AWEIGH

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AWEIGH

A DECENTRALISED FORM OF NAVIGATION

"Over the last century, technological acceleration has transformed our planet, our societies, and ourselves, but it has failed to transform our understanding of these things."

JAMES BRIDLE

"The cardinal rule: know where you are to the best of your ability at all times."

DAVID BURCH

Contents

INTRODUCTION

This is a book about reframing navigation. As team members we navigated through the present state of technology, trying to understand and highlight what we thought were its problems. We created a methodology for addressing those problems. We then recognised the need to focus on a specific area of technology in order to make an impact in the short time available.

We chose to focus on navigation technology, more specifically navigation via satellites, the method used by every person with a smartphone to locate themselves. It seemed strange to us that the average person depends so greatly on Global Navigation Satellite Systems (GNSS) to locate themselves, that other methods are barely known or used. There are many other things we depend on to survive: food, shelter and money. But these dependencies come with choices, such as the choice of what, where and from whom to buy food. M. Ena Insei et al (1)'s work on the need for choice in feeling control lead us to believe that creating an alternative to GNSS navigation could improve the user's feelings of control. We also aim to give control through the ability to understand, create, and adapt our technology to the needs of the user. We hope through using this device one will be able to locate themselves physically and in our contemporary techno-political landscape.

The culmination of our project is Aweigh, a decentralised method of locating oneself, which does not rely on satellites. Our technology was inspired by the vision of desert ants and field crickets, traditional methods of navigation using the sun, along with a paper by Y. Wang et al (2) replicating insect vision for navigation. Aweigh has three options of construction, giving more choice and control back to the user in accordance with their needs.

These options range from:

Version 1:

a pre-made Aweigh device, ready to take out the box and use immediately.

Version 2:

an Aweigh kit including a custom pcb with our technology's circuit and other components available to buy from our online shop, plus detailed instructions for how to build the device. Downloadable 3D printed and cut-and-fold casings can be found on our site, but casings can also be custom made by the user.

Version 3:

a list of components (all standard components which can be bought separately from a list of stores) required to build aweigh and circuit diagrams to instruct assembly.

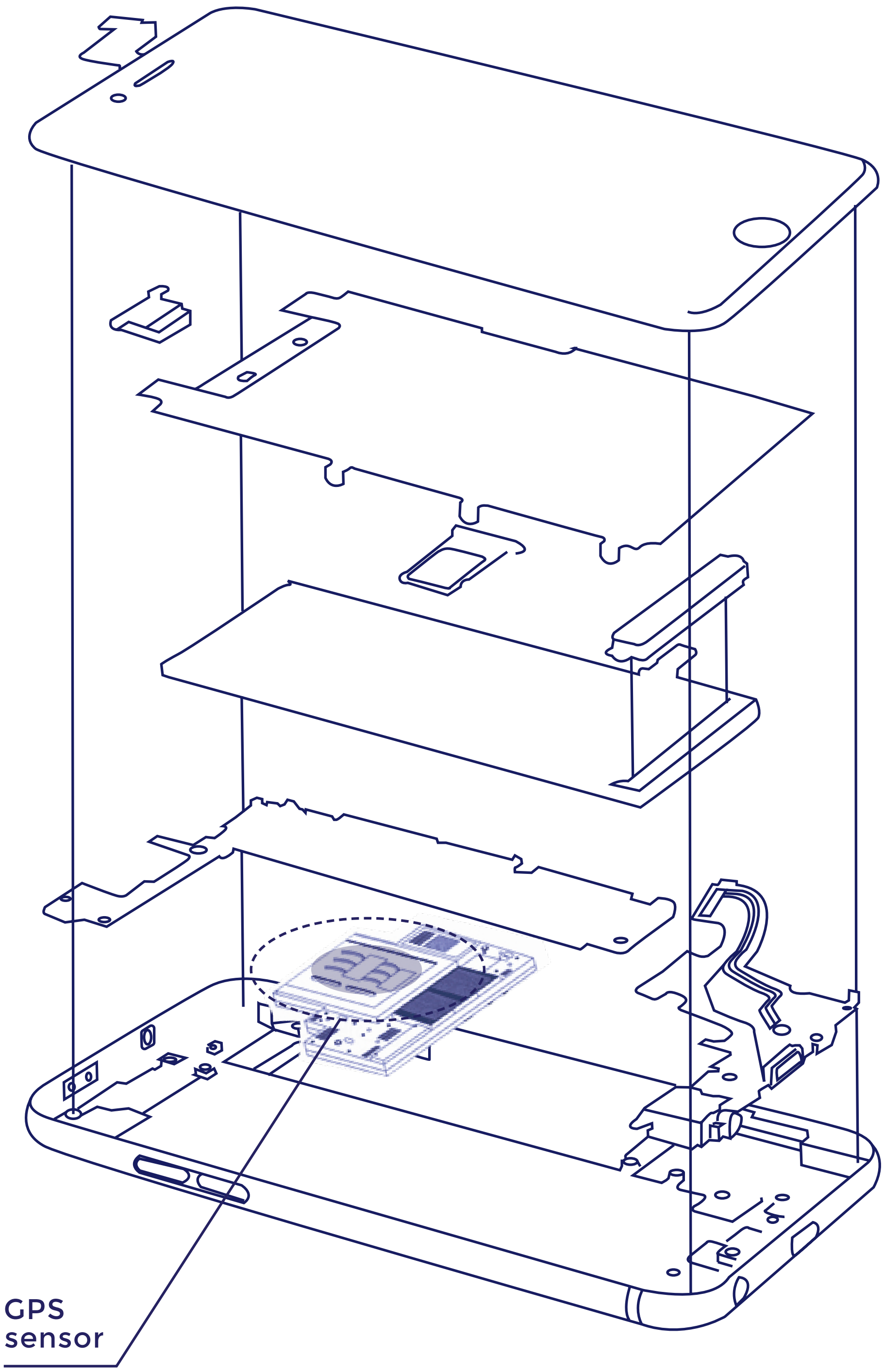
Aweigh is a work in progress. The accuracy of the device needs to be improved for the technology to be used as a serious alternative to GNSS. However Y. Wang et al say themselves that "If the accuracies of polarized-light sensors and compasses can be improved, the accuracies of our device can be improved significantly." It is our intention through making the project open source (3), that we will prevent as much as possible the device becoming a 'black box'. Through open-source individuals can improve Aweigh with their technologically learned knowledge. Much of this book is concerned with de-black boxing the device.

The rest of book is divided up as follows: firstly, we describe the problems found with technology in the 'Technological Landscape.' Then we state the logic behind creating alternative forms of ubiquitous technologies. We give an overview of the natural phenomena and technology which inspired Aweigh and a mention of other projects which inspired us. We describe the detailed method Aweigh uses to find the position of the sun. The method which Aweigh uses to calculate the user's latitude and longitude is given. Detailed instructions on how to use each version of Aweigh is shown, and finally we suggest the next steps in the project.

The power structure of some technology has created a strange phenomenon, where innovation, meant to add value, actually leaves diminished feeling of control than before. Aweigh is a project with the intention to address this phenomenon.

AWEIGH

Technological landscape



The technological landscape of the present day is dense; technology has intercepted almost every aspect of our daily lives and will integrate further as technology progresses. Technology can be as simple as hammer, or as complex as the internet, but it is the latter form of technology which is intercepting new areas of our lives the most. Take for example contraception apps on mobile phones which work by calculating times where one is least likely to become pregnant (5), or machine learning algorithms which determine which of your emails to place in a spam folder are examples of what we would call "Complex Technologies".

'Complex Technologies' are in general poorly understood. James Bridle writes about them in his book: "New Dark Age: Technology and the End of the Future" (7):

"If we do not understand how complex technologies function, how systems of technologies interconnect, and how systems of systems interact, then we are powerless within them, and their potential is more easily captured by selfish elites and inhuman corporations".

With a hammer, a person can intuitively understand that its weight allows it to be used as a paperweight as well as for knocking in nails; however, it is almost impossible to look at more complex technologies and understand their possible uses (their complexity is hidden). In this way, most of them become black boxes.

The Internet itself is perhaps the starkest example of a Complex Technology. People we interviewed, who were all self-confessed heavy Internet users, had little understanding of its structure. Many did not know that the "Cloud" does actually have a physical location, remote buildings which house racks of memory storage and consume 1% of countries entire energy usage (8). Or that 99% of international data on the internet is transmitted through undersea cables (9), many of which follow old colonial shipping routes and favour western, developed countries.

Examples of the potential captured by what Bridle calls "inhuman corporations" came up in our research. In one example, we found backlash10 against Facebook's 'Free Basics', a heavily condensed version of the internet provided through Facebook to developing countries. Ellery Biddle, advocacy director of Global Voices claimed it is 'building this little web that turns the user into a mostly passive consumer of mostly western corporate content. That's digital colonialism."

All this lead us to believe that there is a problem with the centrally-controlled (where an entire system can be affected greatly by a single agent, usually a selfish elite of inhuman corporations) and ubiquitous technology we use today. These technologies are so ubiquitous that alternatives which might exist to solve similar problems are not chosen or considered, or even remembered. With the problem in view, we began to create a methodology for our project.

The logic of creating alternative forms ubiquitous technologies:

Our methodology for the project needed to address the problems of centrally controlled, ubiquitous technology. We realised that these types of technology, like communication, navigation, information gathering, are things we have become very dependent on and find difficult to live without.

We looked at our other dependencies, such as food, housing, and entertainment, and we tried to recognise some differences. We found that what makes complex technology different is often the lack of control in the dependency. We can quite easily choose to shop for food at a whole range of shops, choose to buy what we consider ethically sourced food or food which doesn't harm animals in the process. This contrasts with the difficulty to choose to prevent our personal data being used for targeted advertising. We then decided a method for combatting this problem was to create alternatives to the complex technologies that we use today.

M. Ena Insei et al, writes that power and choice 'share a common foundation - that both are rooted in an individual's sense of personal control'. Experiments she conducted support our view that in a position of little power, such as our lack of power when using complex technologies, by introducing more options would begin to satisfy the 'broader need for control'.

In one of her experiments, Forty-one undergraduates were tested to see if being in a situation of lower power would make them desire more choice. Participants were split into either a low power or high power group, and given a situation to read corresponding to that power, and made to imagine how they would think, feel, and behave in this role. They were presented with two scenarios, each scenario involved deciding whether to make a purchase from a store offering a small assortment (3 options) or a store offering a large assortment (15 options). In the first scenario, the small-assortment store was closer than the large-assortment store. In the second scenario, the small-assortment store was open, and the large-assortment store was closed. Desire for a larger choice set was measured by, respectively, the number of miles participants were willing to drive and the number of minutes they were willing to wait to access the larger choice set.

The undergraduate in the low-power group were willing drive on average 1.6 times further to reach the store with more choice. They were also willing to wait 1.5 times longer for the store with more choice to open. In this vein, we believed that creating an alternative to complex technologies would be desirable for people, who have little power over how the technologies are controlled.

Not only do you have power through choice, you have power through the decentralisation of the technology and your capability of understanding that technology. This technological literacy is super critical in the contemporary because, as stated, complex technologies are ever more ubiquitous.

Focusing on Navigation:

Navigation technology, specifically the method of finding one's latitude and longitude, was chosen as it is a stark example of a dependency with no choices. Although the method a smartphone uses for positioning is a combination of many sources of information (GNSS, Wifi data, cellular towers and an accelerometer), the choice people have is to use it or not. We also chose navigation because we knew that there had been alternative methods used in the past.

We found that the dependency on others satellite technology had already been a concern for the European Union, which created its own GNSS system, called 'Project Galileo' (11). At that time (2005), Europe relied on GPS and GLONASS, America and Russia's forms of satellite navigation respectively. They recognised the possibly catastrophic effect of either GPS or GLONASS refusing use of their satellites since around 800 Billion Euro's worth of the Union's GDP was dependant on satellite navigation.

During the making of this project, developments in the news lead us to believe in the importance of an alternative navigation method. A Financial Times report published in June 2018 (12) stated, as a result of Brexit, Britain would not be allowed full access to the use of Project Galileo, and would not have a say on all aspects of the development of the program. Later, the UK government set aside £92m to study the feasibility of building a sovereign satellite-navigation system (13). Prime minister Theresa May said that "I cannot let the armed forces depend on a system we cannot be sure of. That would not be in our national interest." (14) Currently Britain is to stop working on Project Galileo if and when Brexit is passed.

Forgotten technologies

Our method of finding alternative ways of locating oneself was to look back through the history of navigation technology. We found that older technologies required knowledge of how they worked in order to use it (compared to a phone where no knowledge of its internal mechanism is needed in order to use). Additionally, the design of older technologies was transparent; parts were laid bare to see and form often followed function.

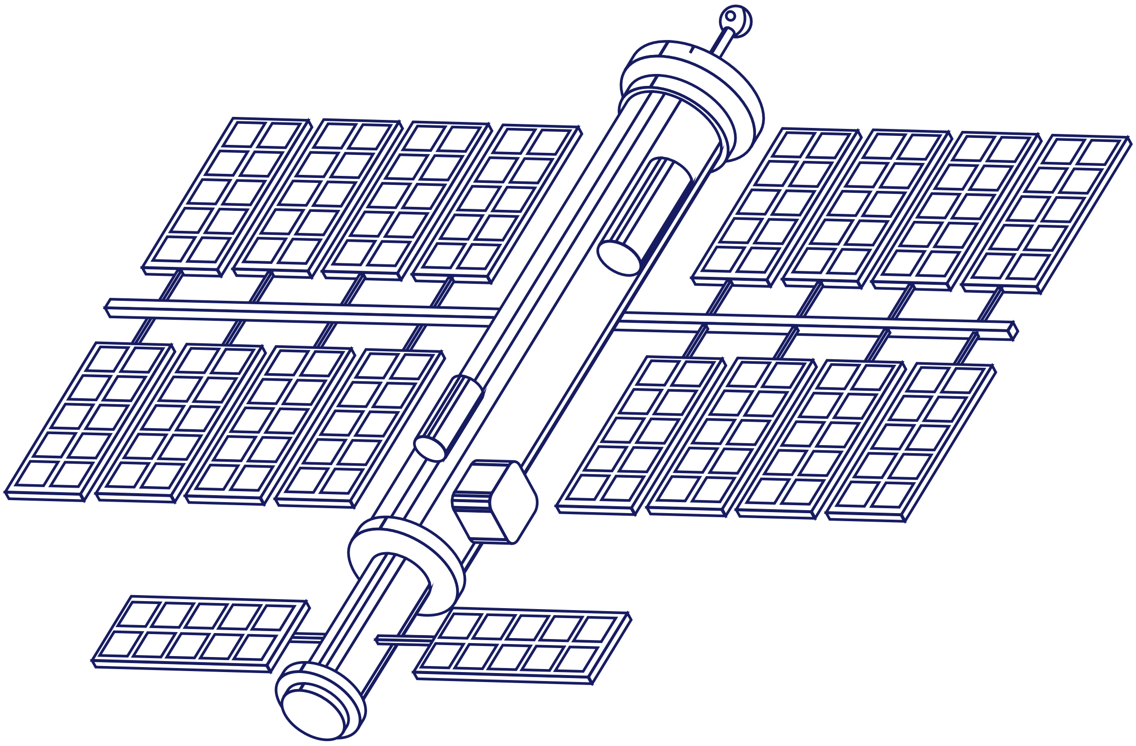
We realised that as the technological landscape progresses, certain solutions to problems get lost or become more obscure. The solution to a problem which survives this progress is not necessarily inferior, it is that which is most suited to the needs of the society in which it is made. This is the ideal situation, however, as technologies become more dependant or entrenched it becomes more difficult to change them. In his book 'You Are Not a Gadget'15 Jaron Lanier labels this phenomenon as 'lock in'.

