Air quality monitoring using an AI-based device

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UNIVERSITY OF
BATH

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Contents

1. Summary

[*Briefly describe the goal of the project.*]

2.   Problem definition and background

2.1   Problem specification

[*This section should state the challenge, motivate why this challenge is important and explain how it relates to AI.*]

2.2   Literature review

[*This section should review the existing solutions for this challenge and critically analyse ethical issues related to them. It is maybe the case that there are no existing solutions for the chosen challenge. In this case this should be clearly stated and analysed why it is so. If applicable, existing solutions for related challenges may be reviewed here. For example, if your solution is based on solutions for other challenges you should review and critically analyse them in this section.*]

2.3   Proposed solution

[*This section should explain your ambitious solution and why it requires or why it benefits from the interdisciplinary approach. If the solution involves novel research the section should explain why you believe that this research is likely to be successful in the foreseeable future (see above).*]

3. Air quality monitoring device

[*Describe the engineering part of the project.*]

3.1 Hardware

3.1.1 Device

Design Specification

Table 3.1: Add caption

No.	Requirement	Wish/Deman (1 low, 5 high)	Importance	Engineering Specification
1	Sensors open to atmosphere	D		
2	Water Proof	D		IP67
3	Long battery life	W	4	Self powered + battery capacity. > 1 week battery life
4	Easy to set up	W	5	
5	Durable	W	4	Sustain accidental drops from height 0.5m
6	Low cost	W	3	Component and raw material cost < £200
7	Recylable	W	2	
8	Transparent	W	4	
9	Easy to charge	W	2	Clear acess to charging port
10	Cheap to manufacture	W	3	Manufacture and assembly cost < £30
11	Small form factor	W	3	Overall dimmensions 30x30x30cm

Long Battery Life (4):
To ensure regular air quality measurements minimum intervention with the device is required. The most involved element is the charging of the device, therefore this should be kept to a minimum by having a long battery life.

Easy to set up (5):
Crucial to ensuring a citizen science approach to monitoring air quality is maintaining a very simple set up of the sensor. As stipulated in the background the device must be portable and thus require 'packing up' and 'setting up'. Therefor both of these processes must be intuitive (completable without any training or instruction).

Durable (4):
Due to the protable nature of the sensor, and to ensure longevity, the device must be durable to general wear and tear. This has the added benefit of reducing the cost of the airmonitoring system by extending the useable life of each sensor.

Low Cost (3:)

In line with the with the goals of a low cost widely distributed sensor network, the manufacture and component costs must be kept to a minimum to ensure affordability of the device.

Recylable (2):
In line with resposnsible use of AI the physcial device should not contribute to environmental concerns. This will be achieved by avoiding non-recyclable materials in the design process were possible. These include sytrofoam, black plastics and bi-material composites which are hard to seperate in the recycling process.

Transparent (4):
The concept of transparent AI can also be extended to the physical device. Ability to view the electronics will demonstrate there are no other devices present such as camera and microphones. An accompanying schematic could be displayed on the website on which the air quality data is displayed. This would detail the comonents and their purposes in lay terms, which the transparent device would then allow confirmation upon inspection.

Easy to charge (2):
In order to engage in citizen science effectively, the device should be easy to charge.

Cheap to manufacture (3):
In addition to component cost the manufacture methods can add considerable cost. Therefore the design should incorporate modularity and simplicity resulting in a minimum number of different manufacturing processes to reduce cost.

Small form factor (3):
The device must be suitable for a variety of different locations, and not take up valueable garden or indoor space.

Concepts

A wide variety of concepts were generated using a brain storming approach. Different design cues and ideas were incoporated into four overall concepts, these are displayed below with key features labelled:

