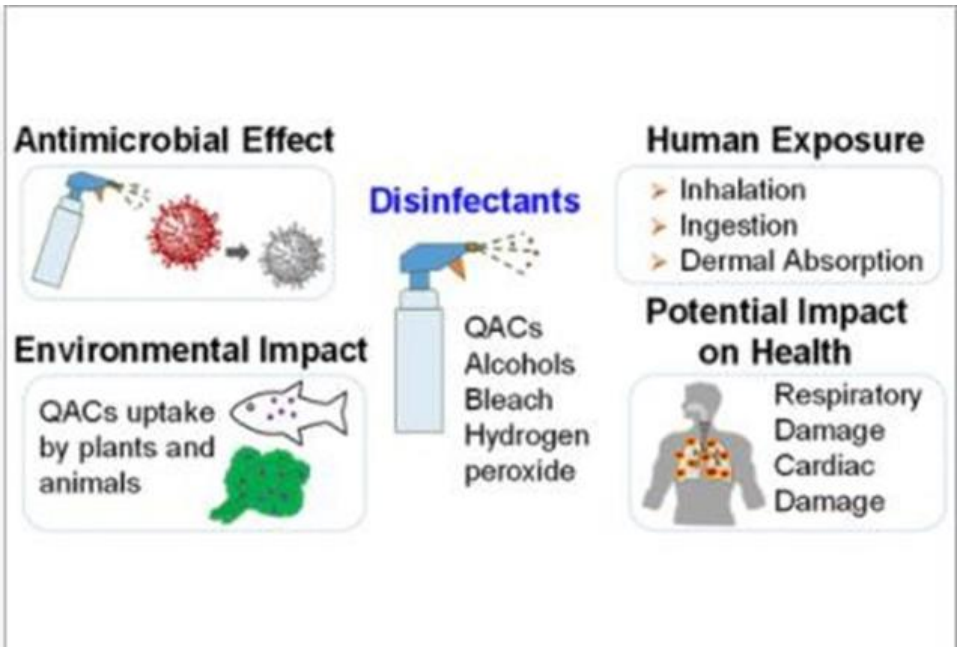


Figure: Problems associated with chemical disinfectants.

Chemical disinfectants also have to be used for certain quantities. According to CDC, Pseudomonas aeruginosa was killed in 10 seconds by all concentrations of ethanol from 30% to 100% [1]. This shows that we require a certain quantity which not everyone can figure out. Requiring a simple to use solution.

Chemical disinfectants also are not effective against all pathogens, some also gain resistance. Resistance to antimicrobial agents occurs through either intrinsic or acquired resistance mechanisms. Acquired resistance occurs through the efficient transfer of mobile genetic elements, which can carry single, or multiple resistance determinants. An accumulation of drug resistance genes through these mechanisms gives rise to multidrug resistant (MDR) bacteria.[5]

Our would be able to kill the pathogen and remove it. Using ultra sound and vacuum technology we will ensure that the problems discussed above are solved. Since we are targeting all citizens of Pakistan, we will be able to make sure every place would be disinfected properly. Hence helping the whole community to live a healthy and safe life.

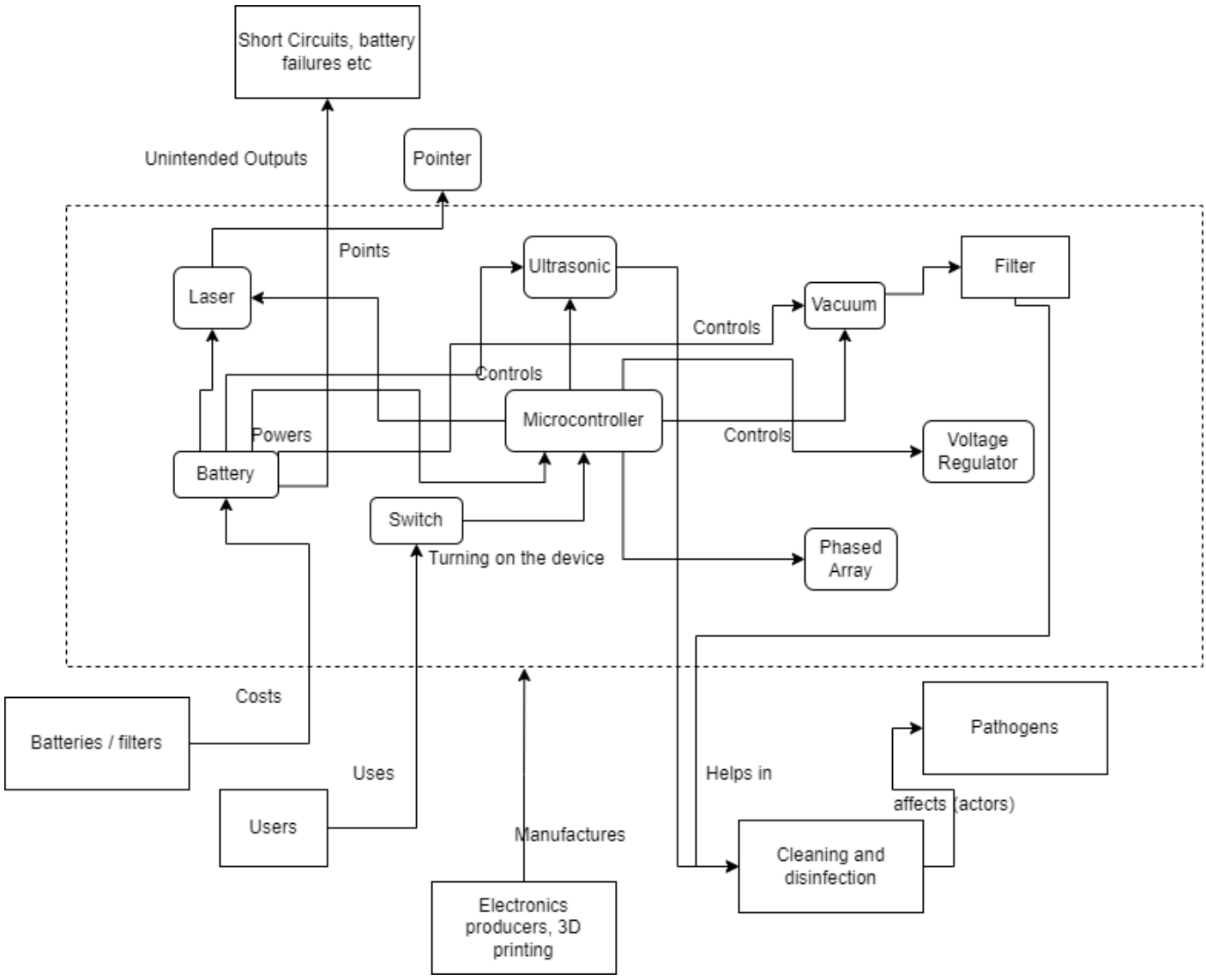
Functional Architecture:

