Origami-inspired Satellite Dish

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1: Abstract

Satellite dishes are used widely throughout the world as a means of communication. However, due to their naturally large size and heavy weight, they are inconvenient for mobile use as they cannot be transported easily and are usually attached to the ground. While there have been developments in improving this situation such as smaller sized satellite dishes, cases such as these are limited for small scale use and are not solving the problem.

In this project, a foldable satellite dish was developed, utilising origami concepts and ideas in its conception. The satellite dish would be able to fold into a structure five times more compact when not in use while still being able to retain most of its reflective capabilities due to precise folding along gradients of the parabolic curve, thereby reducing the negative effects of the creases on the capabilities of the satellite dish. Thus, this allows the satellite dish to be utilised in large-scale use while also remaining mobile and portable.

2: Introduction

On one hand, satellite dishes are an efficient means of improving communication to the remote corners of the world. On the other hand, they are often large and cumbersome. Many satellite dishes are affixed to the ground or surface they sit on, unable to be transported easily.

As of today, the only viable solution to allow satellite dishes to be portable is to shrink the size of the dish. Some companies have manufactured such dishes, with the dish being comprised of 2 main parts; a small dish that usually has a diameter smaller than 1m, and a foldable tripod stand. However, such dishes are very small, and may not be suitable for commercial, larger-scale use.

As such, we propose to design a folding scheme for a satellite dish that is able to fold up into a compact volume for storage and deployment, while still keeping it structurally stable and functional.

Why origami? To start off, the ancient art of origami refers to the art of paper folding, which is often associated with Japanese culture. In modern usage, the word "origami" is used as an inclusive term for all folding practices. It has influenced everyday objects through the ages and has been in the spotlight in recent years as an inspiration for engineering design, from stent grafts to satellite solar arrays.

We chose to use origami as we believed that by implementing various origami folding and locking techniques, we will be able to make a satellite dish that is easily folded and stored, but also has good structural stability when deployed.

In summary, we aim to design a scalable, foldable and portable origami-inspired satellite dish that can not only be applied in both small-scale home use and large-scale commercial use, but can also solve the long unsolved problem of a satellite dish being cumbersome to install.

2. Introduction *(Cont.)*

Case Study: Foldable Drone

In 2015, Dr Stefano Mintchev, a professor of bio-inspired robotics at the École Polytechnique Fédérale de Lausanne, in Switzerland, created a compact, foldable drone inspired by origami that can unfold itself automatically and take flight within a fraction of a second.

The drone not only fits inside your pocket, but it can also self-deploy, said Dr. Mintchev, and when not in use, the arms — made of Fiberglass and light yet rigid polyester — fold up into a trapezoid and wrap around the body of the drone. (LiveScience, 2015)

When the drone is switched on, the drone unfolds using the force generated by the propellers. The rotors spin in the same direction, causing the arms to rotate out the opposite way and open. When the arms are fully extended, their upper section moves horizontally and locks the segment open. Small magnets hold everything in place. When the arms are fully locked in place, a sensor detects it and stops the unfurling sequence, all completed under 50 milliseconds. (EFPL, 2015)

Fig. 1-3. The unfurling of the drone in under 50ms. Adapted from Youtube, https://www.youtube.com/watch?time_continue=61&v=JaEyI0R8ivU

From this case study, we can observe that by integrating vertical folds, a technique adapted from origami, we are able to increase the stability and rigidity of a structure and allow it to be more compact.

2. Introduction *(Cont.)*

Case Study: Starshade

In 2016, Manan Arya, technologist and space origami engineer at NASA's Jet Propulsion Laboratory, was inspired by origami and applied it to Starshade – an immense, folding iris that has been proposed as a way to block light from distant stars.