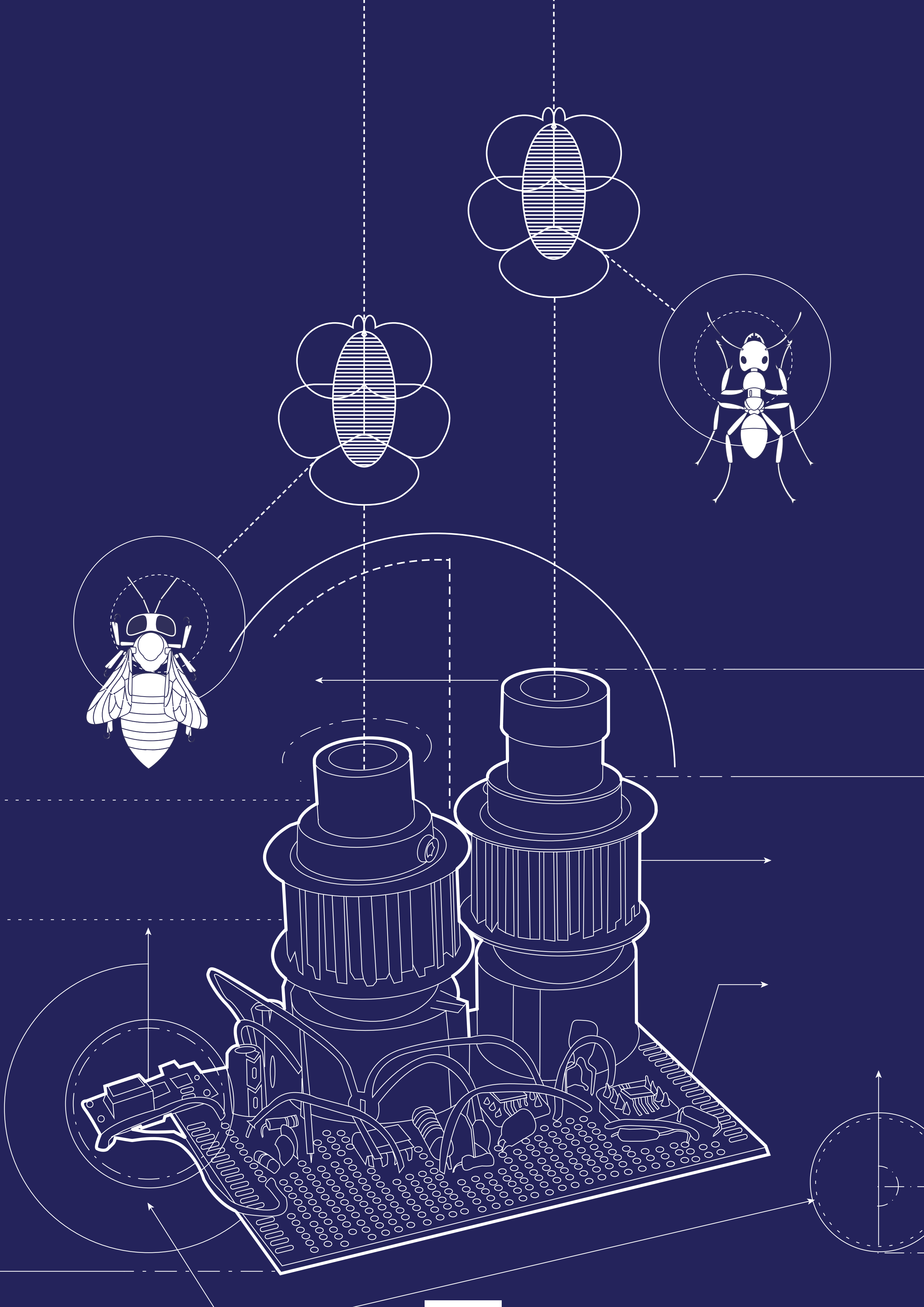
Looking back in history we found that the sextant was a perfectly suitable method of navigation for maritime navigators, and is still used as a backup to GNSS today (16). The accuracy of some of these sextants was in the range of around 370 meters, which was also about the same level of accuracy that GPS had before the 21st century (17).

The sextant is not part of a large networked structure, so it does not suffer from the problems that centralised structures suffer - namely that there isn't a single point of failure in sextant technology that could affect all sextant users. If one user's sextant breaks, only they and those relying on that sextant will suffer. Points of failure in satellites have had incredibly far reaching effects on society. In one instance (18), a bug in the software that runs GPS changed the time on the clocks onboard each satellite:

"cellphone towers lost their connections, U.S. police and fire stations reported communications errors, BBC radio signals were interrupted, and the telescope that tracks asteroids in Earth's orbit went offline. [...] When the U.S. Air Force, which operates the (31) satellites, decommissioned an older one and zeroed out its database values, it accidentally introduced tiny errors into the database, skewing the numbers."

This precarious position of reliance is a common scenario in complex technologies, giving evidence to our assertion that the current form of navigation has become entrenched and does not completely fit with today's society. Positioning technology has already experienced 'lock in', and in doing so has made us blind to alternatives.





Inspiration

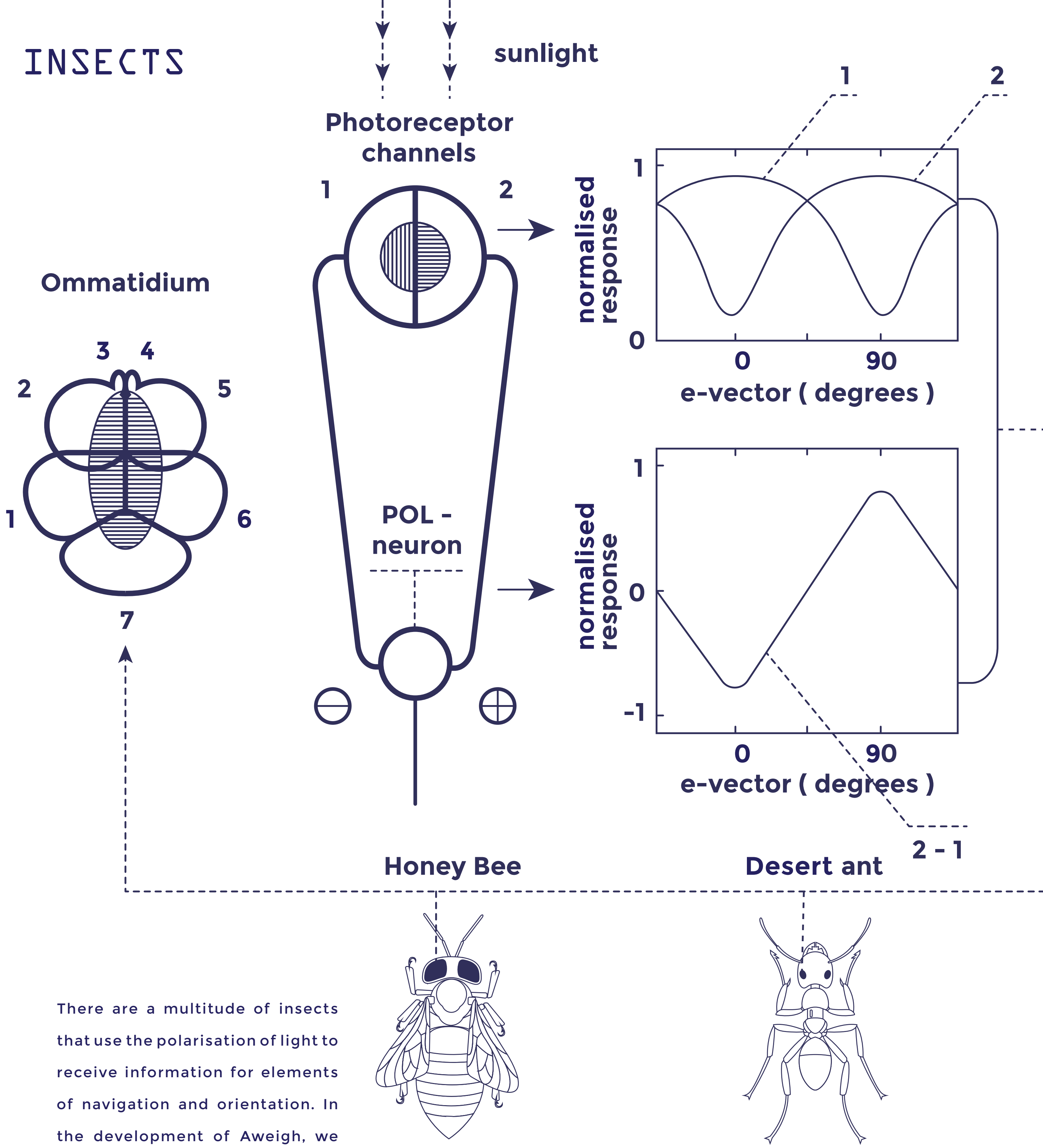
Our inspirations came from a mixture of projects shown in the following pages. These range from air compression energy storage, which today has been almost completely forgotten, to a wind turbine which uses energy made to mine cryptocurrency, in which all the profits go to help fund climate change.

Part of our examination of looking through the history of navigation technologies came from the desire to investigate whether any of the technologies could be repurposed to fit the contemporary technological landscape. We studied the area of insect vision, more specifically the Cataglyphis, or Desert Ant. Desert Ants have polarised vision, meaning they can see the polarisation of light. Studies have shown this is used by the ants as a sun compass. Sunlight becomes polarised when it collides with molecules in the Earth's atmosphere, and the further it travels through the atmosphere, the more the light is polarised. This means that without looking directly at the sun and examining the polarisation of sunlight, it is possible to infer where the sun is.

Our second inspiration came from the sextant, a tool for celestial navigation. A sextant measures the angle between the user's horizon and the sun. Using this knowledge and the time of day, it is possible to calculate the latitude and longitude of the user (more information on this is shown on pages 28-31).

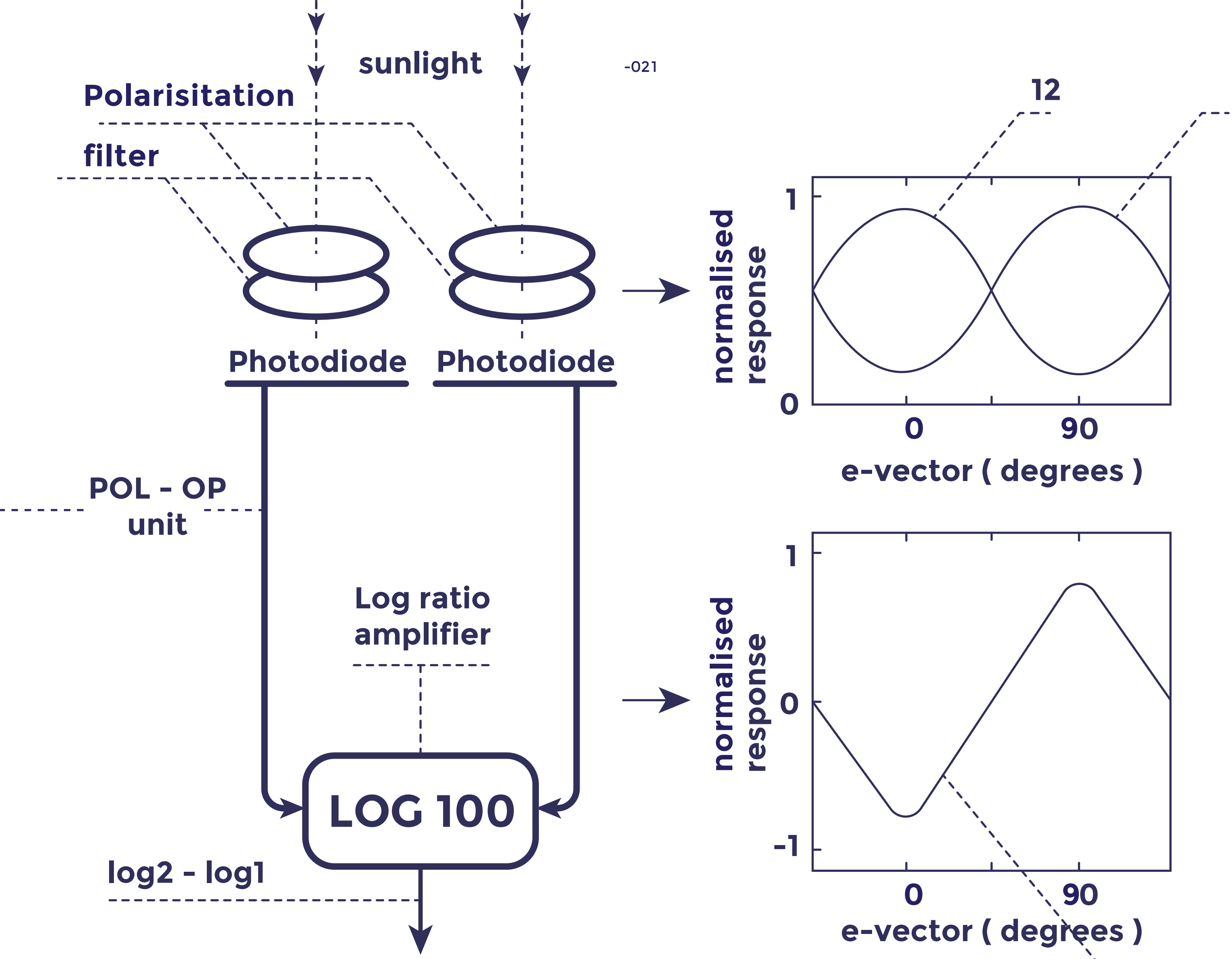
What follows are more detailed explanations of these inspirations.

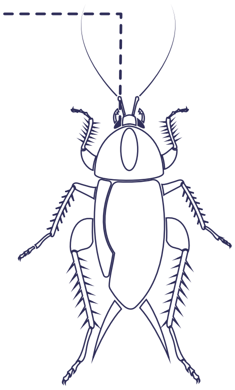
INSECTS



There are a multitude of insects that use the polarisation of light to receive information for elements of navigation and orientation. In the development of Aweigh, we largely looked at research done in the vision of three insects: bees, ants, and crickets. Each of these insects has the ability to perceive patterns of polarised light. Insects' vision is fundamentally different than humans because of the structure of the eye.

While humans have single-aperture eyes, insects' have compound eyes, eyes made up of thousands of clusters of cells called ommatidia. These clusters contain cells which detect changes in light and convert that information into a signal for the brain to process. Most of the cells within the compound eyes only detect changes in light intensity, but research found that bees and crickets have a cluster of ommatidia within their eye that controls the sensing of polarisation of light.





Through research in the Department of Zoology at the University of Zurich, scientists were able to model the way these polarisation-sensitive neurons in crickets functioned. Polarisation neurons are fed information from receptors that are orthogonal to each other.