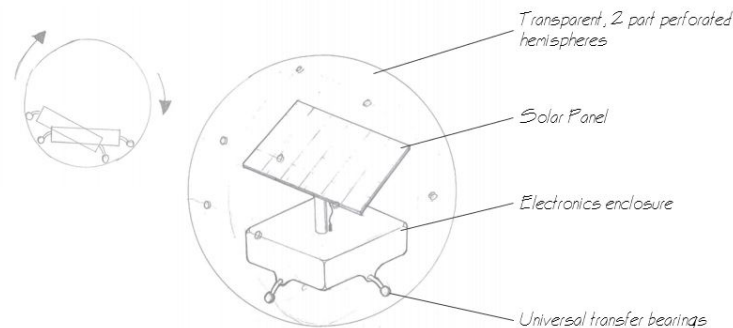

Figure 3.1: **Concept A:** A clear sphere surrounds the sensor hardware, the symetry of the sphere allows the sensors to move within the protective casing. This concept is focused on the specification requirement for easy setup, the self levelling mechanism ensures a solar panel for charging is always facing up to the light, whilst sensors can be open to the environment and protected from rain by always facing down.
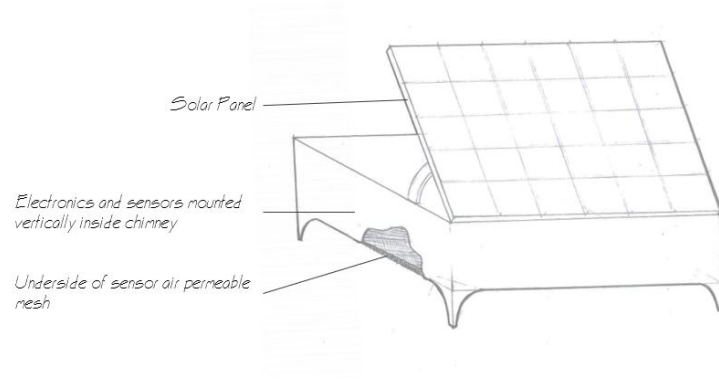
Figure 3.2: **Concept B:** A solid box contains the sensors, open to the environment and protected from water ingress by a casing raised on small legs. This concept is focused on the specification requirement for low cost, at each stage the design was simplified as much as posssible to reduce component cost and simplify the manufacturing and assembly.
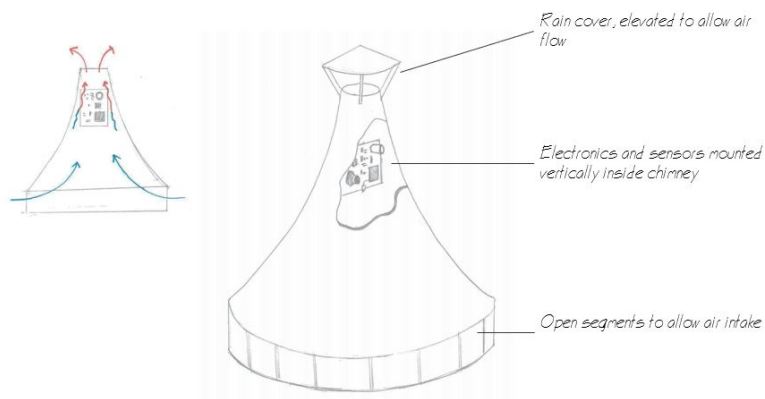

Figure 3.3: **Concept C:** The electronics and sensors are encased in a chumney like structure. This concept was inspired by using natural convection currents produced by heat given off by the electronics or from the sun on casing to drive air past the sensors. This solution would be an energy efficient method for making accurate measurements without the use of an electric fan.
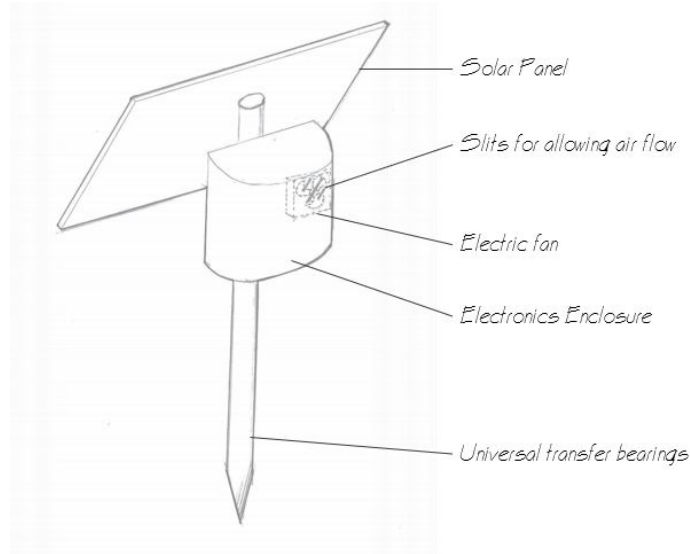
Figure 3.4: C**Concept D:** A protective case houses the sensors and electronics, a larger solar panel is used to power an electric fan which feeds air into the sensors. This design is a larger more robust concept of an air quality monitor with a less portable design.