Our design solution consists of the following 2 subsystems:

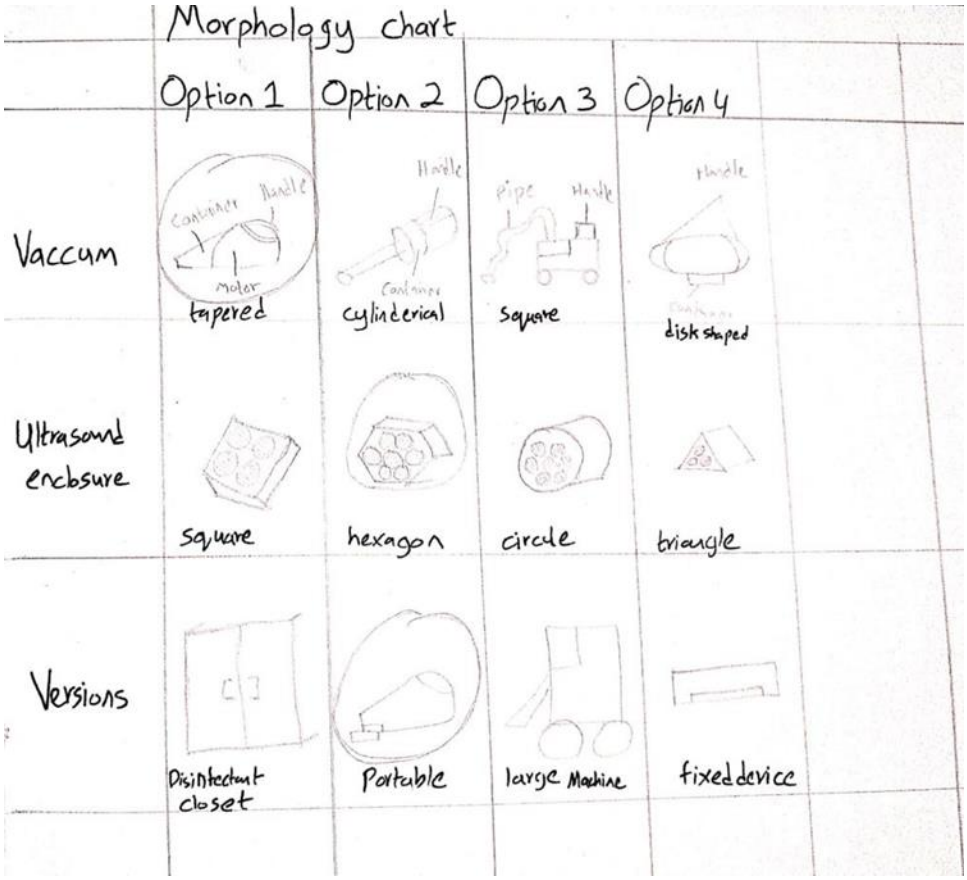
1. Vacuum
2. Ultrasound transducer

	System		
Operator	**Ultrasound**	**Vacuum**	**Other Actors**
The cleaning crew (operator) will switch on the device			
He/she would point to the place where they need to clean			
The light would guide them, as it scans through the surface.			
Keeping a normal pace the device will be moved across surface.			
The device will be ensured to be kept at a minimal distance from the surface			
	Ultra sound will kill all pathogens using resonance		
	Dust and particles will be lodged off		
		Will collect dust	
Device will be switch off			

Functional Overview:


Short Circuits, battery failures etc
Unintended Outputs
Pointer
Points
Laser
Ultrasonic
Filter
Vacuum
Controls
Controls
Microcontroller
Powers
Controls
Voltage Regulator
Battery
Switch
Turning on the device
Phased Array
Costs
Batteries / filters
Pathogens
Helps in
affects (actors)
Uses
Users
Manufactures
Cleaning and disinfection
Electronics producers, 3D printing

Morphological Chart:



Requirements:

- *Tapered end for fast air flow and better maneuverability within curve shaped furniture.*
- *Hexagon is shaped for better phased array performance. The beam formation and steering are optimized. Hence decreases the time for cleaning.*
- *Portability, all in one solution that can easily be moved around.*
- *Disinfectant closet was rejected as more stakeholder required cleaning devices that can be used in entire room.*

Frame Structural System:

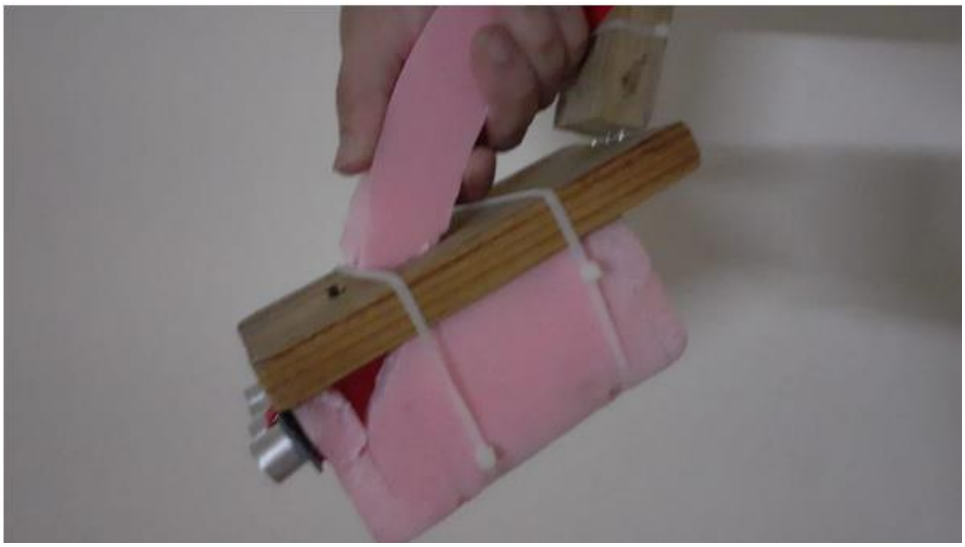


Fig: initial prototype for dimensional reference

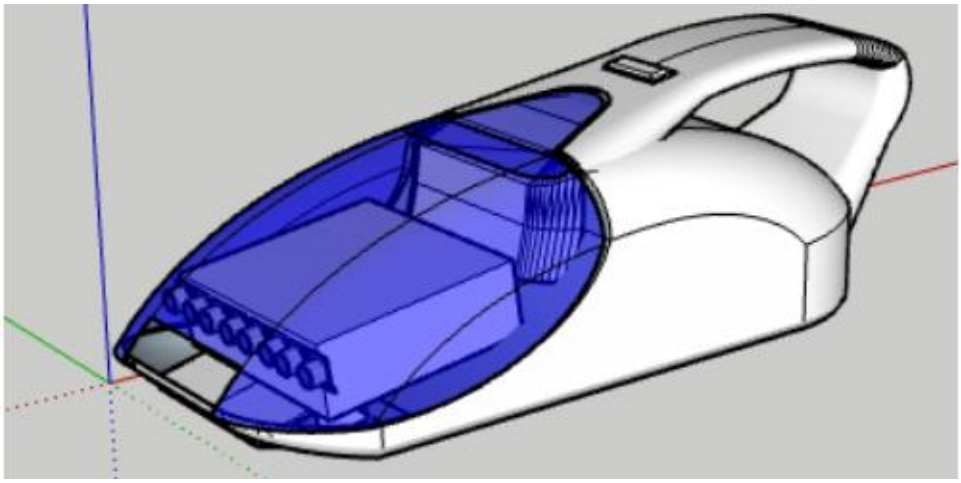


Fig: first 3D design

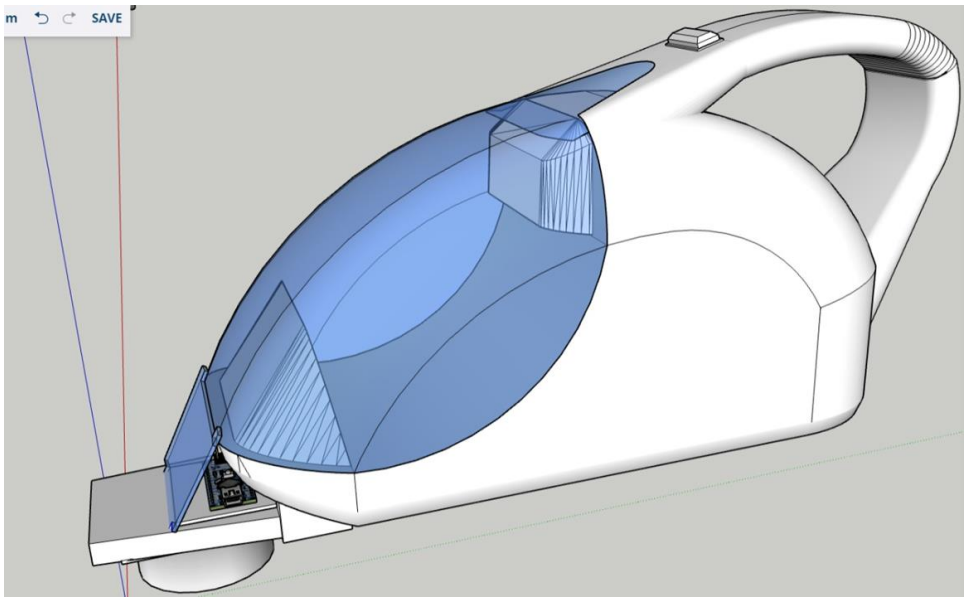


Fig: optimized design after stakeholder feedback

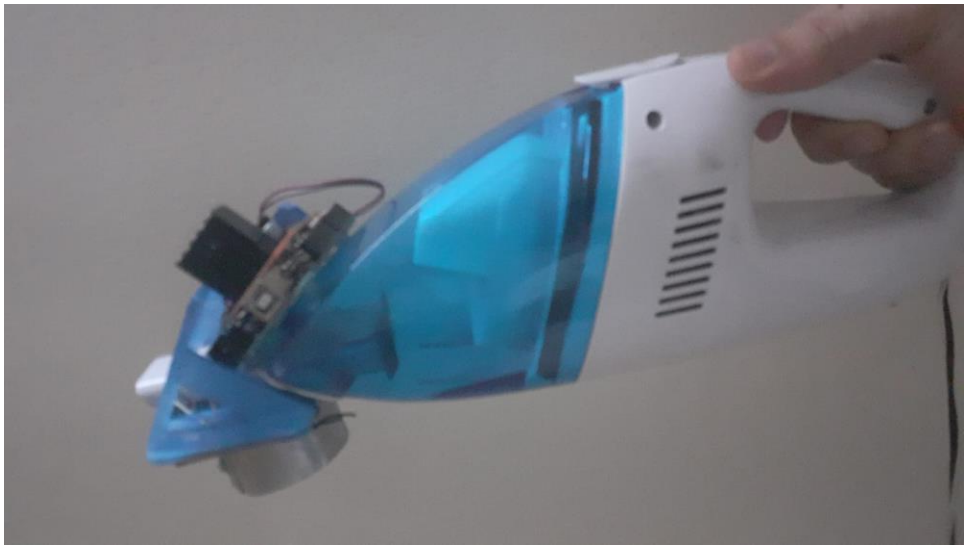
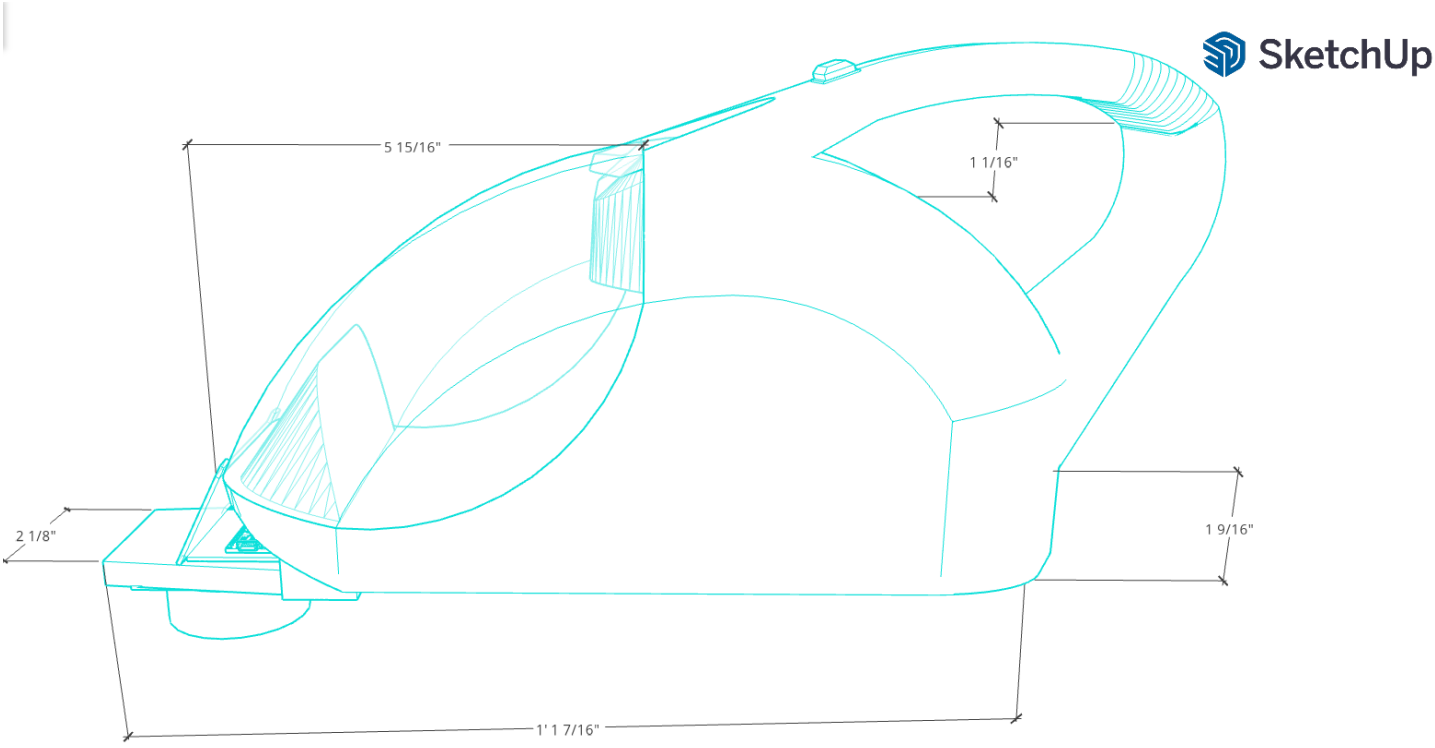