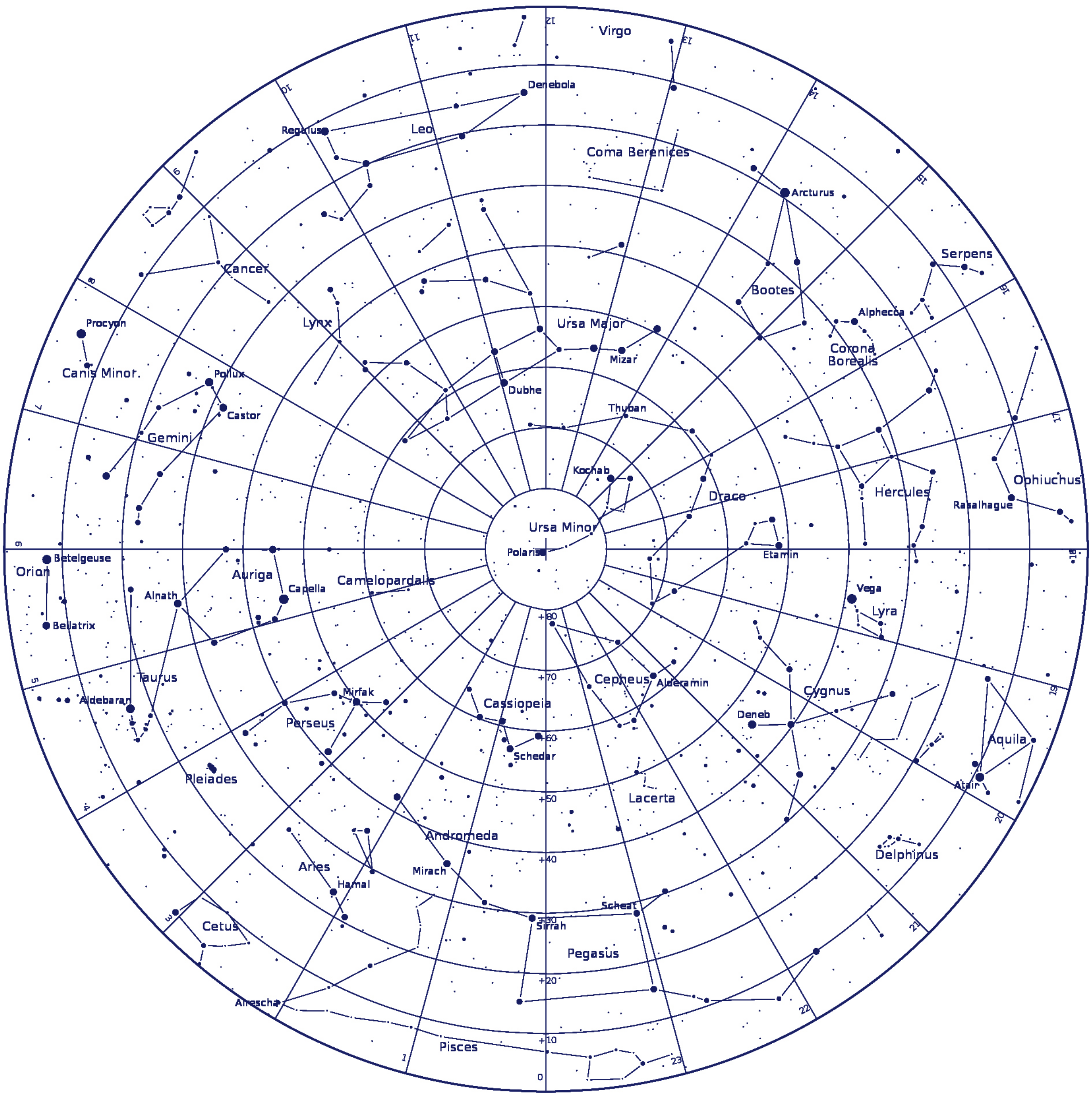
The orthogonality of the receptors allows for e-vector orientation to be isolated from other factors in light such as color and intensity. For example, if an e-vector was oriented at 45 degrees and an insect had each receptor oriented the same - for the example, say at 0 degrees - than each receptor would be receiving the same signal; however, if the receptors were oriented at 0 degrees and 60 degrees, then the two receptors would be receiving different signals and therefore different polarisation information. This different polarisation information is then compiled to determine the orientation of the sun relative to the insect, which then allows the insect to navigate back to its nest if it is foraging for food.

Aweigh structures its circuit based on the neurons of these insects. Instead of just orienting the individual relative to the sun, Aweigh uses processing to find the position of the sun.

CELESTIAL NAVIGATION

Celestial navigation is the process of taking 'sights' or angular measurements between the earth and various celestial bodies in order to find the person's position on earth. Celestial bodies, by which we mean the stars in the night sky, the moon and the sun, can be used as geographic reference points. At a given time, any celestial body is located directly over one point on the Earth's surface. For example Polaris, or the North Star, stays within 1° of true north. In exploring historical navigation technologies, we found celestial navigation inspiring because of the universal accessibility of sunlight, and the impossibility of the celestial bodies being controlled.

Later on in the 'How to' section, we show how it is possible, at the time of the solar meridian, or when the sun is highest in the sky, to calculate a person's latitude and longitude using only the



sun. There are two other methods of finding latitude and longitude at any time of day, one known as the intercept method and the other by using a compass to find north. Both of these methods are explained in more detail on the website.

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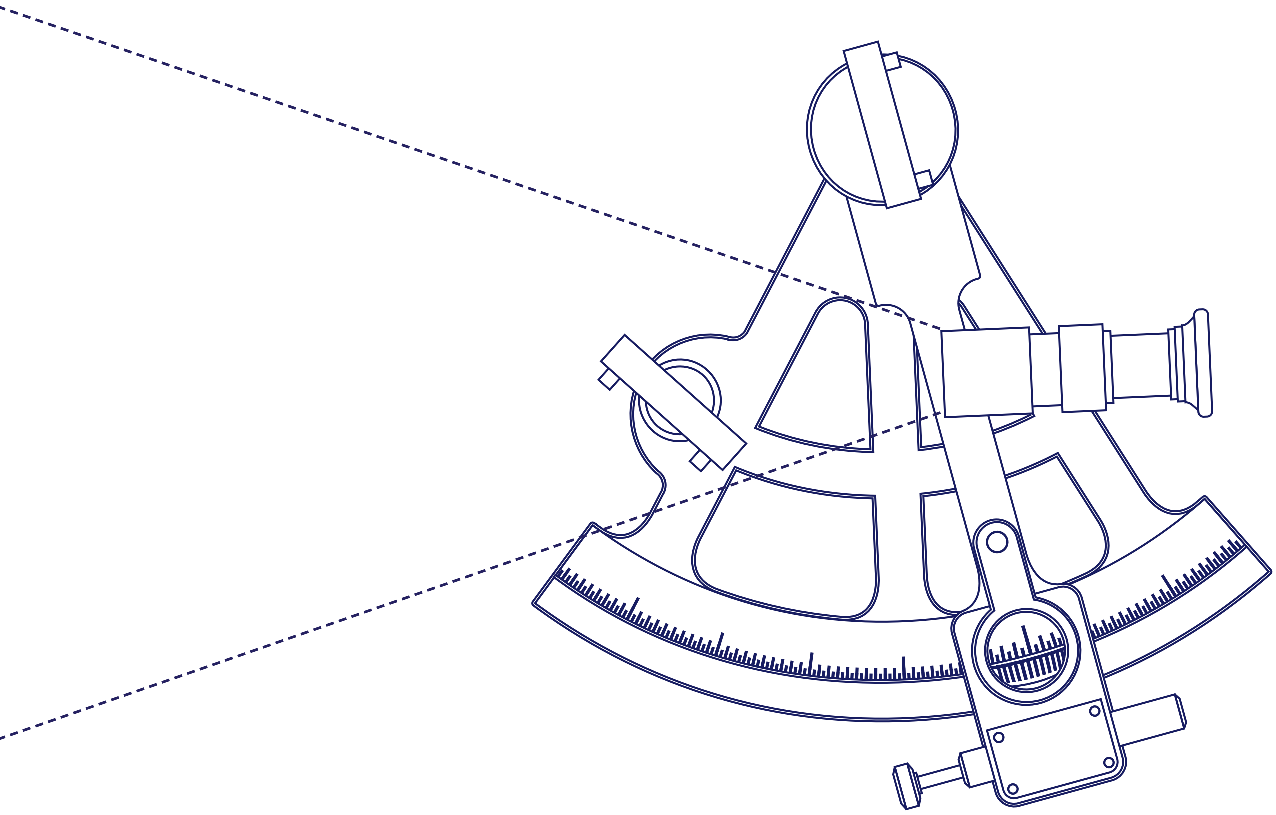
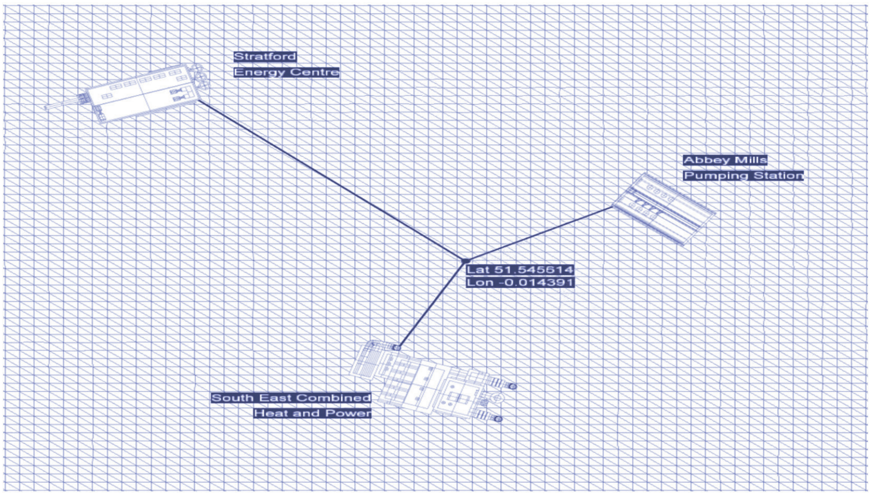


Inspirations

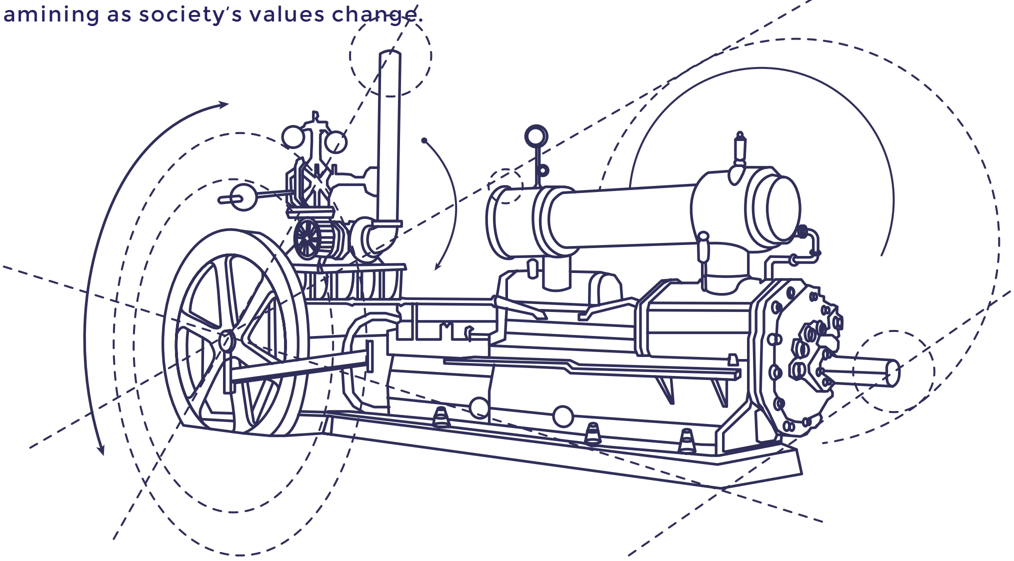
PHILIPP RONNENBERG: OPEN POSITIONING SYSTEM (19)

In Ronnenberg's words "The Open Positioning System is an alternative navigation system based on seismic vibrations. It is an open navigation system. This means that it is not run nor controlled by companies or governmental institutions." We were inspired by his idea of replicating the logic of a ubiquitous technology (GPS) and decentralising it, but did not want our work to sit in a speculative realm. Also this is part of a series which offers 'appropriate methods to prepare for the kill switch after a cyberwar', and we did not want our project to be confined to only end-of-the-world scenarios.



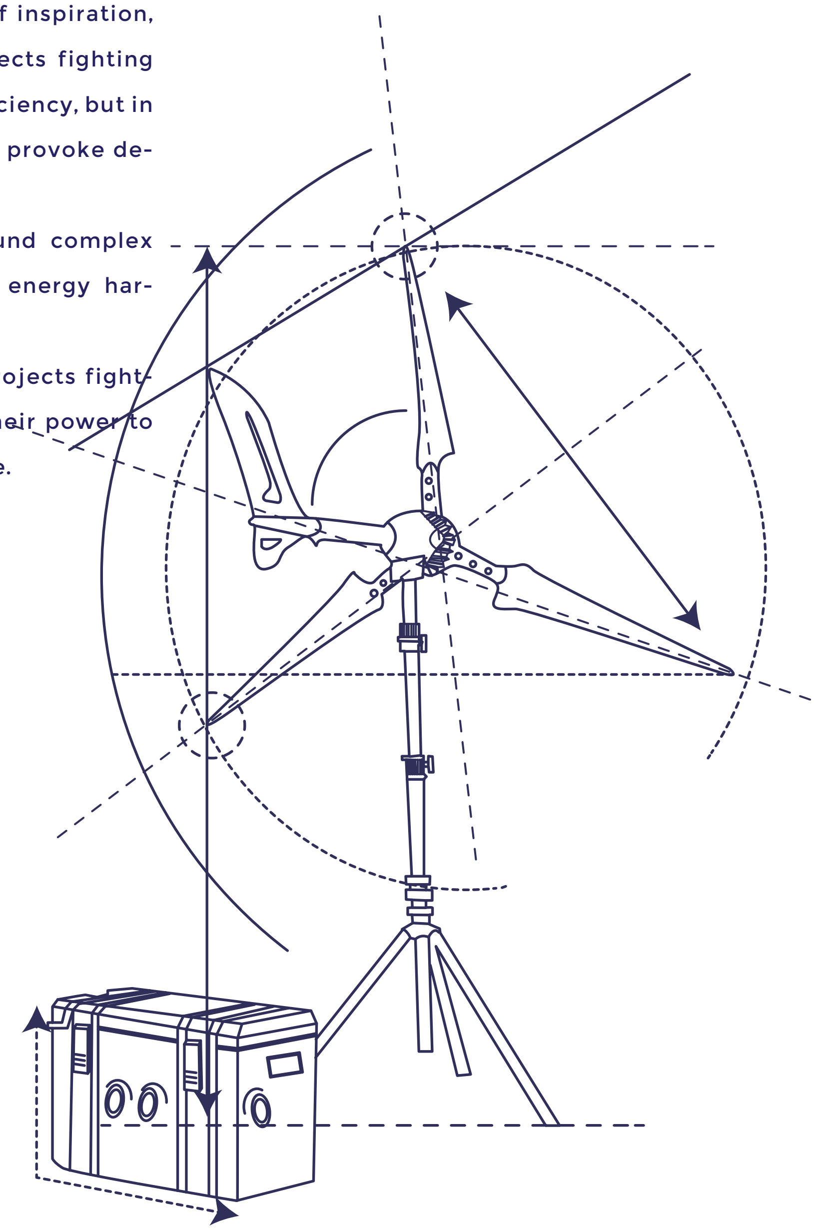
AIR COMPRESSION ENERGY STORAGE

By compressing air potential energy is stored which is released as when it is uncompressed. Notable uses in the past have been cars which ran on compressed air and Paris's air compression network which kept clocks in time, however now it is almost forgotten. It is a low-tech-technology, with few moving parts, of low cost, and, when used in sophisticated ways (the waste heat used for warmth), and the efficiency is very high. Air compression gave us the insight that obsolete technologies are worth re-examining as society's values change.