Working in conjunction with a space-based telescope, Starshade will be able to position itself precisely between the telescope and the exoplanet that is being observed to block the undesired starlight before it even reaches the telescope's mirrors. With the starlight suppressed, light coming from exoplanets orbiting the star would be visible. (Exoplanet, 2016)

Starshade utilises 26 six-metre long, flower shaped petals to create a softer edge that causes less bending of light, allowing the telescope to take images of the distant star without being overwhelmed by starlight. As such, the petals have to be folded with utmost care around the central core of the shade so as to prevent damage when unfolding Starshade, ensuring that the continuous soft outer edge is not damaged in anyway.

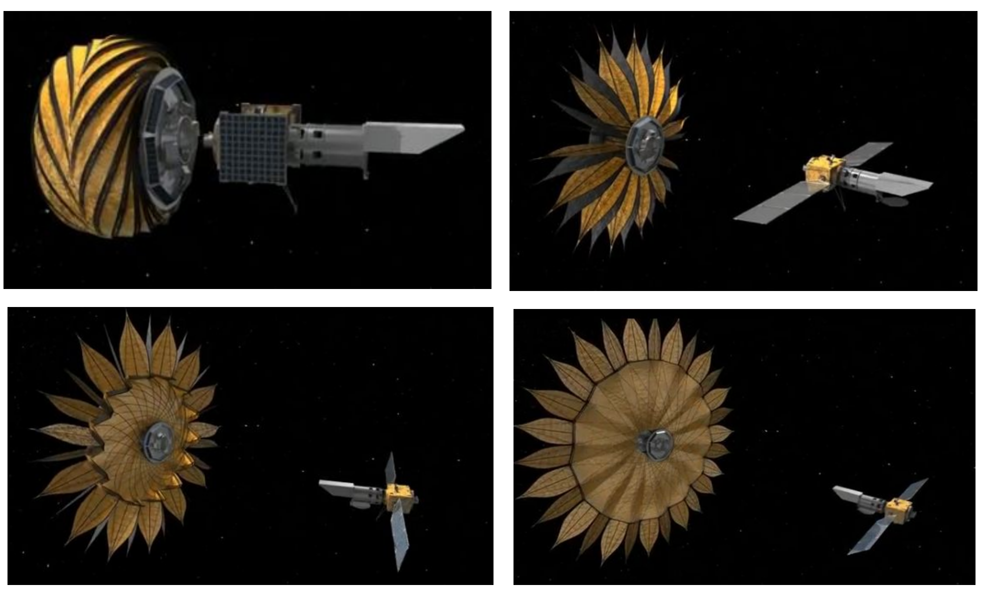


Fig. 4-8. The complete unfolding of Starshade in static pictures. Adapted from "Flower power: NASA reveals spring starshade animation", by Joshua Rodriguez, 2016

From this case study, we can observe that by folding apertures of a large, shade-like device around a central core, we can greatly decrease the surface area of the device when folded up, allowing it to be more compact, a technique that could be applied to our folding satellite dish.

3: Methodology

Project Details:

Satellite dish: estimated 1m diameter

Scalable, 1m for proof of concept

Material: Plastic/Paper

Folding scheme (Paper)

Prototype (Plastic)

2 main modes of designing:

Design on actual paper

Design using Autocad/Fusion 360

As a satellite dish is the shape of a parabola, at a point called the focus, all of the lines entering the parabola parallel to its axis are 'reflected' from the parabolic curve and intersect the focus. By utilising the equation for the curvature of a satellite dish, $y = \frac{1}{2}ax^2$ and $f = \frac{1}{4a}$, where f is the focal length of the satellite dish, we were able to substitute in the values $x = 50$ and $y = 10$ to generate a curve of a satellite dish with diameter being 1m, depth being 10cm and the focal length being 62.5cm away from the origin of the curve. This would be our arbitrary set of values for a proof of concept.