Fig: final working prototype

CAD Model



Goal and Ideal Metrics:

To perform biological tests with our device and ensure the reduction of pathogen population. This can be done in two ways. One by counting colonies on a petri dish, the number is quantified and compared with positive control to see the reduction. The other one is checking turbidity of the solution after inoculation and incubation. The turbidity test is done using an optical density meter.

Testing and Assessment of our Design:

<u>Validation:</u>

Testing with a receiver to get 40kHz

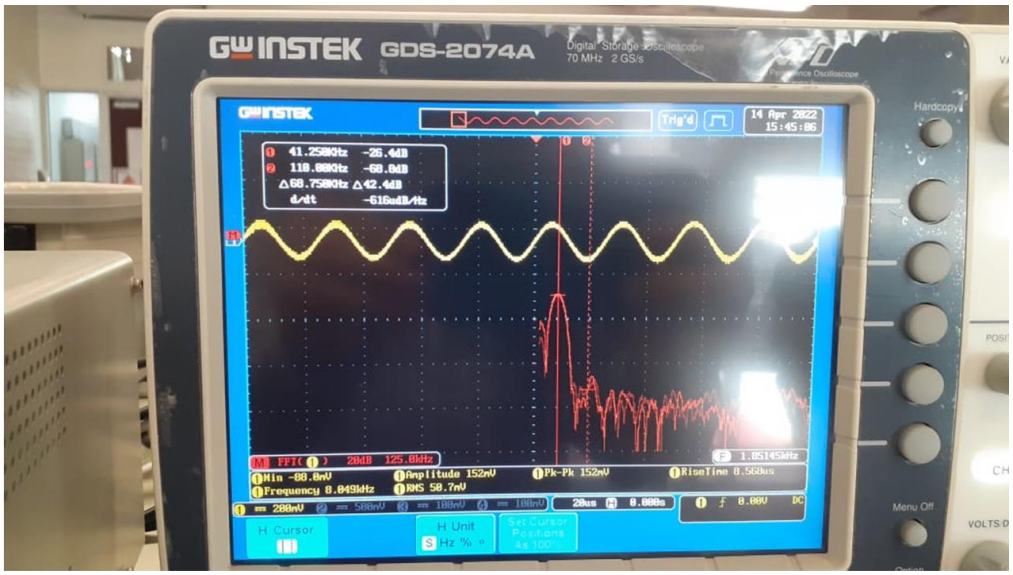


Fig: Hardware test

Matlab simulations:

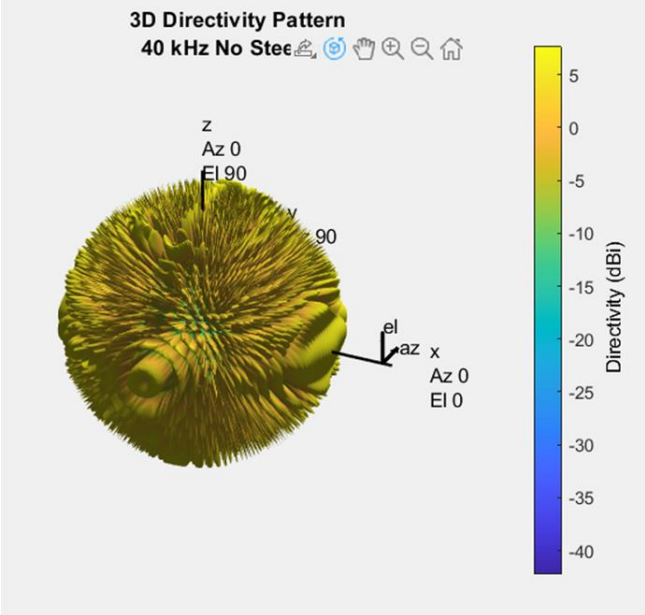


Fig: 3D Sound wave emission pattern

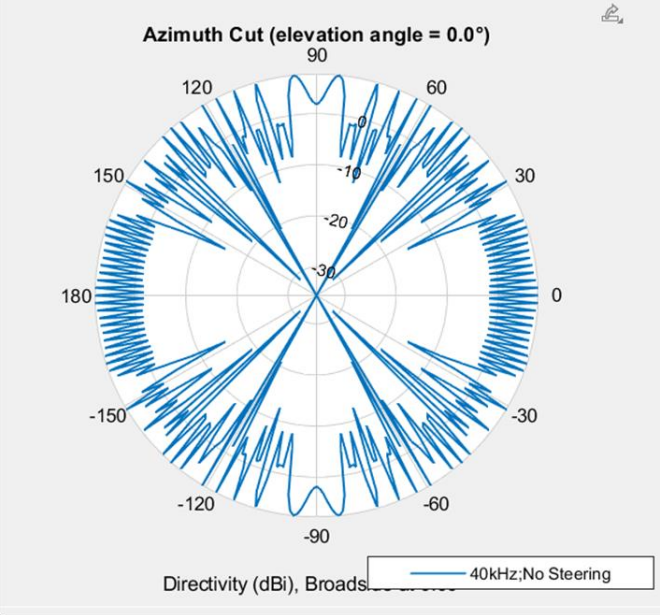


Fig: 2D Sound wave emission pattern

```
byte TP = 0b10101010; // Every other port receives the inverted signal
void setup() {
  DDRC = 0b11111111; // Set all analog ports to be outputs

  // Initialize Timer1
  noInterrupts(); // Disable interrupts

  TCCR1A = 0;
  TCCR1B = 0;
  TCNT1 = 0;
  OCR1A = 200; // Set compare register (16MHz / 200 = 80kHz square wave -> 40kHz full wave)

  TCCR1B |= (1 << WGM12); // CTC mode
  TCCR1B |= (1 << CS10); // Set prescaler to 1 ==> no prescaling
  TIMSK1 |= (1 << OCIE1A); // Enable compare timer interrupt

  interrupts(); // Enable interrupts
}
ISR(TIMER1_COMPA_vect) {
  PORTC = TP; // Send the value of TP to the outputs
  TP = ~TP; // Invert TP for the next run
}
void loop() {
  // Nothing left to do here :)
}
```