JULIAN OLIVER: HARVEST PROJECT (20)

This project uses wind energy to mine cryptocurrency to fund climate-change research.
Empowers the individual against the systemic, economic, political. Harvest uses wind energy to mine cryptocurrency to fund climate-change research. It empowers the individual against the systemic, economic, political aspect of climate change. Oliver creates a transparency around complex technologies such as alternative energy harvesting and cryptocurrency. In fact all of Julian Oliver's work has been of inspiration, but this shows the power of projects fighting climate change not only lies in efficiency, but in their power to convey an idea and provoke debate. I aspect of climate change
Builds a transparent system around complex technologies such as alternative energy harvesting and cryptocurrency.
Insight: sometimes the value of projects fighting lies not in efficiency, but in their power to convey an idea and provoke debate.



How It Works

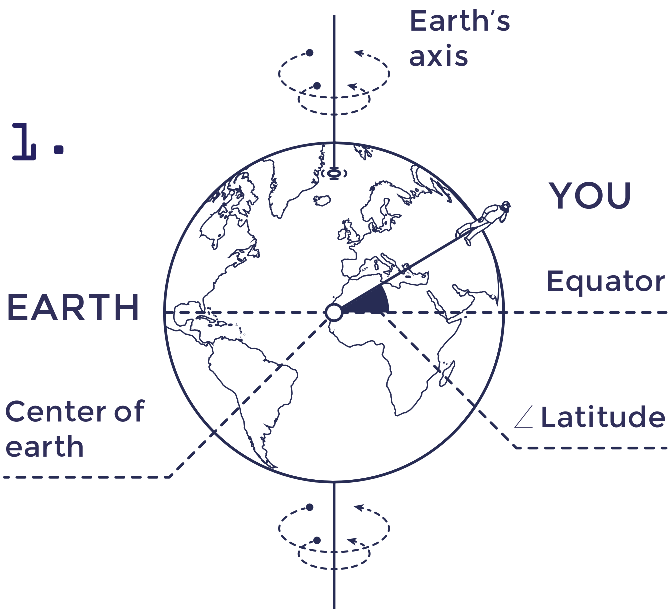
This section is meant to explain briefly how the device works. It starts with the theory behind how a sextant can be used to find a user's longitude and latitude. These concepts are very complicated as your latitude is calculated by a combination of the sextant angle, the time of day, the day of the year, even atmospheric conditions at the time of taking measurements. Links to more information is shown.

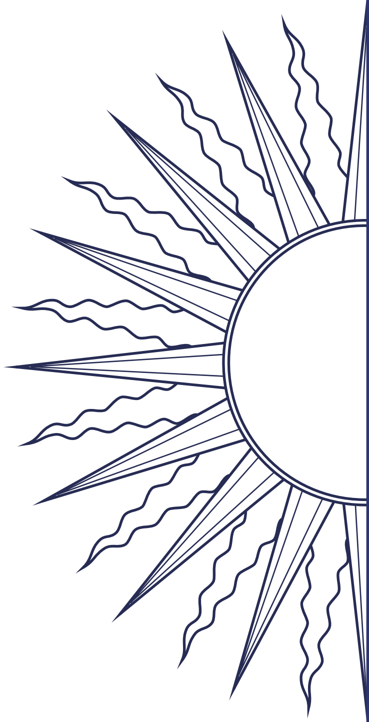
Next the technology behind finding the position of the sun is described. Again, this is a complex process which is difficult to show to a wide audience without leaving certain details out. There is a balancing act between showing so little information that our device becomes another black box, and showing such detail that the average reader will become lost. We decided to keep the explanation more brief in the book yet still explain all the core aspects, and leave the full detail to the website for anyone who chooses to read further. This technology is open source, meaning that anyone can change the code however they want for their own device. We also encourage users to write to us (or push them on our Github) for any improvements on the device or areas they see as being unclear.

It is too much to expect that a reader of this section will come away with a full understanding of how the technology works, but our aim is to make all of the details behind the project open for anyone to study, giving people the ability to understand it if they choose to spend the time reading the source code. Detailed notes will be given in the source code to help with understanding.

Finding Latitude

1.

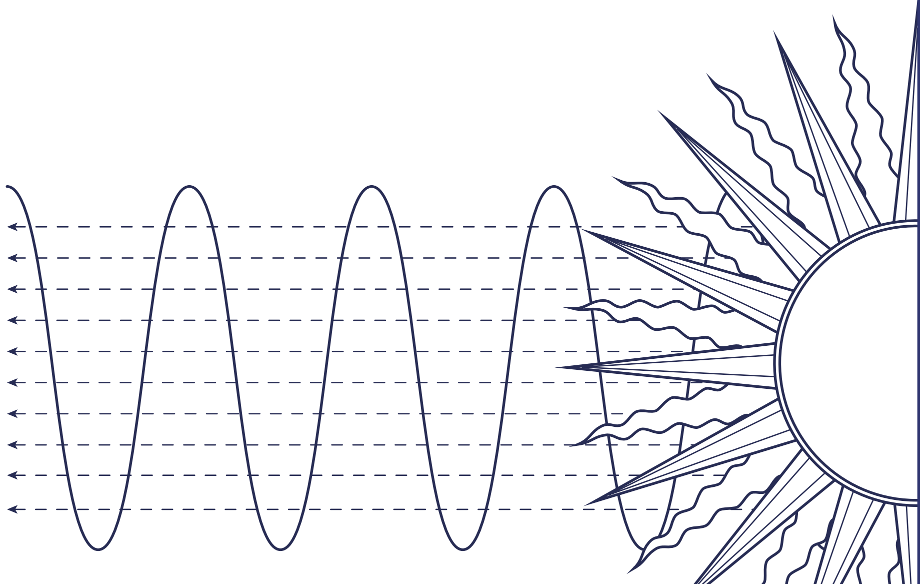




You latitude is the angle between you and the equator from the center of earth.

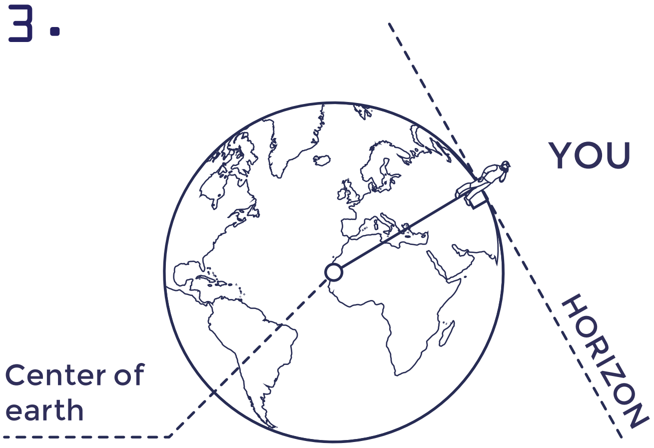
1 ~ 149.597.870.700m

2.



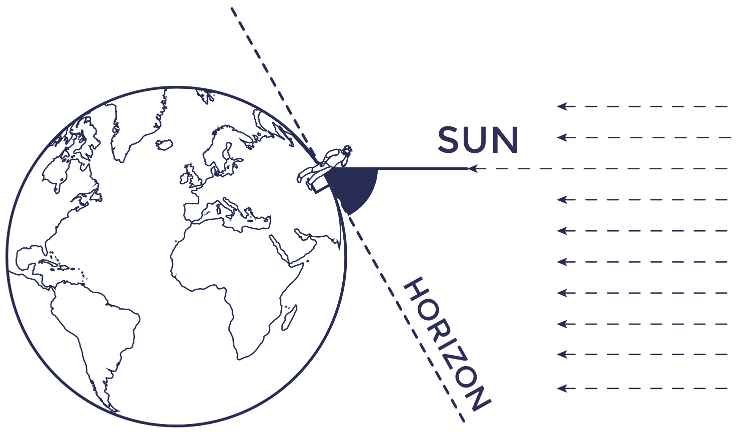
The sun is so far away that no matter which latitude you are at the sun will be hitting at the same angle.

3.

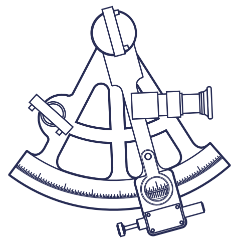


The horizon acts as the tangent to the surface of the Earth at your location.

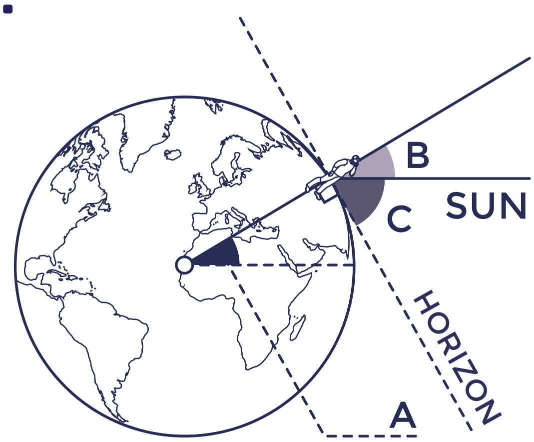
4.



The sextant allows a user to measure the angle between the sun and the horizon.



5.



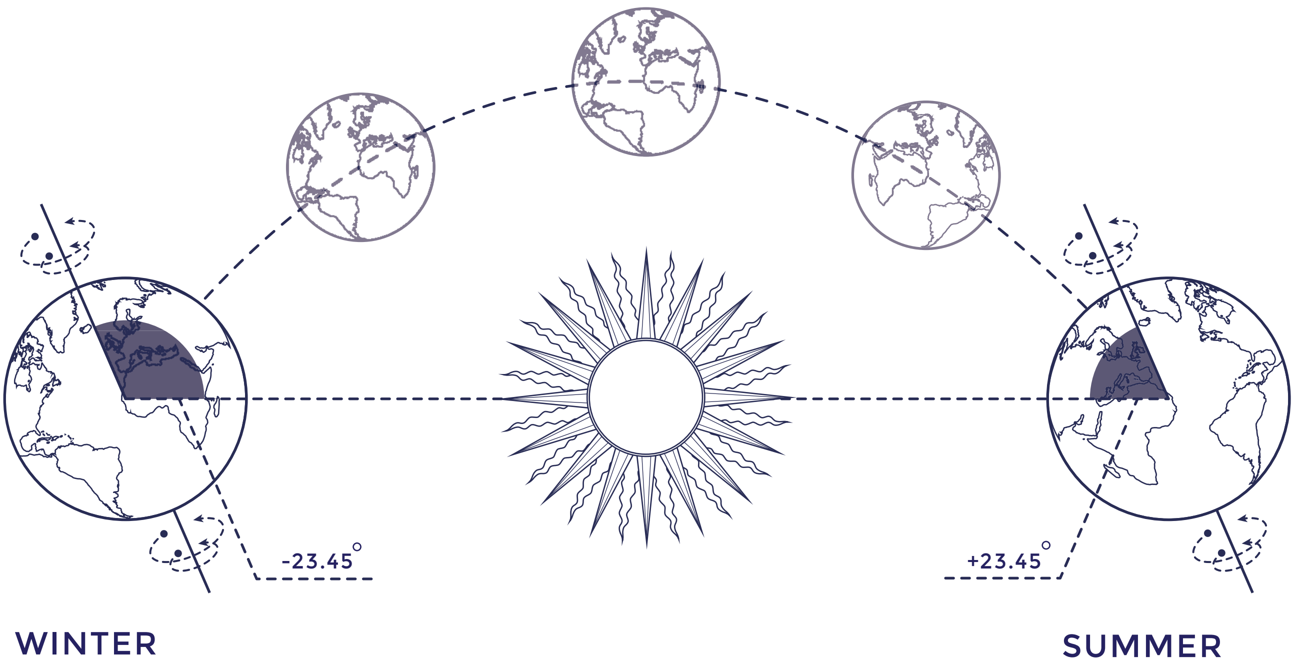
$\angle A = \angle B$

$\angle B = 90^\circ - \angle C$

$= 90^\circ -$ measured angle

Taking the point directly above an obersver's head (known as the zenith) and the horizon, we have a right angle. Using this information and subtracting the angle between the sun and the hirozn, we have the equation for latitude.

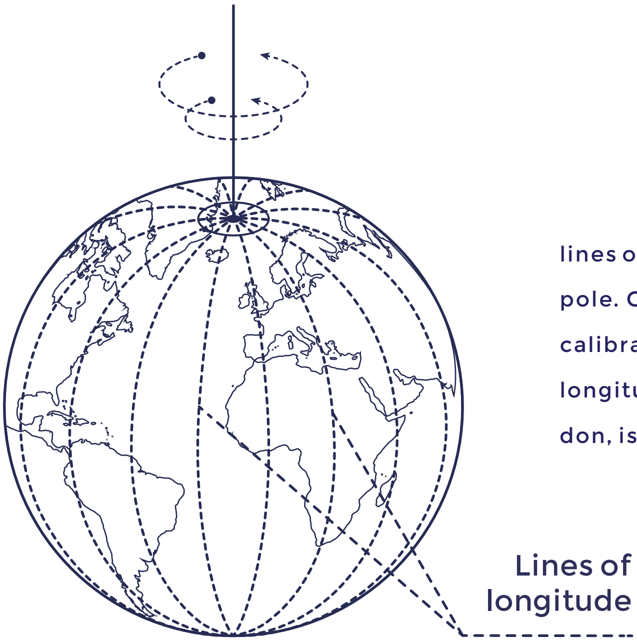
6.



In reality, the axis of the earth is at a tilt. This tilt changes throughout the year between ± 23.45° . A nautical Almanac contains the angle of tilt for every day of the year (also called the earth's declination). To compensate the equation becomes 90 - earth's declination at that day - measured angle = Latitude.

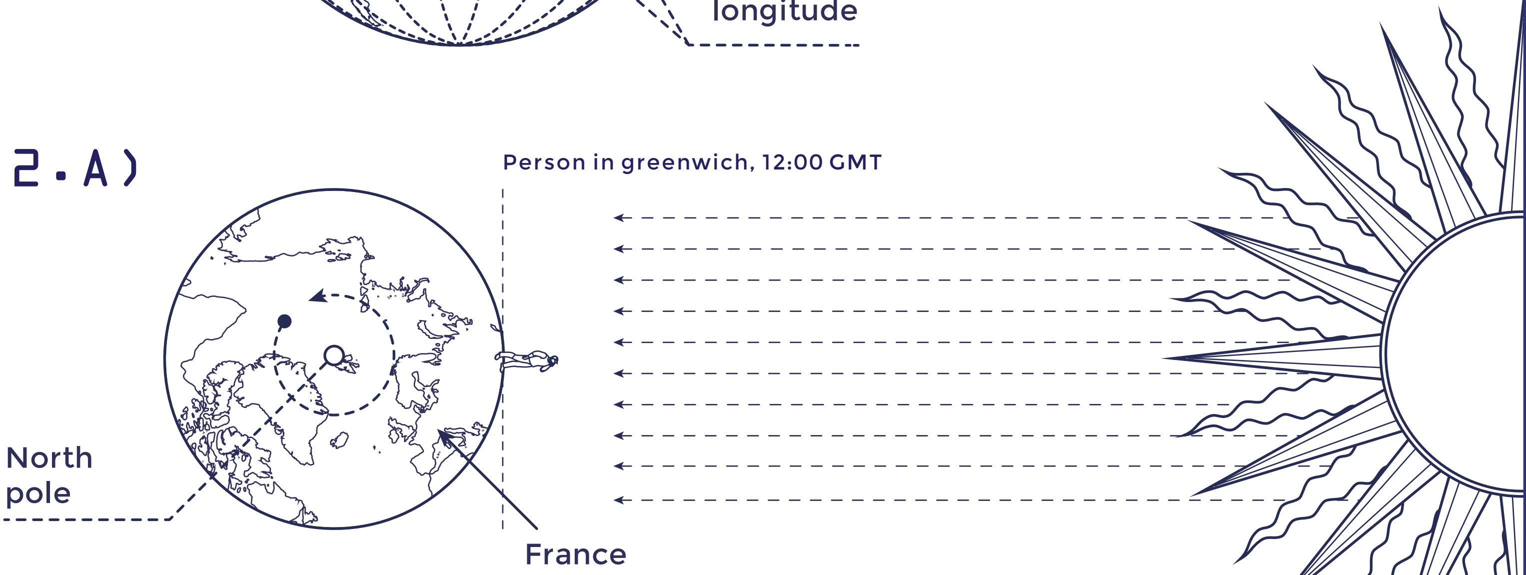
Finding Longitude

1.