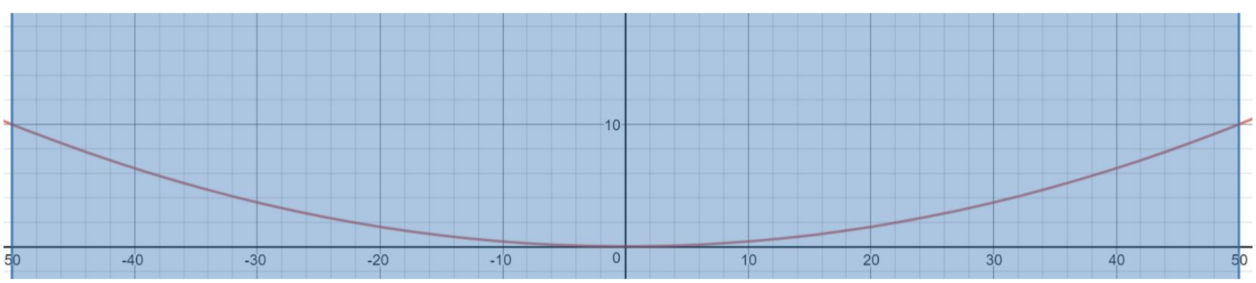


Fig. 9. Generated curve of test dish with diameter of 1m and depth of 10cm.

3: Methodology *(Cont.)*

By combining many line segments, we can obtain a structure similar to a curve. To obtain a structure similar to the curve we generated, we had to use differentiation to find the gradients at points $x = 0,\ 5,\ 10,\ 15,\ 20,\ 25,\ 30,\ 35,\ 40,\ 45,\ 50$ and their respective negative counterparts, giving us a sum of 20 gradients to create a simulated curve. The obtained results will be elaborated and utilised in our folding scheme as shown in chapter 4.

However, this also creates facets on the curved surface, which are non-ideal for the reflector. The reduction in performance and reflectivity of the reflector will be assessed later on.

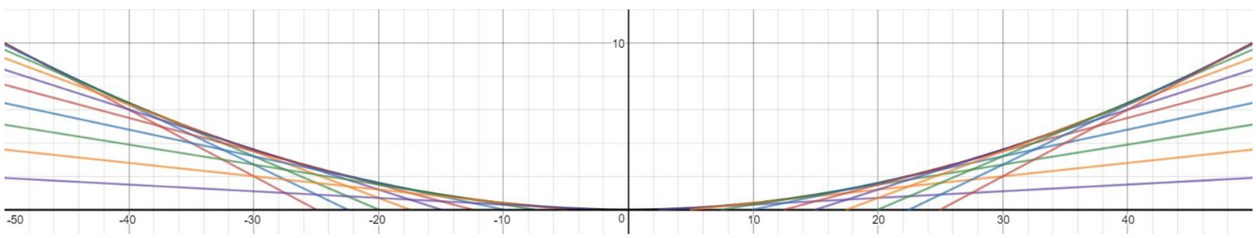


Fig. 10. Curve with gradients generated.

Timeline:

Period	**Action**
Apr-May 2018	Literature Review
June 2018	Draft prototypes of possible folding schemes
After Midterm 2018	Evaluate judges' comments and work on improvements
Jul-Aug 2018	Create second prototype using stronger materials, e.g. plastic
Nov-Dec 2018	Continue project at DSO National Laboratories
Jan 2019	Finalise prototype, project report and poster in preparation for DS event

4: Folding Scheme and Prototype

Folding Scheme:

Using the fractionated curve we generated in Chapter 3, we designed 2 different wireframes for the satellite, the first being 8-sided, and the other being 16-sided.

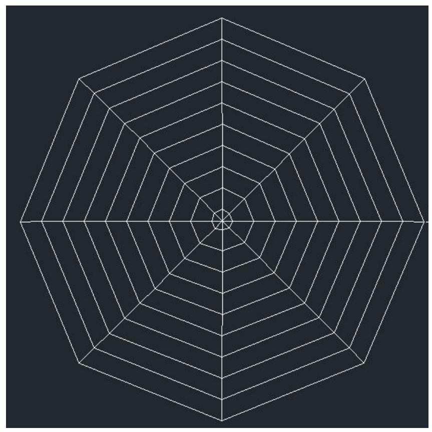


Fig. 11. Top view of the wireframe of 8-sided satellite dish.