The four concepts described were then scored against the design criteria specified in table 3.1. The "demand" categories were a simple boolean pass fail criteria. The "wish" categories were given a numeric score 1-5 with five being the best dependant on how well the concept met the specification, this was weighted by the importance of each specification point and summed to give an overall score.

Table 3.2: Add caption

Spec No.	Concepts			
	A	B	C	D
1	1	1	1	1
2	1	1	1	1
3	3	5	2	4
4	5	4	3	1
5	5	3	4	3
6	4	5	2	3
7	3	3	3	3
8	5	4	5	3
9	3	5	3	4
10	3	4	2	3
11	4	4	3	2
weighted sum	127	126	96	86

The weighted comparison between concepts revealed that concept A, was most suitable for fullfilling the desing brief. Prototype B was very close in the overal score however prototype A was percieved to have a few key advantages:

- A round spherical casing has no localised stress concentrations as opposed to a more angular geometry

of prototype B. The sensor would therefore be more robust to impact fractures that it would be exposed to from being dropped for example.

- Concept A has a significantly more appealing design in terms of intersting aesthetic and movable internal parts. Although hard to quantify and therfore not included as a design criteria, an engaging design is more likely to interest the public for citizen science initiatives.

- The self levelling design of concept A although adding some cost ensures the sensor cannot be setup incorrectly, the reliability of readings that this would likely produce is likely to outweigh a small increase in cost.

Prototype

A prototype was designed and built to test the suitability of the design, the form of the device was designed as a single 3d printed piece. 3d printing is an indiustry standard for rapid prototyping, a PLA plastic material was used due to its low melting point and hence high quality finish. An "off the shelf" Polystyrene, transparent, 180 mm diameter sphere was specified for the casing:

Figure 3.5: The physical prototype, displayed in a typical setting on a window sill.

A 6W solar panel was chosen as the maximum surface area that could be accomodated by a device of this size. The prototype included a lithium ion battery chosen for high capacity compared with size and weight. In addition a UBEC power converter was used to handle the different voltages from solar panel and battery stepping down to 5V as standard for most small DC electronics including Raberry Pi single board computer. 19mm universal bearing were chosen to provide frictionless interface between the sphere and the electronics casing. A large size was chosen to reduce interference between the perferations in the sphere and the movement of the electronics case.
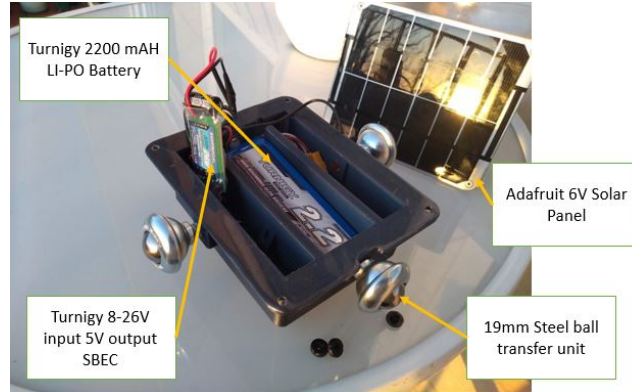
Figure 3.6: Underneath the waterproof solar panel the electronics including battery and power distribution are housed

A raspberry Pi 3 was was used to simulate the custom PCB and sensors developed for this device. The Rasberry Pi runs a linux operating system which can be interfaced with remotely over WiFi. Power was supplied by a USB-C connection connected to the battery circuitry. The GPIO pins on the rasbeery Pi can be used to interface with other hardware devices. A SGP30 gas sensor was attached to te GPIO pins to produce air quality measurements. To make gas measurements i2c messages were passed to the relevant bus adress at an frequency of 1Hz. This was implemented with a Python script run on the Raspberry Pi.
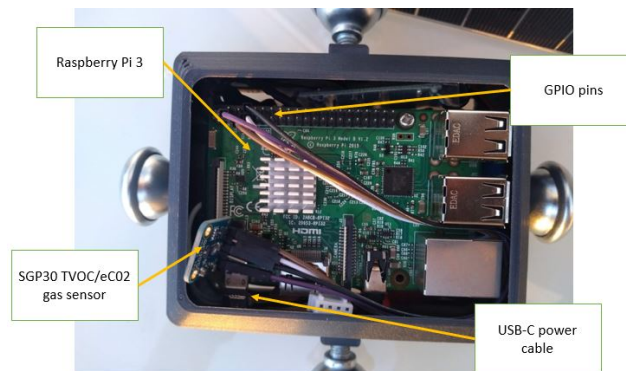

Figure 3.7: The underside of the electronics case is open to the environment to allow sensors to measure the air quality.