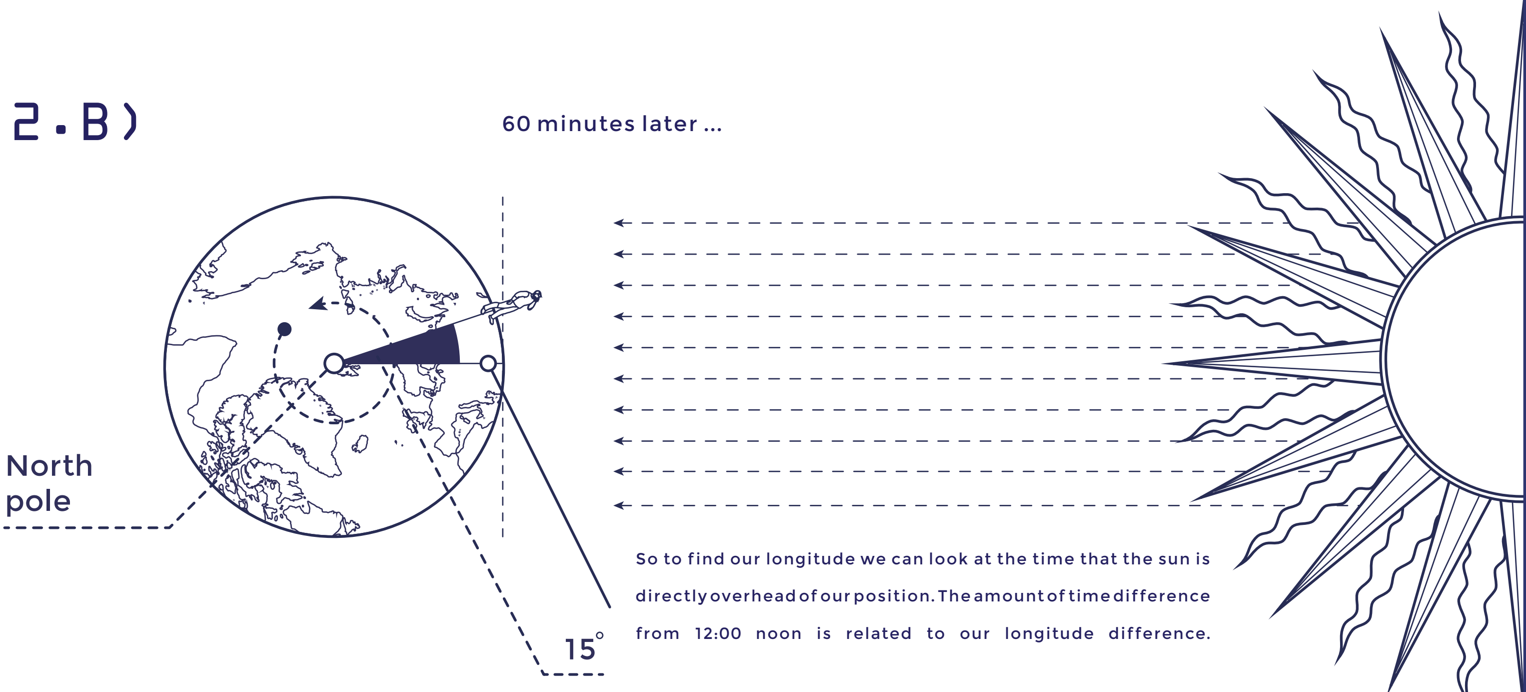
lines of longitude run from the north to the south pole. Greenwich Prime Meridian is the standard calibration for Longitude, which means that the longitude line which crosses Greenwich, London, is 0°.

2.A)



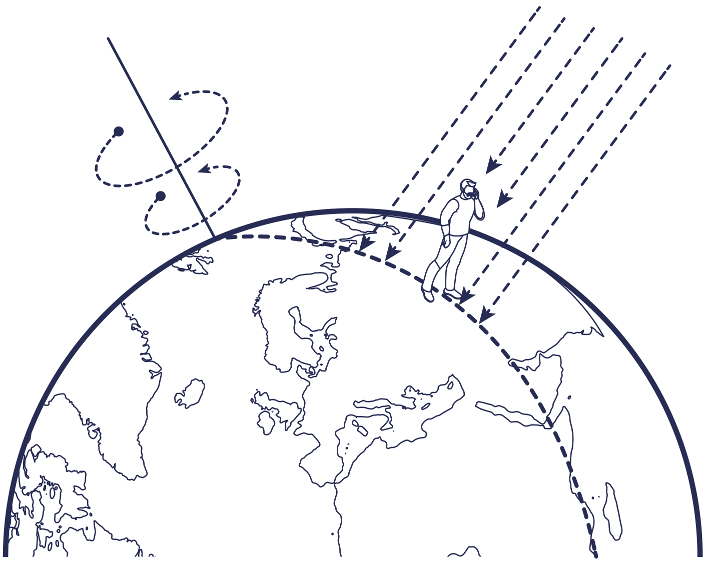
longitude splits the earth into 360°, and within 24 hours the sun will pass above all 360° (from the view of earth). If the sun starts directly overhead of greenwich at 12:00 GMT, one hour later the sun will be directly overhead of 15° west.

2.B)



So to find our longitude we can look at the time that the sun is directly overhead of our position. The amount of time difference from 12:00 noon is related to our longitude difference.

3.



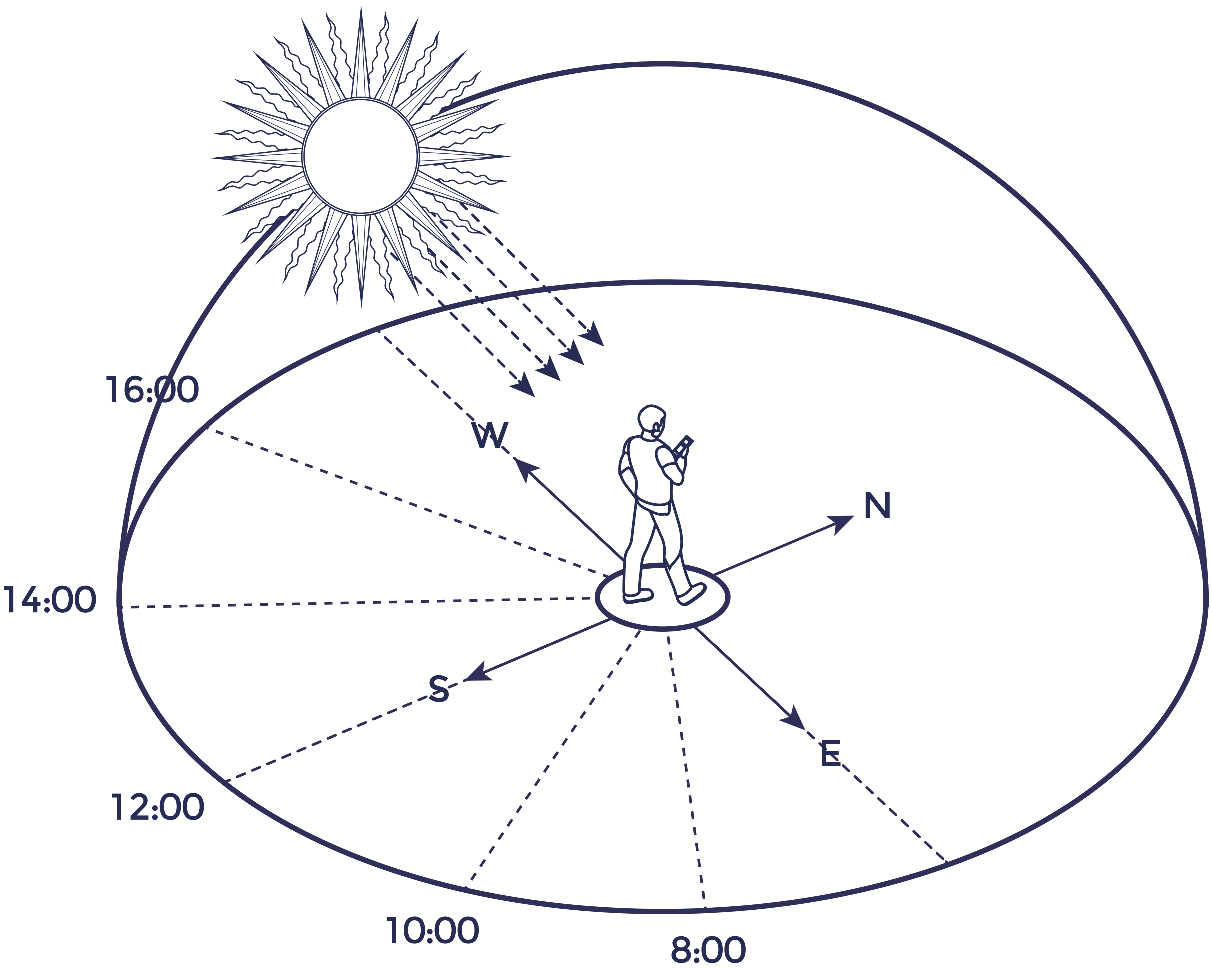
If person has clock set to GMT, and sun is highest overhead at 15:45, then difference is 3h45 or 3.75 hours.

Longitude = 15 degree x 3.75

= 56.25 degree

To find our longitude at any time of day, we need to know north. For this we can use a compass. Then in the northern hemisphere the sun's direction will be directly south when it is highest (and opposite in the southern hemisphere). Using a combination of other factors you can find what angle the sun will be at every time of day. (this is explained in more detail on the website)

4.



How Aweigh calculates your position

1. INTRO

Navigation technology is an essential ability for the survival, development, and organisation of both animals and humans. Aweigh combines a biomimetic hardware mechanism with an algorithm inspired by obsolete technologies to calculate the latitude and longitude of the user. This technology is currently being developed and performance tested as a novel insect-inspired optical compass sensor for applications, such as a hexapod walking robot.

See:

Doi: 10.1038/srep09725

https://doi.org/10.1016/S0921-8890(99)00064-0

DOI: 10.1109/IROS.2017.8206183

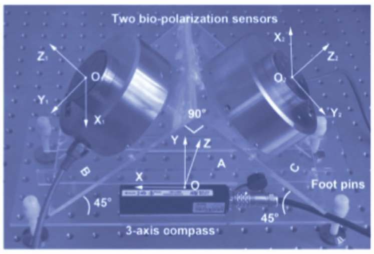


Figure 1 | Structure of the position device and three left-handed coordinate systems. Plane A is the baseboard with a 3-aixs compass, see Supplementary Information SI for details. Plane A is made horizontal by adjusting foot pins with the help of the electronic level meter when the device is being used. Two polarized-light sensors or bio-polarization sensors are set on plane B and plane C, respectively. Three left-handed coordinate systems are built. X_1 and Y_1 are parallel to plane B. X_2 and Y_2 are parallel to plane C. The intersection lines of the three planes are parallel to each other and perpendicular to X, Y_1 and Y_2 respectively. The intersection angles of A and B, A and C and B and C are 45°, 45° and 90°, respectively.

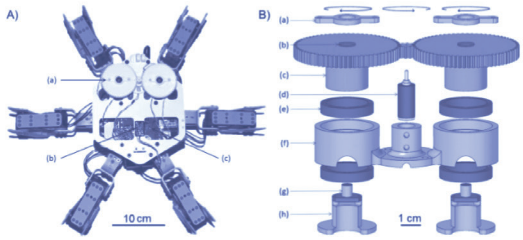


Fig. 2. **A.** Top view of the Hexabot robot equipped with the UV-polarized light compass. (a) UV-polarized light compass; (b) MinImu-9 v.3 gyro, accelerometer & compass (Pololu) used for ground truth measurement of absolute heading direction; (c) Raspberry Pi 2B board. **B.** An exploded view of the UV-polarized light compass. (a) 3D-printed fixation (PLA, polyactic acid) for the UV sheet polarizer; (b) UV linear sheet polarizer (HNP'B replacement, UV grade 275 – 750*nm*); (c) 3D-printed gears (PLA); (d) stepper motor AM0820-A-0,225-7 (Faulhaber); (e) ball bearing; (f) 3D-printed support (PLA) for gears, ball bearings and stepper motor; (g) UV-light sensor SG01D-18 (SgLux); (h) 3D-printed support (PLA) for UV-light sensor.

1. WORKING PRINCIPLE

A) Rayleigh scattering model

Aweigh begins by placing its user within the Rayleigh scattering model, which is an approximation of the sky that takes into account the interactions between light and matter. It explains the optical phenomenon that causes the sky to appear blue. Researchers much smarter than ourselves have come up with a mathematical model, which is described by the looking relationships below:

Λ: wavelength of incoming light

Θ: scattering angle

H: altitude of the point

n: refractive index of air

N: molecular number density

ρ(h): density ratio

$$I = I_0 \, S\left(\lambda, \theta, h\right)$$

$$S\left(\lambda, \theta, h\right) = \frac{\pi^2 \left(n^2 - 1\right)^2}{2} \underbrace{\frac{\rho\left(h\right)}{N}}_{\text{density}} \overbrace{\frac{1}{\lambda^4}}^{\text{wavelength}} \underbrace{\left(1 + \cos^2 \theta\right)}_{\text{geometry}}$$

These relationships enable us to take into account the polarization pattern of skylight, caused by the scattering phenomenon within the Earth's atmosphere. The scattering interactions with atmospheric molecules induce a partially linear polarization of skylight, which means that the direction of the linear polarization of skylight at the zenith point is always perpendicular to the solar meridian. The figure below shows how patterns of polarisation change for a viewer at position O.

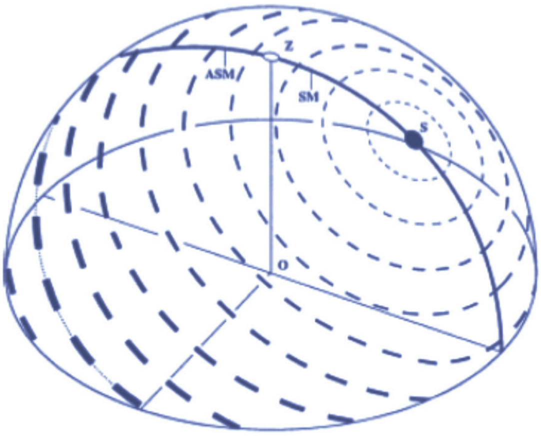


Fig. 1. Three-dimensional representation of the pattern of polarization in the sky, as experienced by an observer in point O. The orientation and width of the bars depict the direction and degree of polarization, respectively. A prominent property of the pattern is a symmetry line running through the sun (S) and zenith (Z), called "solar meridian" (SM) on the side of the sun and "antisolar meridian" (ASM) on the opposite side.