Fig. 12. Side view of the wireframe of 8-sided satellite dish.

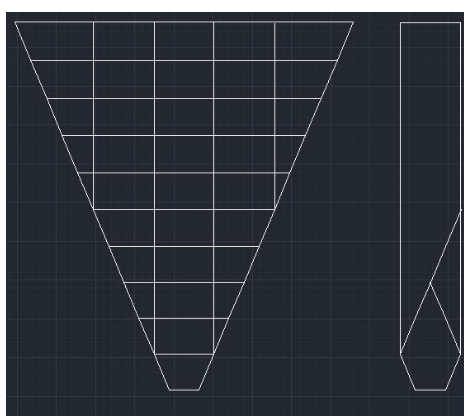


Fig. 13. Folded and unfolded version of 1 section of 8-sided satellite dish.

4. Folding Scheme and Prototype *(Cont.)*

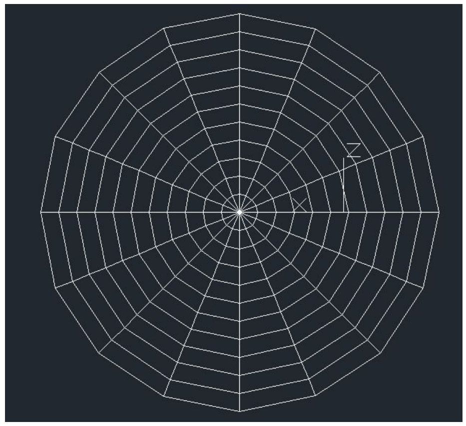


Fig. 14. Top view of 16-sided satellite dish.

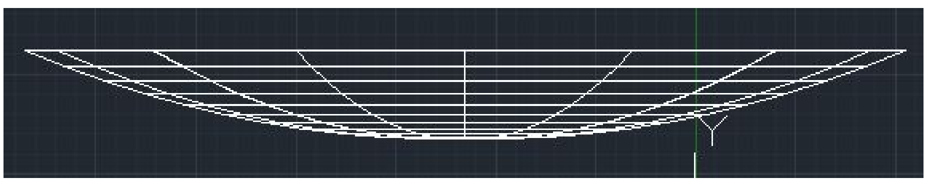


Fig. 15. Side view of 16-sided satellite dish.

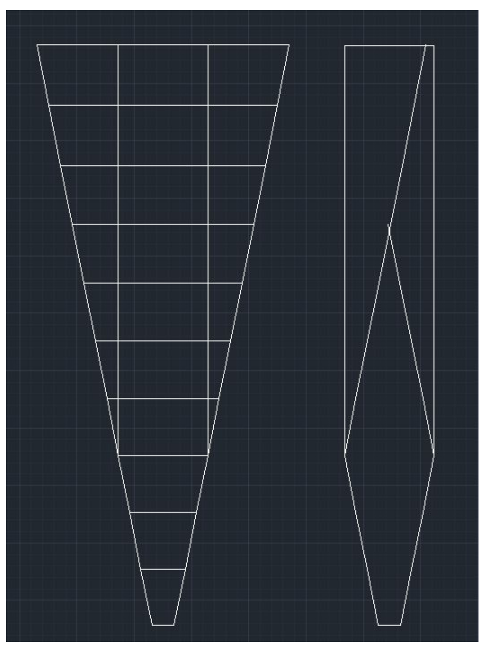


Fig. 16. Folded and unfolded version of 1 section of 16-sided satellite dish.

4. Folding Scheme and Prototype *(Cont.)*

First Prototype:

For our first prototype, we decided to use paper to create a prototype ⅕ of the intended size. We also decided to use the 8-sided tessellated satellite wireframe for our model as it had much fewer components and was less complex.