Code for ultrasound pulse at 40kHz

Test 1

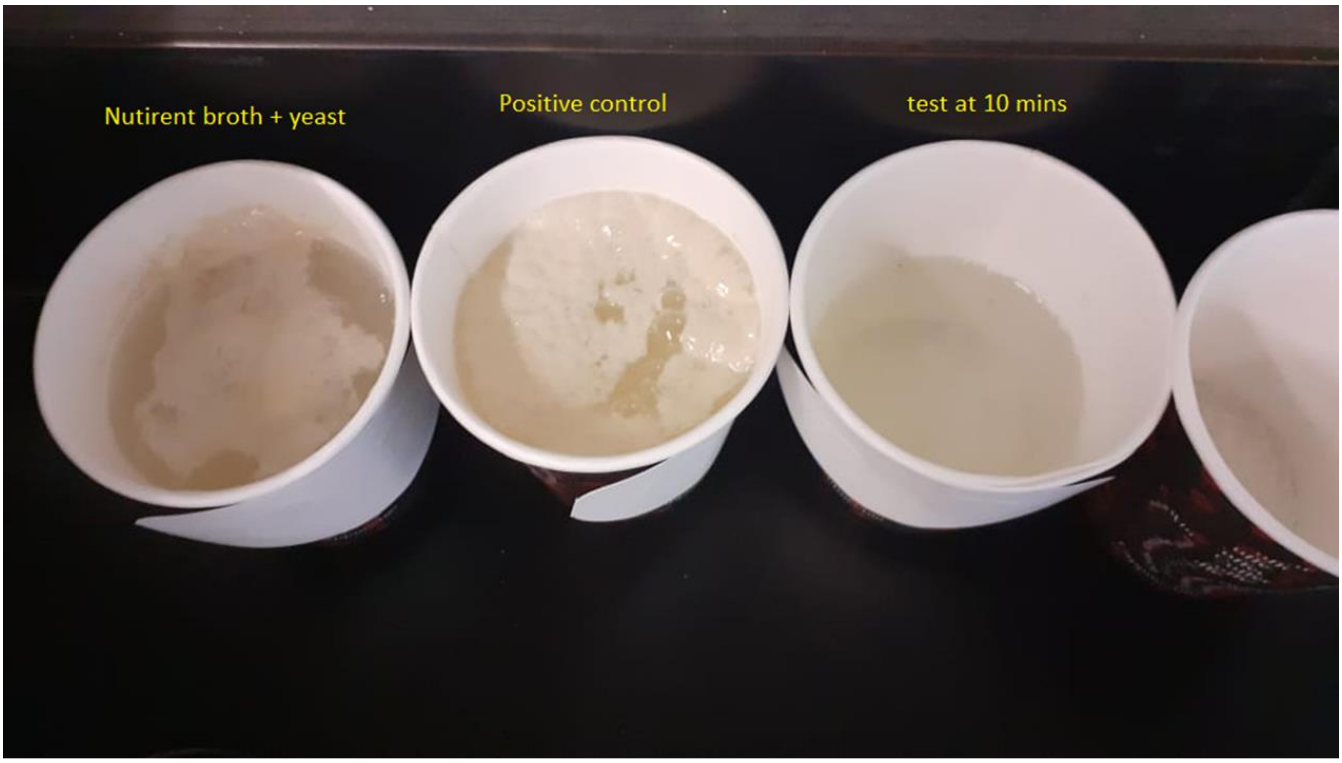


Fig: Visual Test

Test 2

Fig: ultr-sonic device to inoculate E.coli bacteria

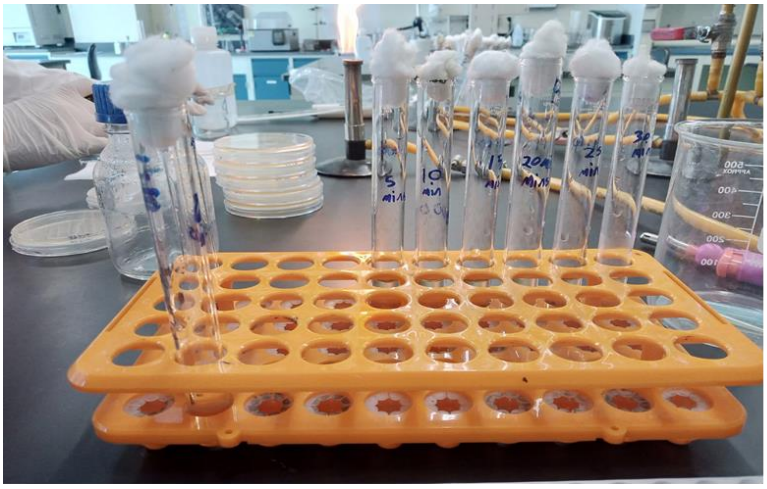
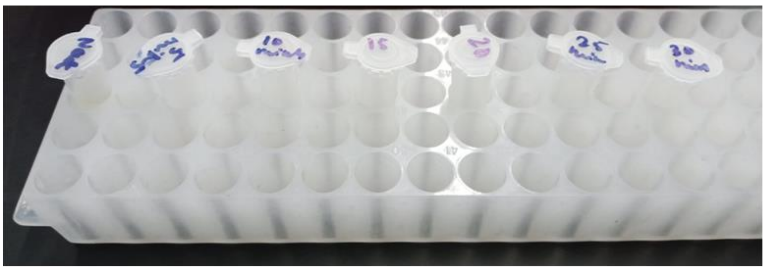


Fig: Test tube sample containing inoculated at different time



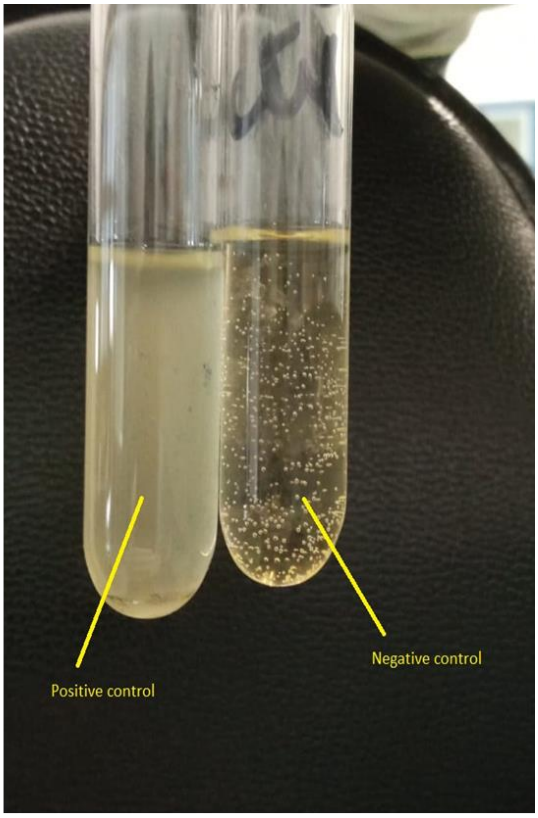
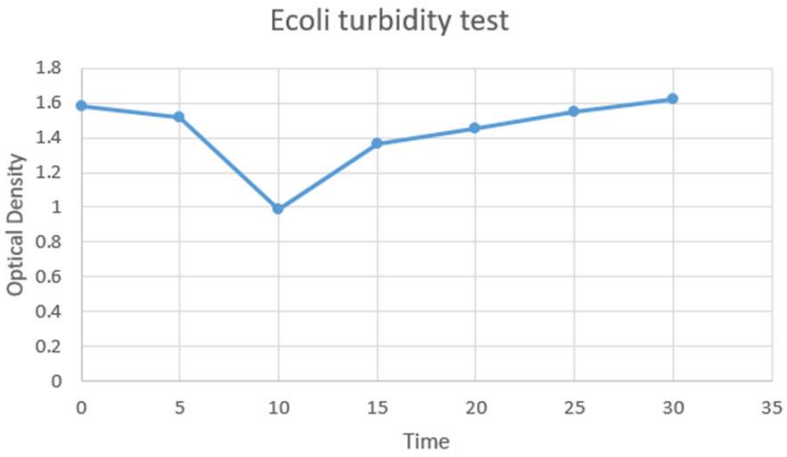


Fig: Control used for comparison

Optical density meter

Results:

Time (mins)	absorbance (OD)
0	1.58
5	1.52
10	0.986
15	1.364
20	1.45
25	1.55
30	1.62



Stakeholder's Interviews and Our Journey:

	Stakeholder name/Role	Designation	Power/ Interest Class	Primary Benefits	Primary Detriments	Net Impact (Neg/Pos)
1	Immunocompromised patients	Primary consumer (people being affected by the use)	1	Reduced chances of getting contagious diseases	Purchasing Cost. A minor load to carry along.	Positive
2	Admin Established Places (e.g., educational institutes, offices, shelter homes etc.)	The authorities that are responsible for managing the crowd areas with the involvement of the public.	3	This stakeholder will have decreased the number of absences as less people will get infected by contagious diseases.	Purchasing Cost. A minor load to carry along.	Somewhat Positive

3	Disinfectant and Cleaning Companies	Competitor producers of cleaning / disinfecting agents	5	A new method/concept/way to address the problem to bring in new products in order to compete.	Decrease in sales, as people will buy our portable self-cleaning device	Mostly Negative
4	Family members	Relatives of the affected primary consumers	2	Reducing the anguish experienced by families whose loved ones might get affected by a contagious disease.	None as such.	Positive
5	Public Places (e.g., Train stations, Airports, public parks, malls, cinemas etc.)	The places where chances of getting a contagious disease and involvement of public is higher than average.	2	Cleaned and Healthy areas, providing safer public environment to the public	None	Mostly Positive

6	Cleaning Staff	Users of the proposed solution to prevent the contagious disease from spreading	1	Reduce the chances of spreading diseases through the touch, as our concept/device eliminates the necessity of touching to disinfect.	A minor load to carry while cleaning	Mostly Positive
7	Hospitals	Hospitals cater to the immunocompromised patients who get infected due to contagious diseases.	2	Less consumption of medical resources used to treat immunocompromised patients.	Less Revenue	Somewhat Negative
8	Research Institutions	The institutions involved in exploring the areas of cleaning through multiple ways using the concept of ultrasonic cleaning.	4	A testing ground for further research in automating the process using this concept of disinfection and much more.	None	Mostly Positive

Interview word art

Features

Priority	Must – Have Features	Nice – To – Have Features
1	Disinfection	Portable
2	Affordable	Time Optimization
3	Efficient	Rechargeable
4	Adaptable	Battery Life
5	User Friendly	Low-Noise
6	Environment Friendly	Concept Product Implementation
7	Safety	Recyclable
8	Maintainable	Guiding Laser