The other significant property in the Rayleigh scattering light model is that the degree of polarization is related to the scattering angle. In other words, the scattering angle increases from 0 degrees to 90 degrees and will decrease when the scattering angle increases from 90 degrees to 180 degrees. In the figure below, the angle of polarization for an arbitrary scattered beam of light was defined.

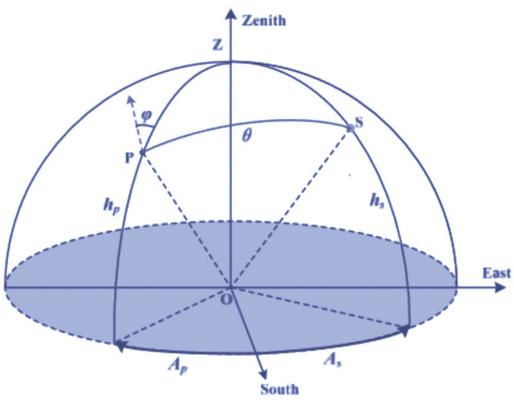
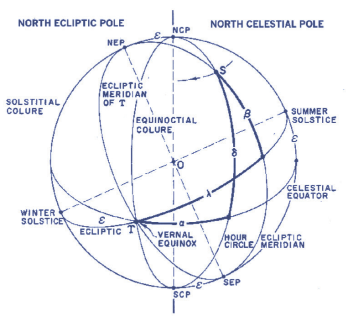


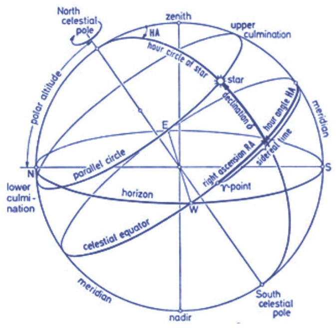
Figure 1. The angle of polarization (AOP) of an arbitrary scattered skylight as experienced by an observer in point O. S stands for the solar position and Z stands for the zenith. P stands for the direction of scattered light. h_s and h_p stands for the elevation angle of sun and skylight, respectively. A_s and A_p stands for the azimuth angle of sun and skylight, respectively. θ stands for the scattering angle. φ stands for AOP, which is the angle between the polarization direction (the blue arrow) and the reference plane (OPZ).

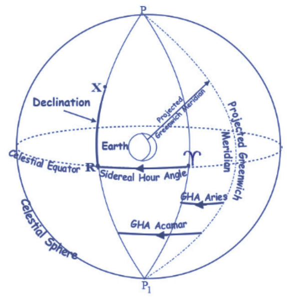
This means that if we can somehow measure the angle of polarization of sunlight from a viewer's position, we can understand the general pattern of light scattering in the sky. The goal is to determine the position of the sun, which will then enable us to calculate latitude and longitude.

B) Celestial sphere approximation

In astronomy and celestial navigation, the relationship between the observer's position and solar angles are given by a number of different variables, each relating to celestial bodies and changing over time. If you go online, you'll be able to find an entire range of different relationships and values, which have been used in the past for different applications.







Aweigh's algorithm is interested in two specific variables that describe the user's position relative to the sun:

h = solar altitude

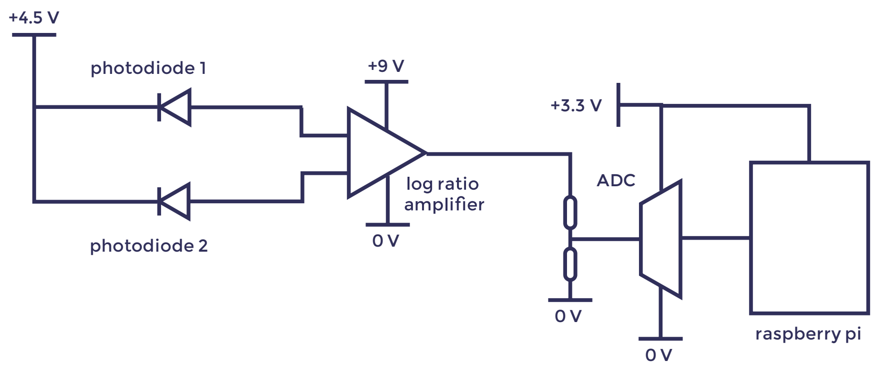
Φ = solar azimuth

The solar altitude is the angle of the sun relative to the Earth's horizon. This angle varies based on the time, the day, and it related to the latitude of the viewer. The solar azimuth angle is the horizontal angle that defines the sun's relative direction along the local horizon. These two values are calculated from readings taken by the polarization sensors and allow Aweigh to calculate the "coordinates" of the Sun. Once you are able to locate the exact position of the sun, you can also locate yourself by using trigonometric relations within the celestial sphere approximation.

3. CALCULATIONS EXPLAINED

The following explanation describes each step of Aweigh's technology, which combines principles from the Rayleigh scattering model and the celestial sphere approximation.

Aweigh first takes readings from a hardware system composed of a pair of polarized light sensors, followed by log-ratio amplifier. the polarization sensors together model the configuration of desert-ant eyes: if a continuous amount of data points are taken, a three-dimensional representation of the polarization pattern of the sky would appear. The log-ratio amplifiers allow light measurements from the sky to be normalised and enable us to perform a comparison of polarised light values at different angles.



The output of the polarization sensors is described by the following equation:

$$s(\phi) = KI\left(1 + d\cos(2\phi - 2\phi_{\max})\right) \qquad (1)$$

where I is the total intensity given by $I = I_{\max} + I_{\min}$, with $I_{\max}$ and $I_{\min}$ being the maximum and minimum intensities, respectively. d is the degree of polarization, ϕ is the current orientation with respect to the solar meridian, $\phi_{\max}$ is the value that maximizes $s(\phi)$, and K is a constant. The outputs of the direction analyzers are described by

$$p_1(\phi) = \log_{10}\left(\frac{1 + d\cos(2\phi)}{1 - d\cos(2\phi)}\right)$$
$$p_2(\phi) = \log_{10}\left(\frac{1 + d\cos\left(2\phi - \frac{2\pi}{3}\right)}{1 - d\cos\left(2\phi - \frac{2\pi}{3}\right)}\right) \qquad (2)$$

Equations (2) assume a difference of 60 degrees between the two sensor configurations. We need to now solve for the two values p1 and p2 by using an inverse logarithm and a trigonometric function operation.
First, we apply a sigmoid function:

$$\frac{1}{10^{p(\phi)} + 1} = \bar{p}(\phi). \qquad (3)$$

This means that our equations for p1 and p2 have now become:

$$\tilde{p}_1(\phi) = 1 - 2\bar{p}_1(\phi) = d\cos(2\phi) \qquad (4)$$
$$\tilde{p}_2(\phi) = 1 - 2\bar{p}_2(\phi) = d\cos\left(2\phi - \frac{2\pi}{3}\right) \qquad (5)$$

Then, we want to eliminate the influence of the polarization degree by presenting a new transform:

$$t_1(\phi) = \frac{\tilde{p}_1(\phi) - \tilde{p}_2(\phi)}{|\tilde{p}_1(\phi)| + |\tilde{p}_2(\phi)|} \quad (7)$$

$$t_2(\phi) = \frac{\tilde{p}_2(\phi) - \tilde{p}_3(\phi)}{|\tilde{p}_2(\phi)| + |\tilde{p}_3(\phi)|} \quad (8)$$

Once we simplify these relationships, we obtain:

$$t_1(\phi) = \begin{cases} 1, & \phi \in [0, \frac{\pi}{12}) \cup [\frac{3\pi}{4}, \pi) \\ -\sqrt{3}\tan\left(2\phi - \frac{\pi}{3}\right), & \phi \in [\frac{\pi}{12}, \frac{\pi}{4}) \\ -1, & \phi \in [\frac{\pi}{4}, \frac{7\pi}{12}) \\ \sqrt{3}\tan\left(2\phi - \frac{\pi}{3}\right), & \phi \in [\frac{7\pi}{12}, \frac{3\pi}{4}) \end{cases} \qquad t_2(\phi) = \begin{cases} \sqrt{3}\tan(2\phi), & \phi \in [0, \frac{\pi}{12}) \cup [\frac{11\pi}{12}, \pi) \\ 1, & \phi \in [\frac{\pi}{12}, \frac{5\pi}{12}) \\ -\sqrt{3}\tan(2\phi), & \phi \in [\frac{5\pi}{12}, \frac{7\pi}{12}) \\ -1, & \phi \in [\frac{7\pi}{12}, \frac{11\pi}{12}) \end{cases} \quad (10)$$

This results in a new way of characterizing p1 and p2, now defined as s1 and s2:

$$s_1(\phi) = \frac{1}{2}\arctan\left(\frac{t_1(\phi)}{\sqrt{3}}\right)$$

$$s_2(\phi) = \frac{1}{2}\arctan\left(\frac{t_2(\phi)}{\sqrt{3}}\right) \quad (12)$$

These relationships show that we can calculate the polarization degree of each sensor from the values read directly. Next, we solve for a variable, which we will call c for simplification, by performing the following set of simultaneous equations:

$$c = \begin{cases} -\sqrt{3}\tan(2\phi - \frac{\pi}{3}) \\ -\sqrt{3}\tan(2\phi - \frac{\pi}{3}) \end{cases} \quad (13)$$

The variable c corresponds to the polarization angle of the user's current position. The algorithm needs this value to determine the solar azimuth:

$$\phi = \frac{\arctan(-\frac{c}{\sqrt{3}}) + \frac{\pi}{3})}{2}$$

$$\phi = \text{Solar Azimuth} \quad (14)$$

The polarisation reading s1 and s2 are required to calculate the solar altitude described by:

$$\tan(h_s) = \frac{\sqrt{2}\sin(s_1 - s_2)}{\sqrt{\left[\frac{-\sqrt{2}\sin(s_1 + s_2)}{2}\right]^2 + [\cos(s_1)\cos(s_2)]^2}}$$

$$h_s = \arctan\left[\frac{\sqrt{2}\sin(s_1 - s_2)}{\sqrt{\left[\frac{-\sqrt{2}\sin(s_1 + s_2)}{2}\right]^2 + [\cos(s_1)\cos(s_2)]^2}}\right]$$

$$h_s = \text{Solar Altitude} \quad (15)$$

Once we have calculated the current solar azimuth and the solar altitude, a few other variables are needed to determine latitude and longitude: day, time, hour angle, and declination.

The hour angle can be found by using the results of the previous calculations:

Hour Angle: $$\omega = \sin^{-1}\left[\frac{-\cos(h_s)\sin(\phi)}{\cos(\delta)}\right] \qquad (16)$$

The current declination can be found by using values taken from the RTC clock:

$$\delta = 23.45\frac{\pi}{180}\sin\left[\frac{2\pi(284+n)}{36.25}\right]$$
$$n = day \qquad (17)$$

When the clock is initialized, it should be set to GMT.

Finally, to output latitude and longitude, the following relationships are used. E, the difference between the true solar hour and the mean solar hour was ignored in the current implementation of our algorithm.

LONGITUDE: $$LONGITUDE = \omega - (UTI + E)*15 + 180$$

LATITUDE: $$\cos(\phi) = \frac{\sin(\delta) - \sin(h_s)\sin(LATITUDE)}{\cos(h_s)\cos(LATITUDE)}$$

The algorithm's output gives: (LATITUDE, LONGITUDE).

The user can then input a destination. In order to find the direction of the true north, the user will also need to input their current city. This will allow Aweigh to define the magnetic declination and finally trace a vector between the user's current position and their desired destination.

Aweigh

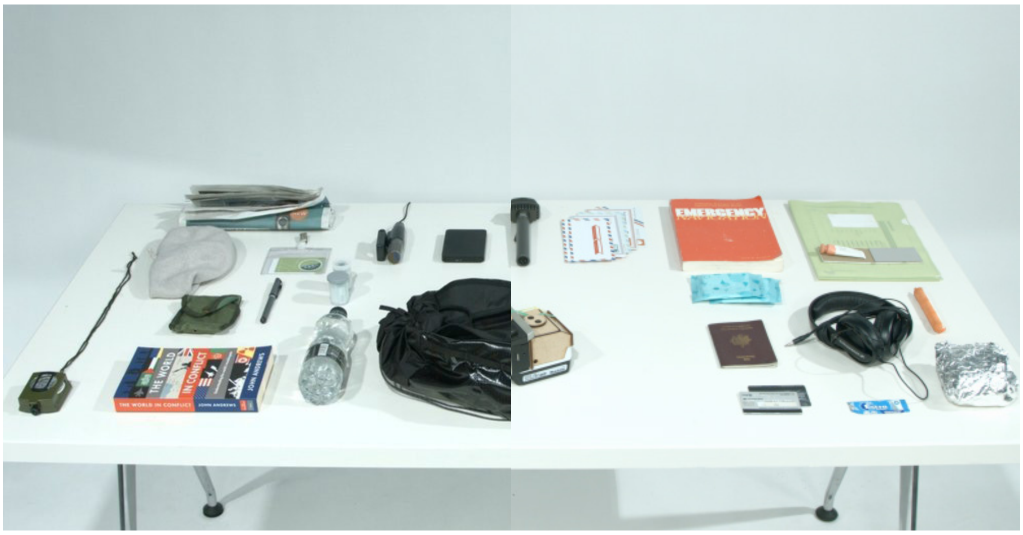
The physical aspect of Aweigh comes in three different options as the aim was to reach as many people as possible. In the section that follows, each option, known as 'Variations" are described. Instructions for how to use all the Variations are given.

VERSION 1-USE

" Aweigh is not about removing infrastructure, it's about self-determination and self-reliance. "

C. , INVESTIGATIVE JOURNALIST

Aweigh - Version 1 was created for users, like C. , who wish to use a decentralised navigation technology for purely functional reasons. This version of the technology allows one to navigate, independently of network connection, political affiliation, and data surveillance. Aweigh - Version 1 has a small screen on the front connected to a RaspberryPi, attached to a custom PCB and mechanical reading mechanism. Everything is encased in a 3D printed handheld device, which the user can add downloadable accessories to.



List of all the components

Functional navigation device

5V battery or power supply

List of handy equipment

Scissors

Process

Step 1 - Open up Aweigh packaging.

Step 2 - Read instructions and check device for faults.

Step 3 - Plug in 5V battery or power bank.

Step 4 - Turn the device on and follow instructions on the interface.

Step 5 - Anchors aweigh!

Process

Step 1 - Open up Aweigh packaging.

Step 2 - Read instructions and check device for faults.

Step 3 - Plug in 5V battery or power bank.

Step 4 - Turn the device on and follow instructions on the interface.