By using a folding scheme where we folded each section of the satellite dish around a central core, we were able to fold the satellite dish up into an area 5x smaller than the original.

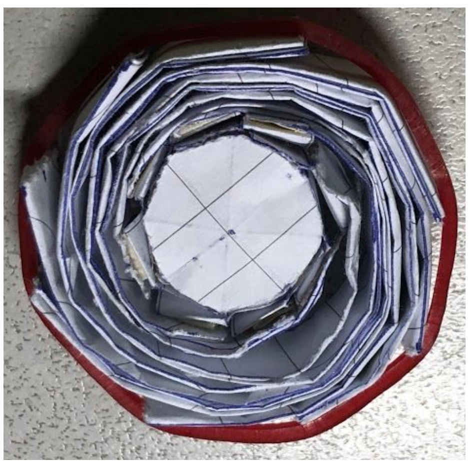


Fig. 17. Satellite dish that has been folded up.

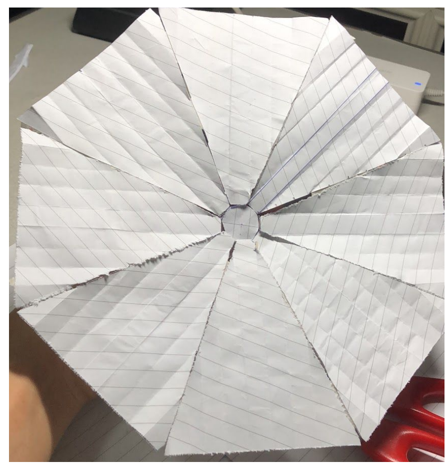


Fig. 18. Satellite dish fully unfolded.

We were able to adapt both the vertical folds from Dr Stefano Mintchev's folding drones and the concept of folding around a central core from NASA's Starshade, in order to allow the originally horizontally situated satellite dish sections to fold up vertically so that they would be able to fold around the central core of the satellite dish.

4. Folding Scheme and Prototype *(Cont.)*

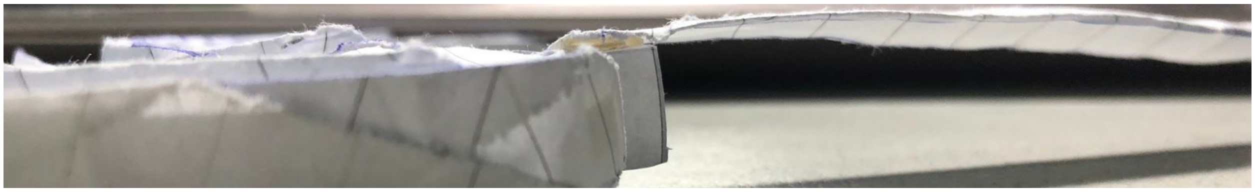
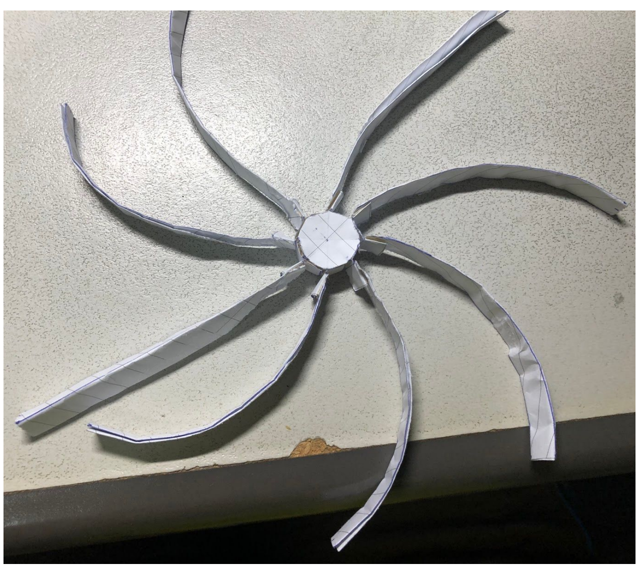


Fig. 19. Horizontally situated satellite dish sections.