Feature Description:

- **Disinfection:** Minimizing the risk of getting infected by disinfecting diverse surfaces using the concept of ultrasonic cleaning and phased array. This is one of the main key features of our product which is evaluated by stakeholders as it is their primary requirement in it.
- **Time Optimization:** Save time by cleaning/disinfecting the hard-to-kill pathogens/diseases instantly.
- **Portable:** Easy to carry while moving in order to clean, or locomote.
- **Guiding Laser:** A laser to path to show the areas being cleaned/disinfected. This feature has become a key feature as it is proposed by the utilizers in order to guide them while cleaning the area.
- **Recyclable:** The material of the product will be recyclable.
- **Affordable:** The price of the product will be as per the targeted audience estimated affordability.
- **Efficient:** The proposed concept/solution will be efficient enough to address the problem.
- **Adaptable:** The proposed idea/concept is adaptable to the requirement of the consumer.
- **User Friendly:** The proposed idea/solution is easy to use, keeping in mind the background of the user.
- **Safety:** The product ensures the safety of consumers and surroundings
- **Repairable:** The product is easily repairable in case any kind of concern occurs in it.
- **Concept Product Implementation:** The proposed prototype will be a practical application of the concept under research which can be utilized as a platform for further research
- **Low-Noise:** The noise of the device won't be too high I.e., discomforting the users and environment.
- **Battery Life:** Battery life of the device will be sufficient enough as per the requirements of the consumer in the case of rechargeable batteries.
- **Rechargeable:** The device will also be available in a rechargeable variant, depending upon the needs of different consumers.

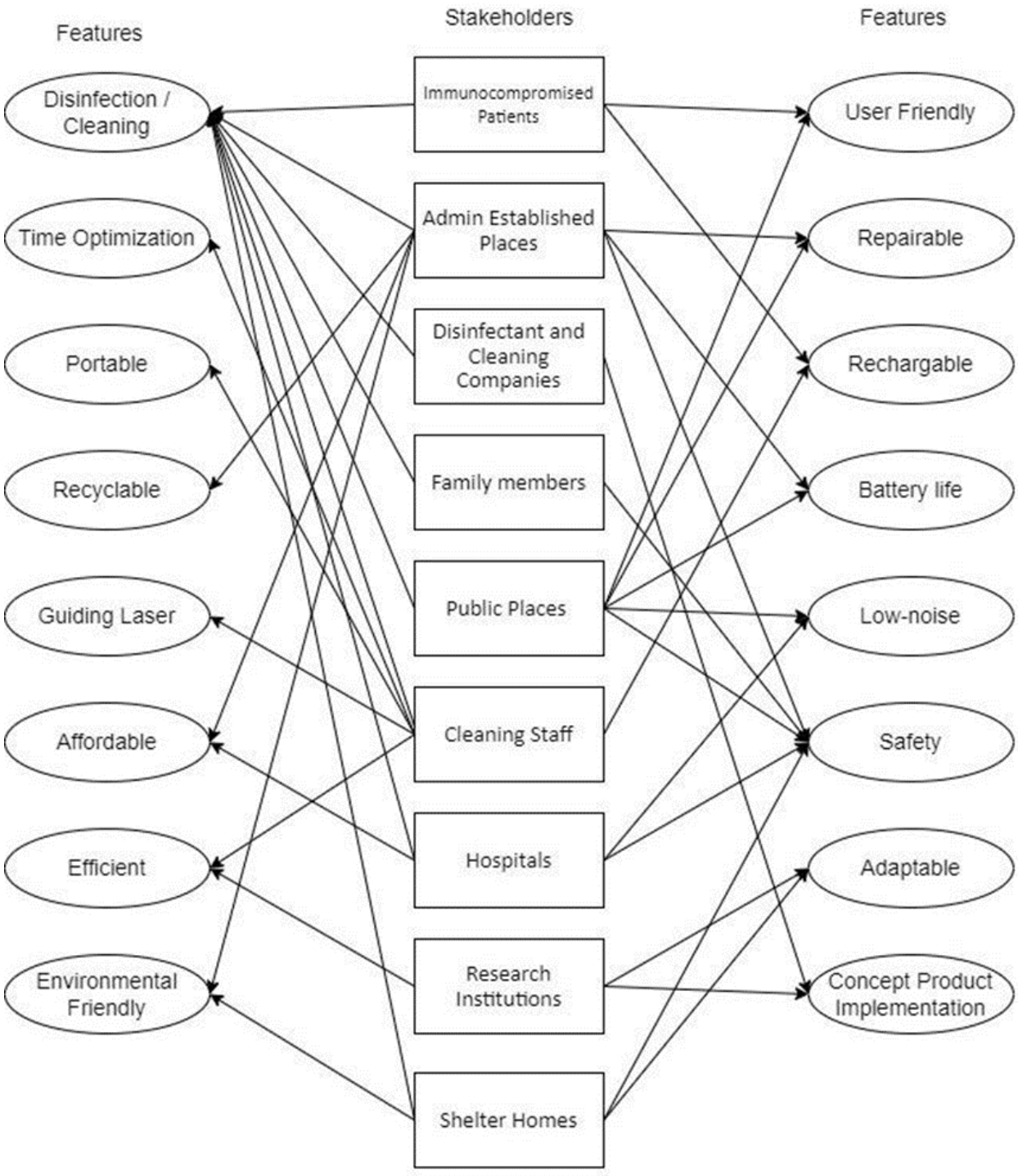


Figure: Stakeholder and the device features

Originating Requirements of Our System:

Table 1: Technical requirements for a Disinfecting and Cleaning Device.