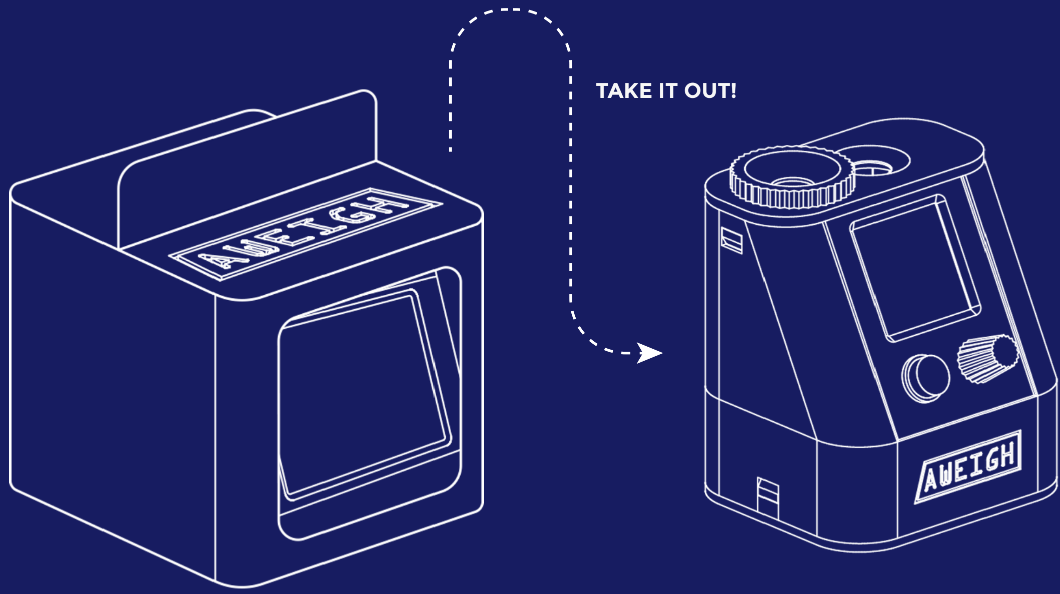
Step 5 - Anchors aweigh!

VERSION 1-USE

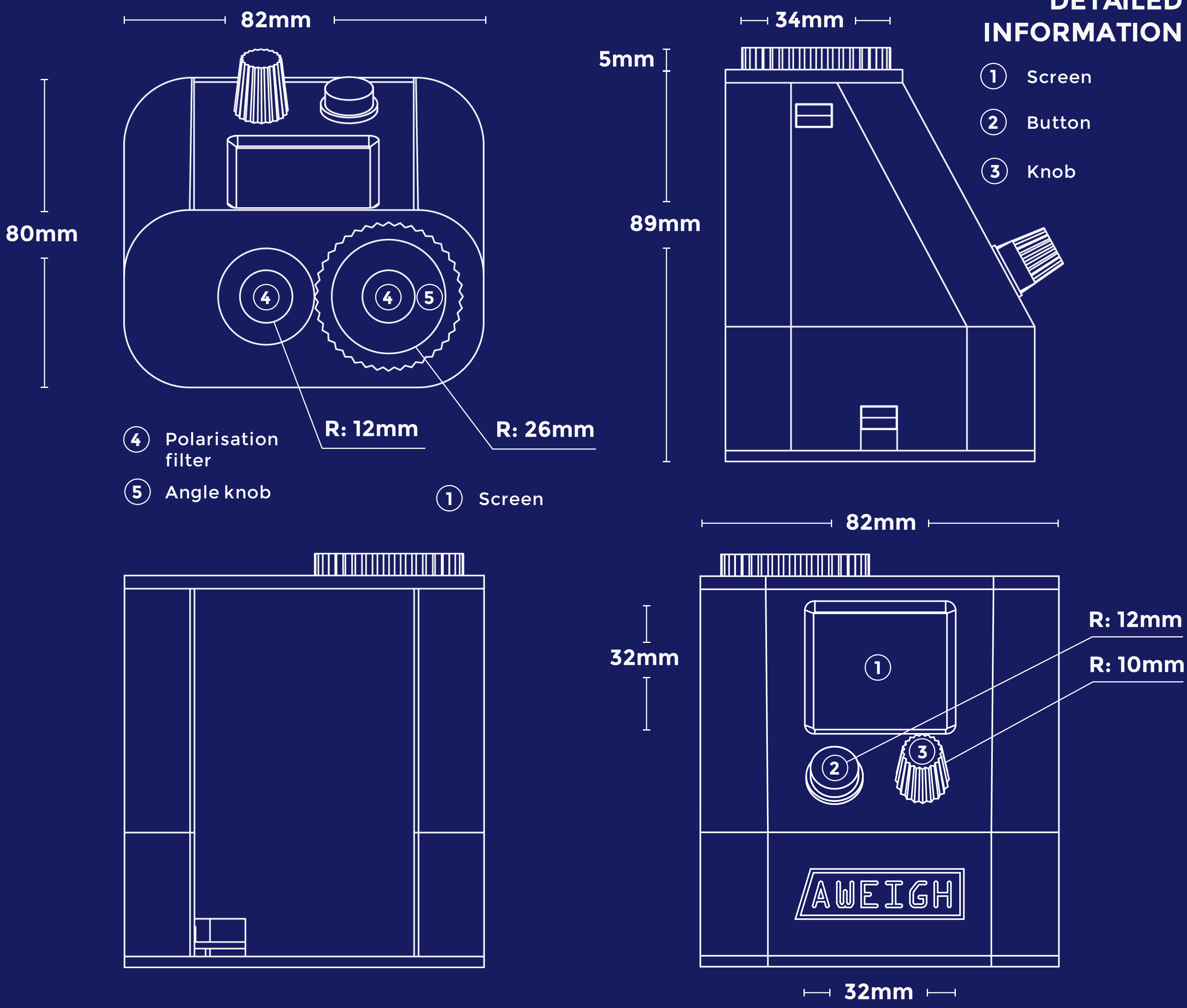
VERSION 1-USE

AWEIGH PACKAGE

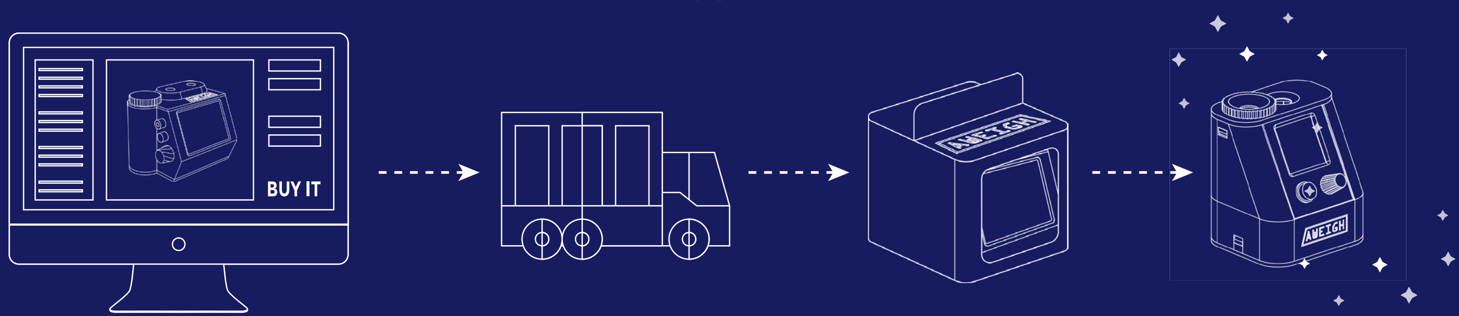
FULL OBJECT



DETAILED INFORMATION



HOW TO GET IT



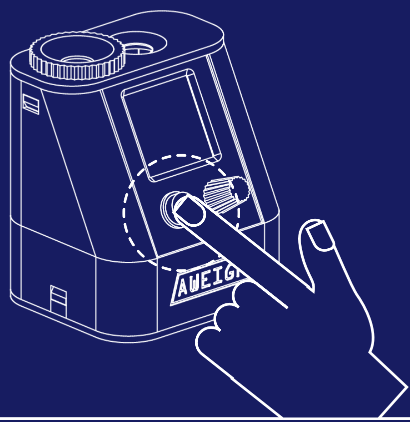
BUY DEVICE VERSION THROUGH THE AWEIGH WEBSITE

WAIT FOR DELIVERY

RECEIVE AWEIGH BOX!

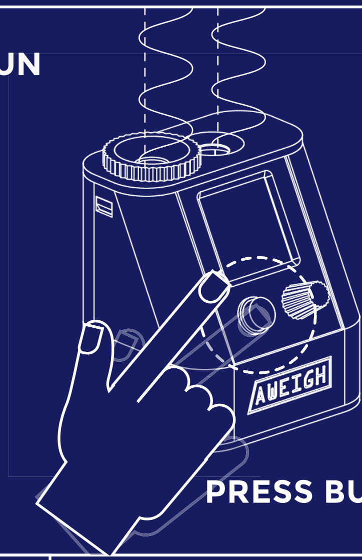
UNPACK

TURN ON BY PRESSING ONE TIME



FIND THE SUN

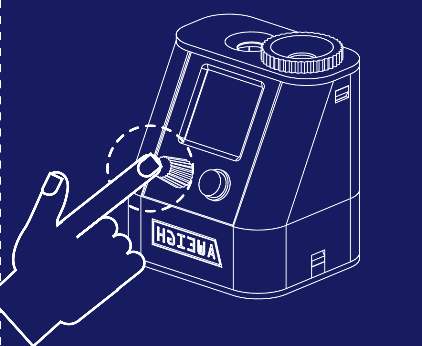
DETECTING...

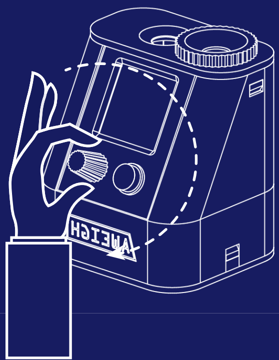


PRESS BUTTON x 2

ENTER DESTINATION

PRESS KNOB TO ACTIVATE LOCATION INPUT INTERFACE



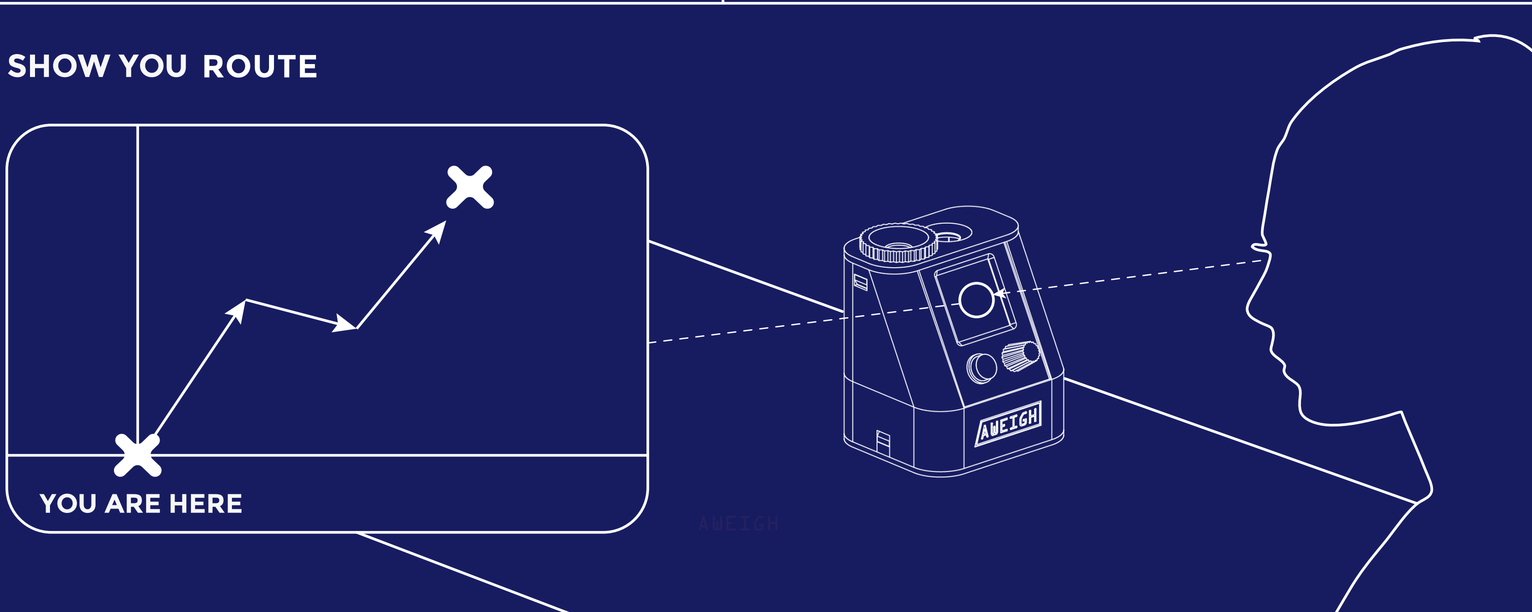


ROTATE THE KNOB TO INPUT LOCATION BY LONGITUDE & LATITUDE

SAVE LOCATION

PRESS BUTTON X 2 FOR SAVING LOCATION FOR NEXT TIME

SHOW YOU ROUTE



VERSION 2-LEARN

" It's important to deprofessionalize knowledge. I think Aweigh does this quite well by producing literacy outside of traditional learning domains. "

M. , MEMBER OF THE ANARCHIST FEDERATION

Aweigh - Version 2 was created for users like M. who align with the project's values and wish to gain more digital literacy. This version of the project uses building blocks for each aspect of the device: hardware, software, and mechanics. It uses the Aweigh self-navigation board, 3D printed templates of inner system, self-snapping casings, and a prepackaged software files. The set up, assembly, and use of these tools are free for the user to modify and build on. All modules are compatible with the latest version of Raspberry Pi. Each component can be ordered through the website or constructed through publicly available means. Version 2 is made to be constructed in a variety of forms chosen for their affordances or aesthetic qualities.

List of all the components

Aweigh self-navigation board - including pre-soldered logamps, photodiodes, polarisation filters, RTC, magnetometer and accelerometer, ADC, and all necessary capacitors/resistors.

3D printed or paper casing

Raspberry Pi Model 3 B+

3D printed mechanical gear and measurement system

3.5″ Raspberry Pi compatible screen

Micro SD card

Micro USB cable for power

USB power supply or battery

List of handy equipment

3D printer

Lasercutter or paper cutting scalpel and ruler

Small Phillips screwdriver (cross head)

Elastic bands or zip-tie

Double-sided tape or glue

Jumper wires

PROCESS

Step 1 - Assemble and download all components from Aweigh website.

Step 2 - Set up software as described in instructions here.

Step 3 - Download all additional module libraries.

Step 4 - Connect self-navigation board to Raspberry Pi according to schematic.

Step 5 - Wire the screen using available pins, observing the orientation of the reading mechanism shaft.

Step 6 - Fit the entire system into the chosen casing and fix using elastic bands or other off-the-shelf attachments.

Step 7 - Turn device on by plugging in the battery to the main board.

Step 8 - Enter Pygame GUI.

Step 9 - Level the device and verify with levelling interface.

Step 10 - Use the button to take a reading.

Step 11 - Wait for the system to register the array of values and determine resolution of the result.

Step 12 - After initial calibration, repeat the reading for positioning.