Fig. 20. Originally horizontal sections folded up vertically using vertical folds.



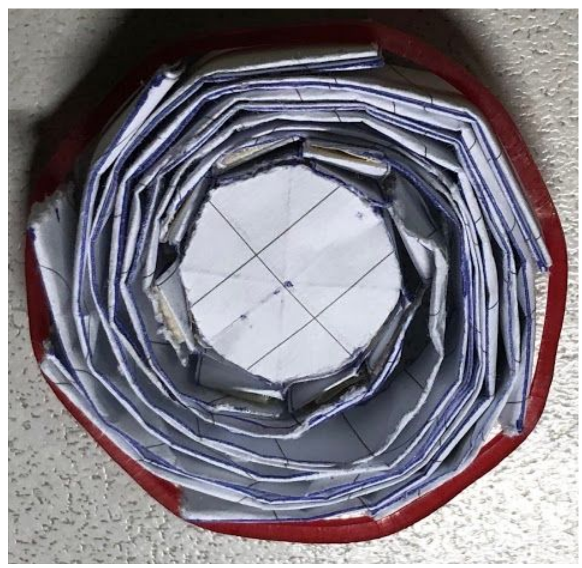


Fig 21. Unfurled vertical sections of satellite dish.

Fig 22. Vertical sections of satellite dish folded around a central octagonal core.

4. Folding Scheme and Prototype *(Cont.)*

Second Prototype:

For our second prototype, we used a stronger material – compressed foam – to better emulate the fractionated curve that we generated. To strengthen the satellite dish, we decided to use 2mm wide aluminium wire to create an actual wireframe for the satellite dish. We also made a prototype that unfolds into a satellite dish 50cm in diameter.

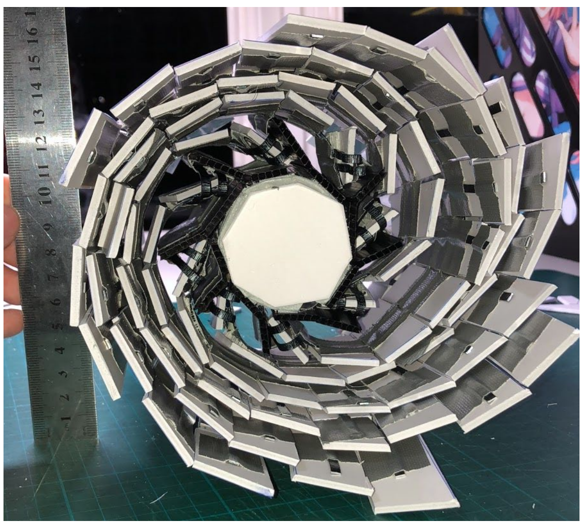


Fig 23. 50cm satellite dish fully folded up.

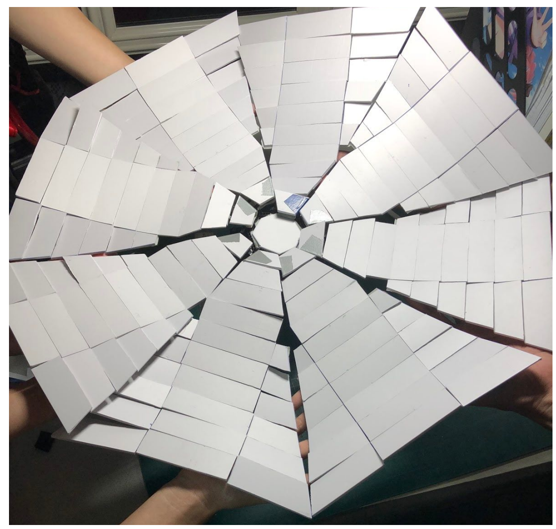


Fig 24. 50cm satellite dish fully unfolded

Furthermore, for each section of the satellite dish, instead of folding twice to make it more compact, we decided to fold it only once to help reduce the thickness of the folded section as the 3mm foam used proved to be too thick.