Technical Drawing — prototype air quality monitor case

Dimensions (top view):
- 136,00
- 108,50
- 50,50
- 31,50
- 2,00
- 80,50
- 112,00
- 11,00
- Ø3,10x4
- Ø2,70 -20,00 DEEP
- R2,00
- 10,00

Section G-G (1 : 2)
- 15,00
- 30,00
- 5,00
- 10,00

Section E-E (1 : 2)
- 15,00
- 10,00
- 15,00
- 7,00
- 15,00

Front / side views:
- G
- 68,00
- 3,00
- 11,40
- 19,00
- R3,90
- R6,00
- 5,00
- 10,44
- 22
- 30,00°
- E
- 3,20
- 3,20
- 19,00
- R3,90
- 60,00

Evaluation of prototype:

The prototype provided valueable lessons that influenced the final device design. The need for custom electronics was apparent due to the space requirement of many components and their associated wiring. Additionally the thickness of the sphere was an important consideration since the weight of the device was sufficient to warp the sphere at the points of applied pressure. This warping was problematic since the universal bearing based design was dependant on equal dimensions along both axes to ensure smooth movement.

It was decided to change the design to use a circular frame attached to the spherical case using ball bearings allowing pivoting along one axis. The electronics case is then attached to the frame perpendicular to the first axis of rotation, and free to pivot using a second pair of ball bearings. As before the electronics case will self level since the center of mass is below the pivot point, however the warping of the sphere will not impede the rotation since it is only in contact at two points.