Code	Requirement	Actors/Blocks	Inputs/Outputs	Function	Verified by
C-1	Wall Outlet shall provide power to the system. • Voltage should be 220V rms	Wall outlet system	Electrical Power input	Recharging the Battery	Instrument test
S-1	Breaking and connecting circuit • Short detected (DMM) (0 – 12 V)	Switch	System power control input	Controls device power on/off	Instrument test
A-1	Rigid body to enclose the system, environment friendly • Measurabl e tensile Strength (from Data sheet) (37 MPa)	3D printed plastic frame	PLA, Environment friendly, sufficient enough space to enclose entire system	Protection of system from surroundings, Isolation of system	Body Tests (we can try to deform it to check the strength), Datasheet
US-1	Able to generate a certain amount of frequency of sound • Measured through another ultrasonic sensor (receiver) (20k- 40kHz)	Ultrasonic Sensor	System Sound Output	Disinfection and killing the bacteria	Instrument test, datasheet

V-1	Able to generate sufficient amount of suction • Measured through datasheet	Vacuum	System Suction Output	Removes dust and cleans the surface along with bacteria	Instrument test, datasheet
	(0.15 MPa)				
L-1	Able to point in the direction of focused phased array movement • Visual test/ datasheet to check the viability of device (685 Lumens /watt)	Moving Laser	System Visualizing Output	Let the user know where the ultrasonic sensor is performing the disinfection at the moment by pointing the laser at that point	Instrument test, datasheet
B-1	Provide sufficient power to phased array, laser, and vacuum • Charging measured using DMM (24V)	Battery	System Power input	Powering the up the ultrasonic sensor, laser, and vacuum	Instrument test (Through DMM), datasheet

B-2	Provide sufficient space to hold the dust • 0.8 liters per device (limitation)	Vacuum bag	System storage output	Space to contain the collected dust by vacuum	Instrument test (filling up the bag by water and measuring that volume of the water)

Alternative solutions and existing solutions

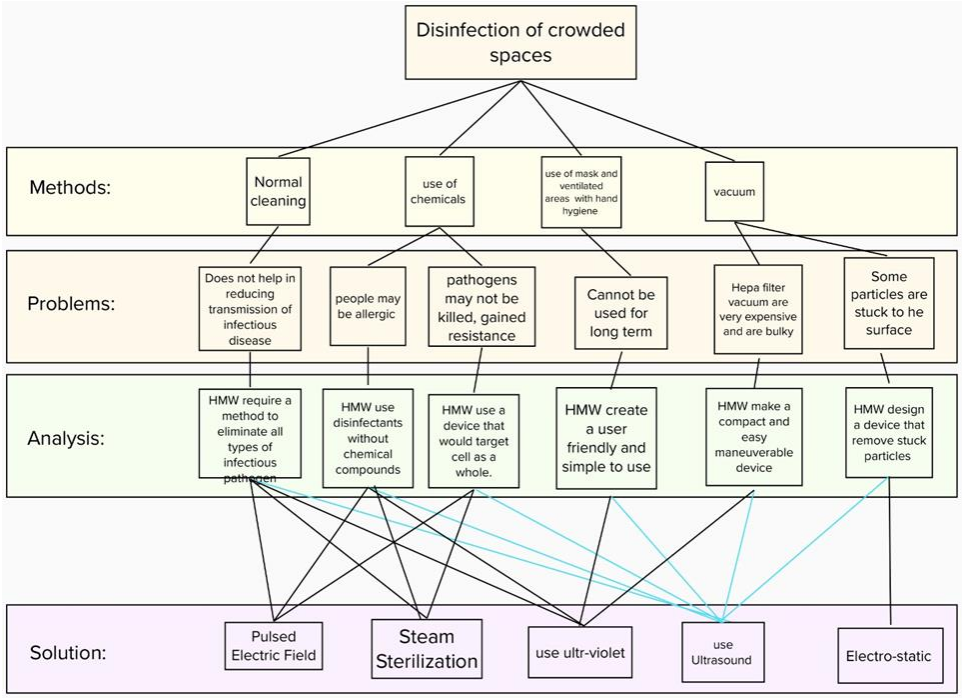


Figure: Decision process

Conclusion and Future Work:

Our main objective was to design an ecofriendly portable solution for cleaning and disinfection. We spent a large amount of time identifying and analyzing the problem. This helped us to find an optimized solution for our stakeholders. One of the major issues with disinfection is that many chemicals are used which damage everyday items and cause a lot of pollution. Our solution is not only environmentally safe but also pet safe. We were able to validate our prototype by testing each functionality separately to insure its workability. Then we did some tests in order to verify the quantification of our need statement. Right now, we have promising results that can scale up if we get more funding to develop a better prototype. It is envisioned that in the future, our phones may have the capabilities to produce ultrasound hence disinfection would automatically be taking place. Hence we have provided a frame work for further research in order to reach that level.

References:

1. "Chemical disinfectants," *Centers for Disease Control and Prevention*, 18-Sep-2016. [Online]. Available: https://cdc.gov/infectioncontrol/guidelines/disinfection/disinfection-methods/chemical.html. [Accessed: 09-Mar-2022].
2. G. Nabi, Y. Wang, Y. Hao, S. Khan, Y. Wu, and D. Li, "Massive use of disinfectants against COVID-19 poses potential risks to urban wildlife," *Environmental Research*, vol. 188, p. 109916, 2020.
3. M. Penn, "Statistics say large pandemics are more likely than we thought," *Duke Global Health Institute*. [Online]. Available: https://globalhealth.duke.edu/news/statistics-say-large-pandemics-are-more- likely-we-thought#:~:text=Based%20on%20the%20increasing%20rate,in%20the%20next%20few%20decade s%20Pendemic. [Accessed: 09-Mar-2022].
4. R. Kohli, "Electrostatic removal and manipulation of small particles and surface cleaning applications," *Developments in Surface Contamination and Cleaning: Applications of Cleaning Techniques*, pp. 391–421, 2019.
5. S. Mc Carlie, C. E. Boucher, and R. R. Bragg, "Molecular basis of bacterial disinfectant resistance," *Drug Resistance Updates*, vol. 48, p. 100672, 2020.

Appendix A:

Interviewer: Omer Rastgar

Interviewee: Ahmed Bilal

Date and Place of Interview: 12/04/2022 - Habib University

Questions and Responses:

1. What is your name and where do you live?,

My name Ahmed Bilal and I am from Karachi.

2. Do you require regular cleaning and disinfection?,

Yes, I actually need it very often in my animal shelter that I'm running at Malir cantt.

3. What are some of the problems that you face every day regarding cleaning?,

I often have problem trying to get the area around clean enough for pets to not to get infected and catch diseases because they get ill quickly. Also, I face problem while cleaning as cats run away when cleaning is happening

4. Would you rather have a device which actually make sures of cleaning and disinfection together?

For sure, I'd love to have such device. Do you have such solution for this problem which also ensures that animals don't get affected and run away from it?

5. Yes, we have made a solution using ultrasonic cleaning and vacuum to make sure of 100% infection free cleaning. Would you be willing to buy it?

Yes, certainly, I'd buy it even if it costs me 10,000 pkr.

7. Actually our device costs under 3k.

That's a lot better, I might actually get plenty of it and help you promote your device once I get used to of it.