4. Folding Scheme and Prototype *(Cont.)*

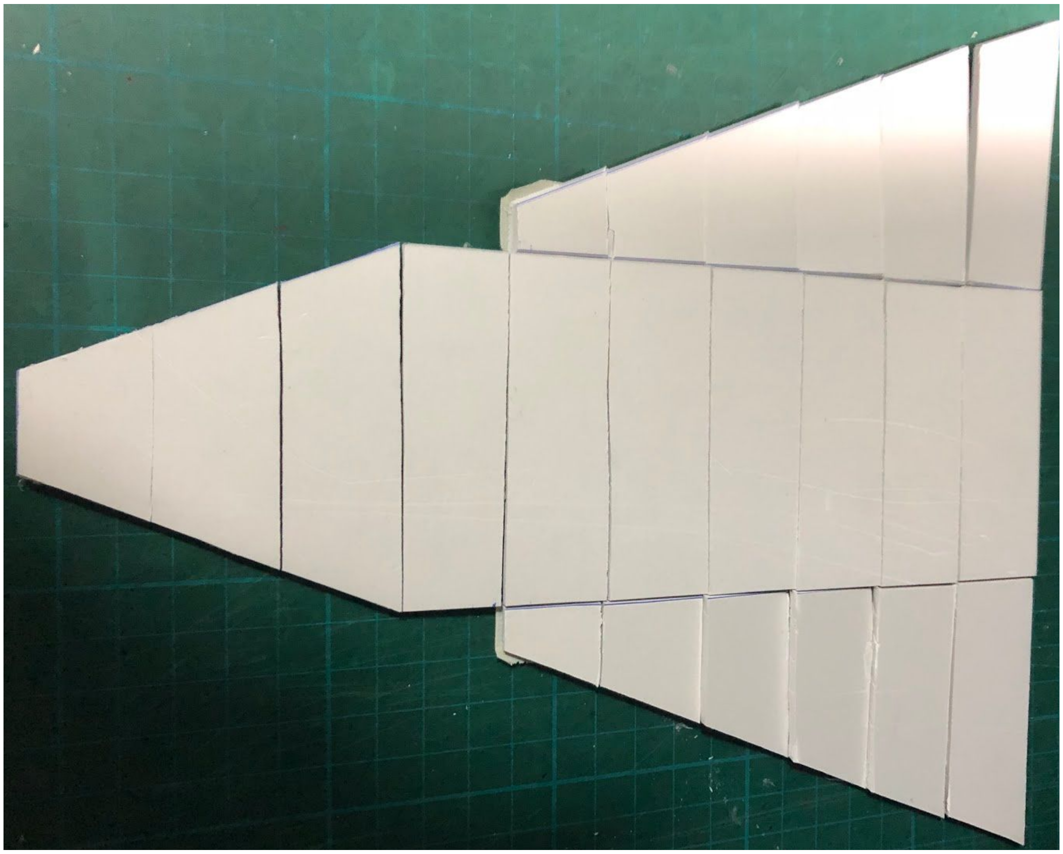


Fig 25. Fully unfolded section.

Fig 26. Folded up section.

5. Results and Discussion

Results:

We planned on using the GRASP software made by Ticra, a software specifically designed to simulate near and far-field conditions, in order to test for the radiation patterns for different satellite dish reflectors.

However, in addition to being fairly new to the software, there were no guides on how to properly utilise the software, so we were unable to simulate the design for our origami-inspired reflector.