To design a tolerence that would minimise the size of the device whilst allowing for warping of the spherical case finite element analysis was carried out on the case. The resulting distortion was quanitified and a slightly larger tolerence chosen to avoid inteference.
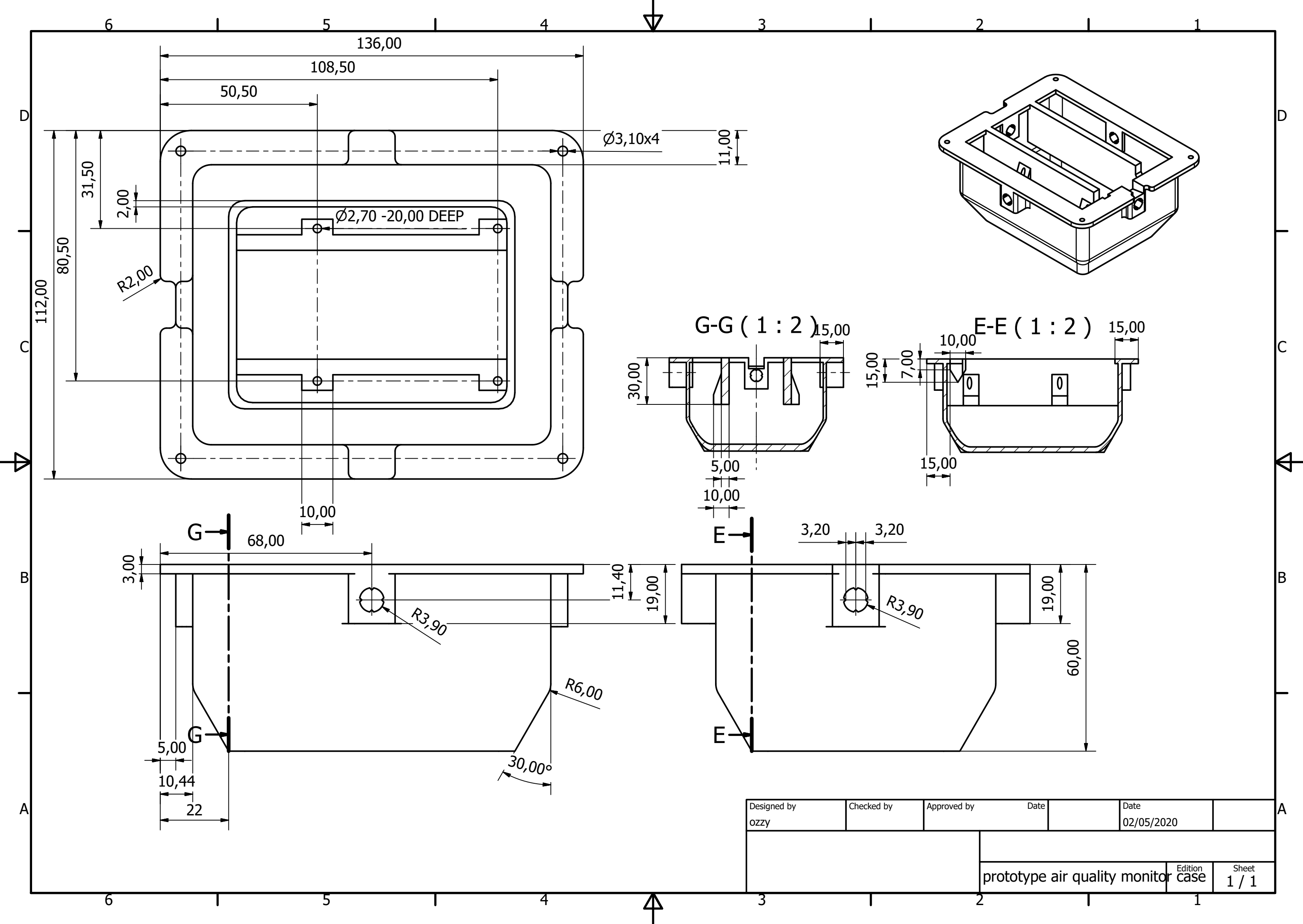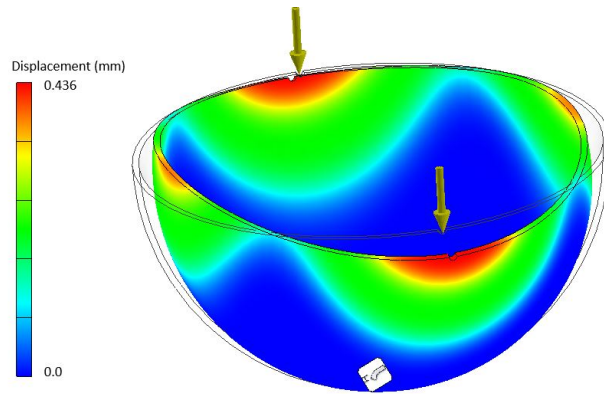

Figure 3.8: The underside of the electronics case is open to the envoronment to allow sensors to measure the air quality.

Final Design A prototype design was incrementally improved to produce a final design. This includes a wider use of materials, custom parts and manufacturing techniques not available for a rapidly prototyped design but suitable for cost effective large scael manufacture. The final dsign was rendered in a photo-realstic environment to give an impression of the final product:
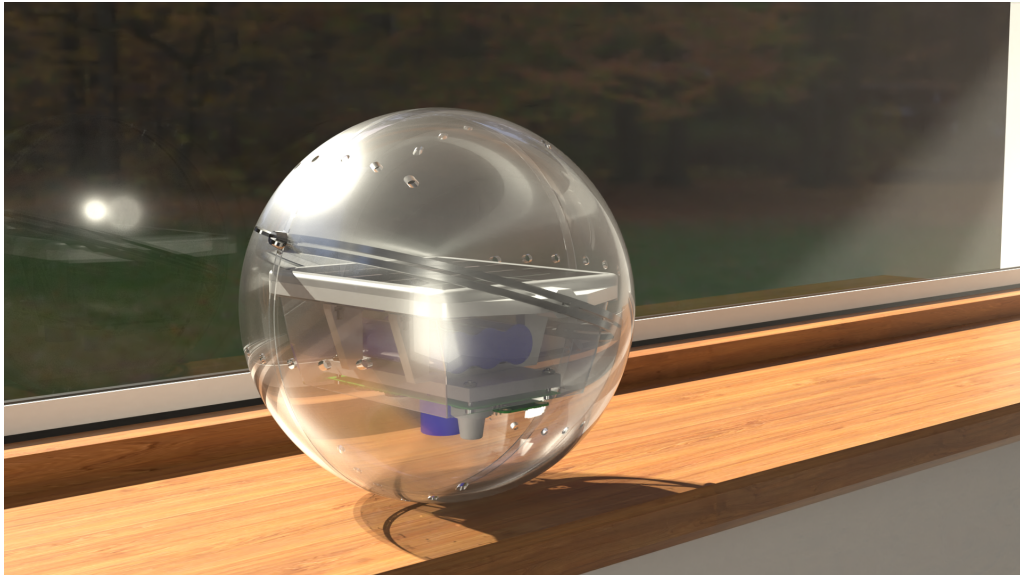
Figure 3.9: Photo realistic render of the final air quality monitoring device.

The notable changes from the prototype design are:

- Mechanism for self levelling changed to two axis design.

- Battery capacity upgraded to 6600mAH

- Custom PCB for electronics and sensors

- Electronics casing updated to multiple mass producable components as opposed to single 3d printed structure.

An exploded view lists all the components that make up the device, and demonstrates the hierachy of components into an assembly:
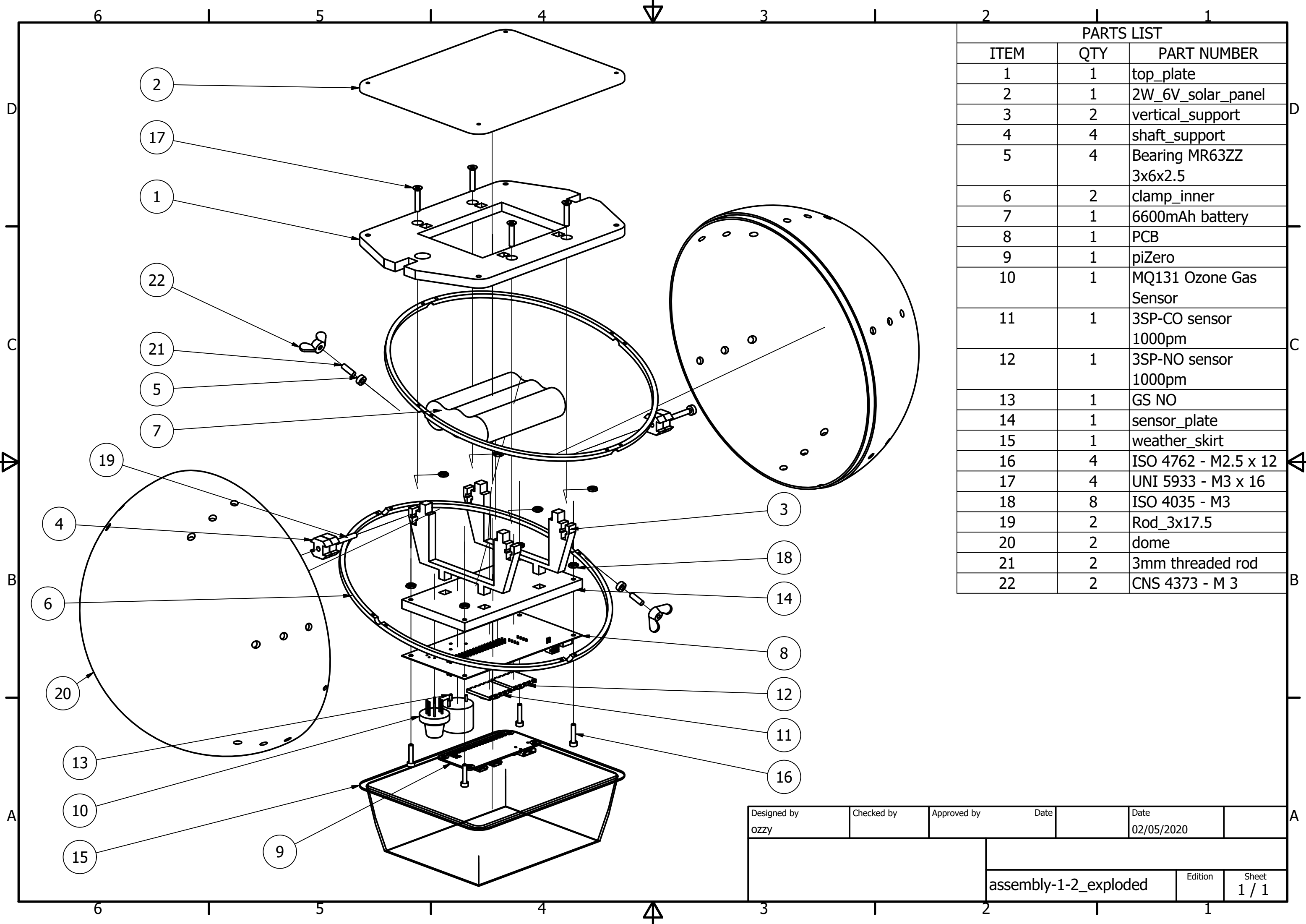
PARTS LIST