Despite this, we were able to obtain simulation results of other patterned meshes to assess the validity of using a non-ideal paraboloid reflector dish. The figure below, extracted from TICRA, a company specialising in antenna analysis and synthesis software, shows the co-polar radiation pattern of a uniform triangular mesh design applied to a satellite dish (in blue) and the co-polar radiation pattern of an ideal paraboloid reflector dish (in red). From the figure, we can tell that the reflective capabilities of the uniform mesh dish is mostly similar to that of the paraboloid reflector, except for the regions where the nodes intersect, where it can be seen that the first grating lobe at around ±12° has a co-polar radiation amplitude of about 21 dB higher than that in the ideal paraboloid reflector.

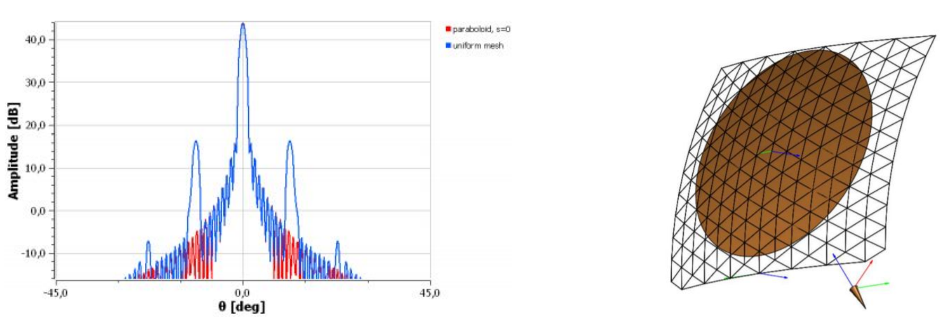


Fig 27. Comparison of radiation patterns of uniform paraboloid reflector (red) and uniform mesh reflector (blue), which is shown on the right.

5. Results and Discussion *(Cont.)*

Thus, we can conclude from these radiation patterns that using a non-ideal paraboloid pattern for the satellite dish is still feasible, although performance of the dish is slightly compromised due to reflectivity being distorted and peak directivity being reduced by the many facets on the satellite dish. Grating lobes are also produced as explained earlier as a result of a non-ideal paraboloid reflector being used, which cause visible reductions in the dish's reflective capabilities.

According to Cappellin (2016), these grating lobes appear at the angle θ_g and is given by the formula:

$$\sin\theta_g = \frac{2\lambda}{s}$$, *where s represents the size of the facets of the mesh*

As an ideal paraboloid reflector dish does not contain any facets in its structure and is composed of a single uniform sheet, s, in the equation above can be considered to be 0, thus, no grating lobes appear and the reflectivity of the reflector dish is optimal.

However, by introducing imperfections into the reflector dish's structure, such as when we introduced several gradients to the dish at fixed intervals, the value of s can no longer be considered to be 0, and thus, grating lobes appear, affecting the reflector dish's capabilities. Thus, in order to reduce the effect of such imperfections on the reflectivity of the dish, the size of each facet should be minimised in order to bring the non-ideal paraboloid reflector closer to the optimal ideal paraboloid of the dish.

6. Conclusion

In conclusion, we have managed to fold a satellite dish into a size about five times more compact than when it is opened up, achieving the goal of allowing the satellite dish to be more compact and thus, more mobile and transportable. This was achieved from applying origami techniques and concepts inspired by Dr. Stefano Mintchev's folding drone and NASA's Starshade to our prototype of the satellite dish.

A main limitation we faced throughout the project was the lack of access to and knowledge of software that could help us test out the feasibility of our prototype as a reflector dish in an actual satellite. We tried our best to overcome this problem by extrapolating from current existing data from other established research papers in this field to validate our own prototype.

Further extensions to the current project would include finding a more suitable material for the prototype to be built in as the materials we are currently using are not sturdy enough. While we have changed from using paper (in our first prototype) to compressed foam and flexible metal wires(in our second prototype), the compressed foam proved to be too heavy for the metal wire, and as a result, many metal wires broke as they were unable to support the weight of the compressed foam, making the satellite dish more unstable.

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