ITEM	QTY	PART NUMBER
1	1	top_plate
2	1	2W_6V_solar_panel
3	2	vertical_support
4	4	shaft_support
5	4	Bearing MR63ZZ 3x6x2.5
6	2	clamp_inner
7	1	6600mAh battery
8	1	PCB
9	1	piZero
10	1	MQ131 Ozone Gas Sensor
11	1	3SP-CO sensor 1000pm
12	1	3SP-NO sensor 1000pm
13	1	GS NO
14	1	sensor_plate
15	1	weather_skirt
16	4	ISO 4762 - M2.5 x 12
17	4	UNI 5933 - M3 x 16
18	8	ISO 4035 - M3
19	2	Rod_3x17.5
20	2	dome
21	2	3mm threaded rod
22	2	CNS 4373 - M 3

Designed by	Checked by	Approved by	Date		Date	
ozzy					02/05/2020	

assembly-1-2_exploded

Edition

Sheet 1 / 1

Design for Manufacture The form and material of parts have been carefully considered to provide the required characteristics whilst being mass producable with simple method for manufacture to reduce cost. Each custom made part has its manufacturing method detailed numbering is per the exploded view:

- Item 1: Top plate is laser cut from 6mm acrylic. 6mm is standard thickness of acrylic sheet, this manufacturing method is very adaptable allowing design changes to be incoporated wihtout any expensive re-tooling. This manufacturing could be easily transferred to injection moulding once sufficient production through put is required. Post processing requires countersinking for screw heads, this can be performed by hand or easily automated with a multiheaded attachment to the laser-cutting machine.

- Item 3: Same as 1

- Item 4: Laser cut part (same motivation as part 1) in addition high tolerence of laser cut part allows for

Design for assembly

Cost

cad designs

parts and cost break down?

images

review

Final Design Short comings of prototype FEA final design

3.2 Software

3.3 Prototype Description

[This section should explain the scope of your developed prototype, explain how it works and how it relates to the whole solution. It should clearly demonstrate the interdisciplinary effort in this development. If interdisciplinary development was not possible (see above) it should be clearly stated in this section and explain why it was not possible to exploit some of the expertise from members of your group. This section should also reflect how the experience of developing this prototype has confirmed or questioned your whole solution and how it may have changed your view on the whole solution or possibly the challenge in general.]

4. AI model

[Describe the AI model in the project]

4.1   Datasets

4.2   Methodology

4.3   Results

4.4   Etc

5.   Social implications

6. Discussion

6.1 Critical reflection of proposed solution

[*This section should provide an analysis of how the proposed solution meets accountability, responsibility, transparency and other ethical concerns. It should honestly reflect both the positive and negative impact the solution may have. If the view from the ethical perspective on the solution has changed during the work on this project this section should describe that and explain why the view has changed.*]

6.2 Future work

[*This section should describe immediate and long-term steps after development of the prototype that should be made to achieve the whole solution. If during development of prototype or critical reflection of the solution you come to the conclusion that the proposed solution is not useful or not ethically responsible or the overall challenge should not be formulated in this way (see above), this section should clearly state this case and may omit description of future work.*]

6.3 Teamwork process

[*This section should describe how your group organised teamwork, what communication channels and collaboration tools you used, how you distributed the tasks, what process allowed you to learn from another discipline during this project.*]

6.4 Lessons learnt (project)

[*This section should reflect on the whole project from the teamwork perspective: what was done well, what could have been improved, what would you change if you were to work on another project in this group, what could you recommend for an interdisciplinary team.*]

6.5 Lessons learnt (per discipline)

[*Each member of the group should state what they learnt from another discipline during this project.*]

6.5.1 Person 1

6.5.2 Person 2

6.5.3 Person 3

6.5.4 Person 4

6.5.5 Person 5

7.   Conclusions

8. Individual contributions

[*This section should briefly state individual contributions from each team member.*]

Appendix A: Code Etc