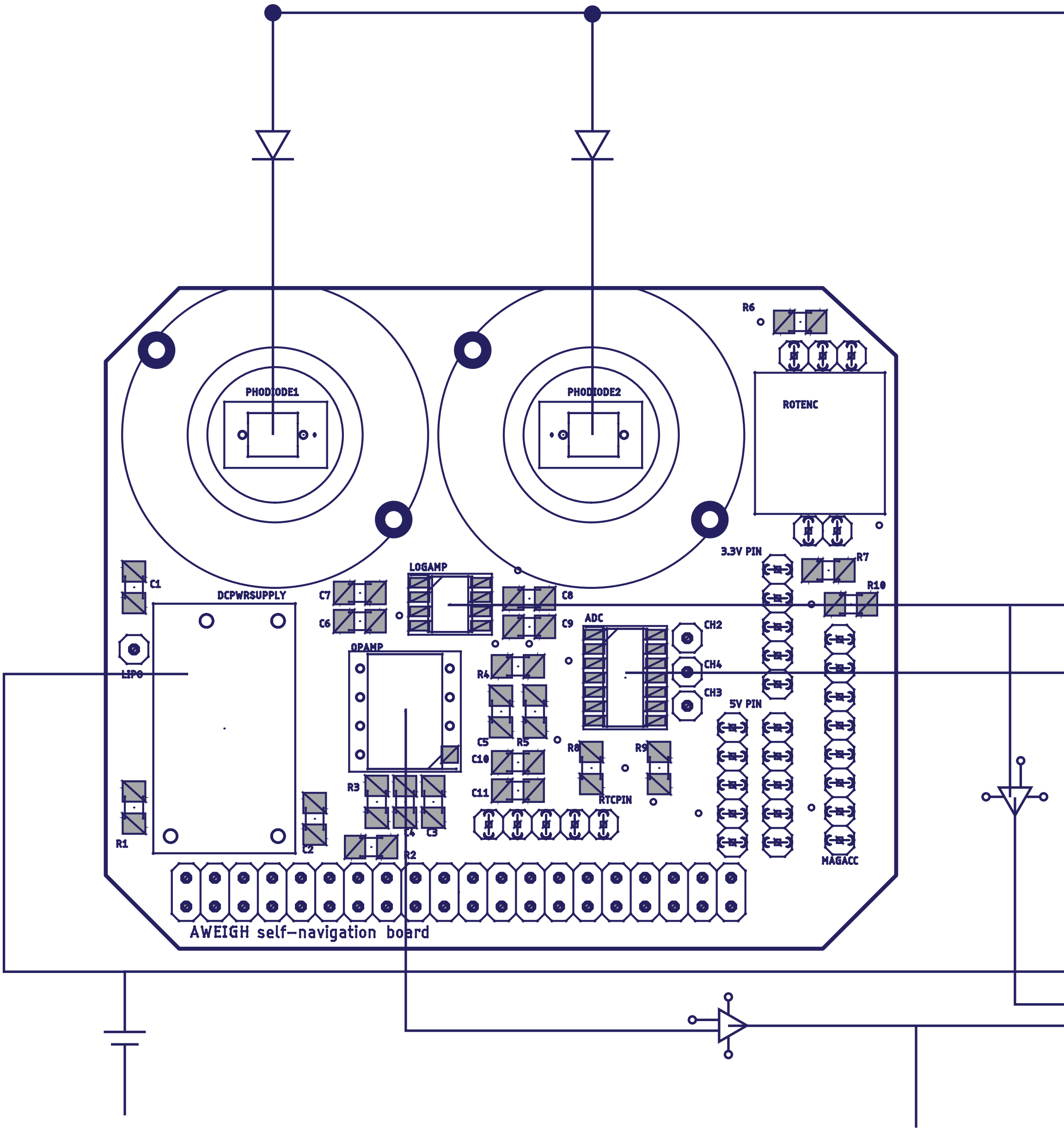
Step 13 - Enter destination latitude and longitude, using the knobs.

Step 14 - Follow the direction of the vector drawn on the GUI and repeat process when necessary during the itinerary.

Step 15 - Anchors aweigh!

SELF-NAVIGATION BOARD

MAIN COMPONENTS:



BOOST DC CONVERTER

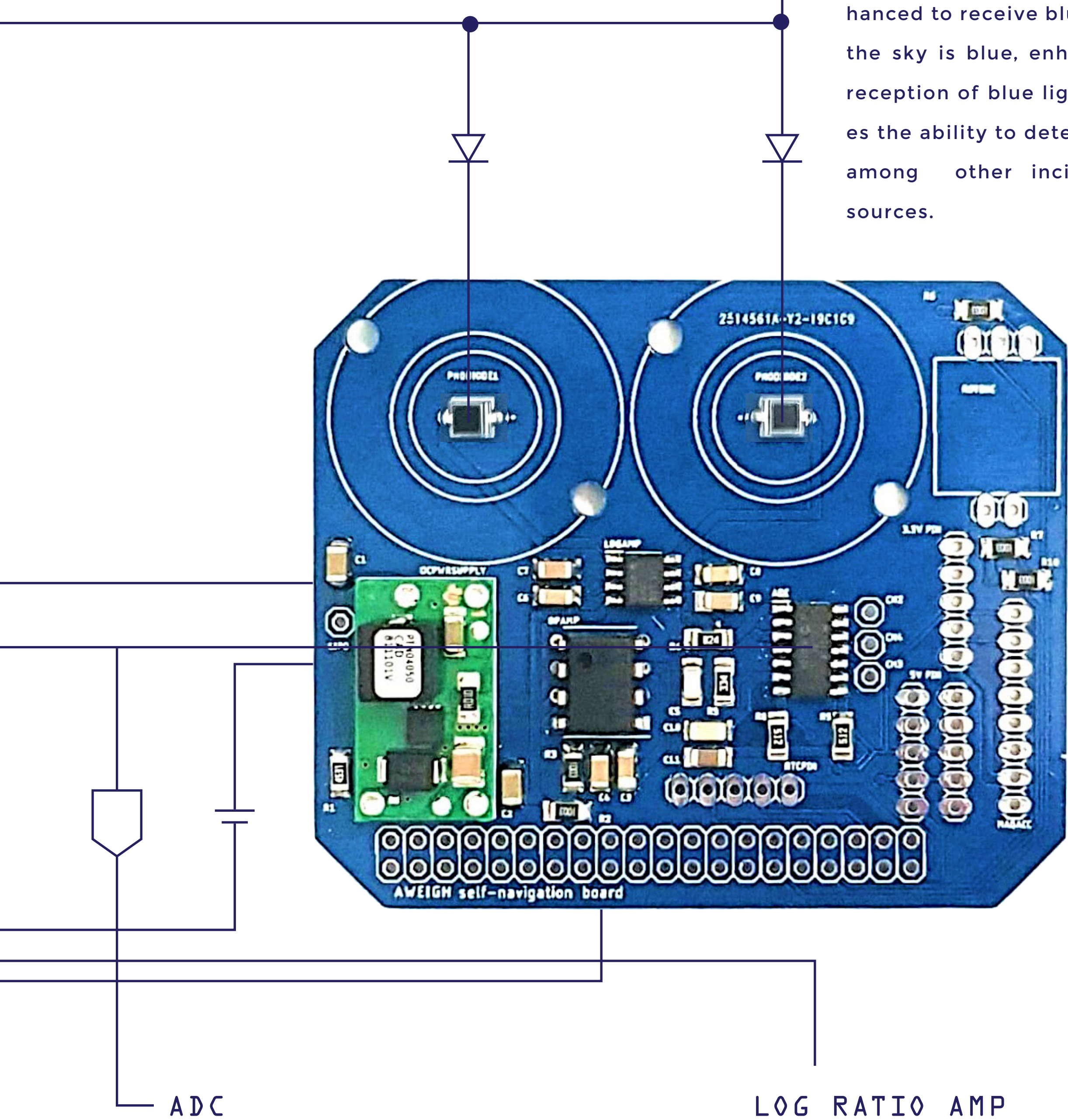
Aweigh's circuit requires 9V. We recognized that providing 9V via batteries is bulky and can get expensive, so we provided this converter which takes 3.7V- the voltage of typical LiPo battery- and outputs 9V.

UNITY GAIN OP AMP

This component is a non-inverting operational amplifier (op amp). Op amps usually amplify an input signal, but in this case the gain of the input signal is 1 to keep our voltage signal stable; without stability accuracy diminishes. 4.5V is the input and 4.5V is the output.

PHOTODIODE

A photodiode generates current based on received light. Aweigh's photodiodes are enhanced to receive blue light. As the sky is blue, enhancing the reception of blue light increases the ability to detect skylight among other incident light sources.



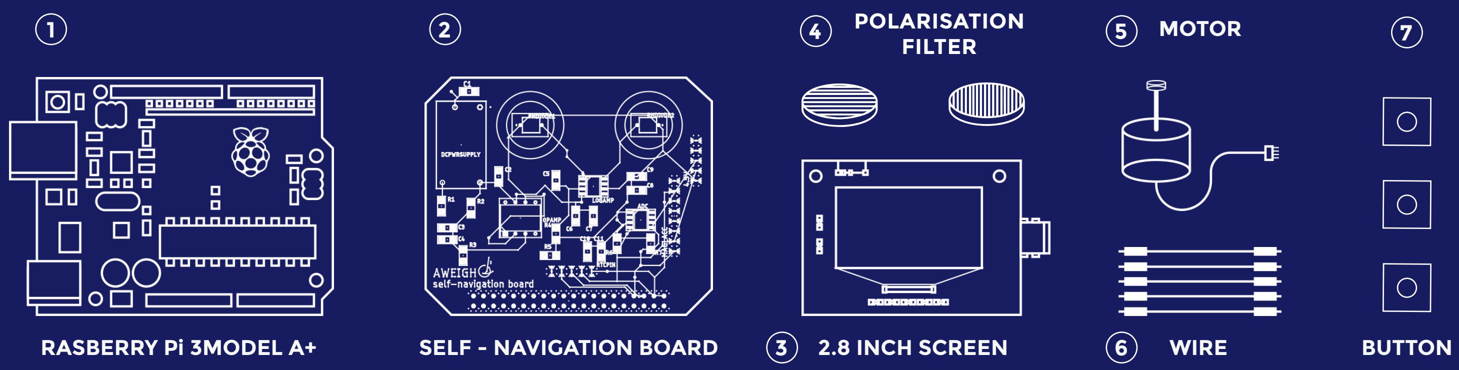
ADC

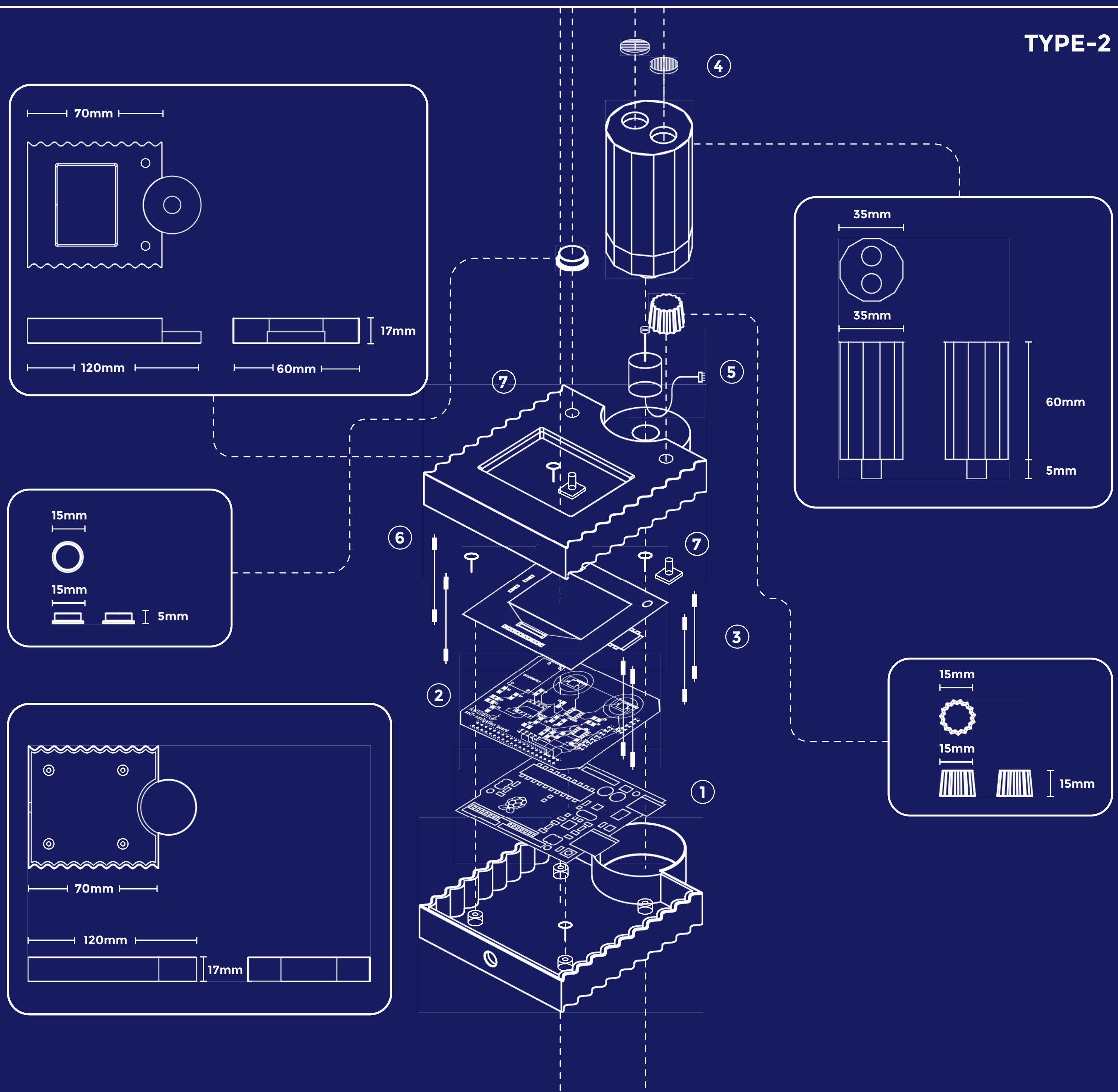
An analog to digital converter (ADC) is the last integrated circuit within the larger circuit before processing. The ADC is used to convert the analog signals gathered from light into a digital signal which then the raspberry pi can use for processing.

LOG RATIO AMP

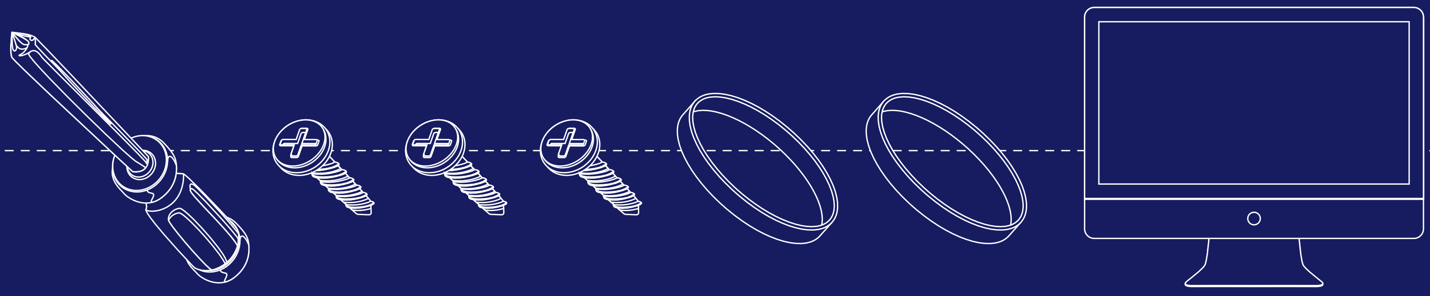
Aweigh's logarithmic (log) ratio amplifier (amp) is an integrated circuit (IC) component taking that produces a voltage from the two currents of the photodiodes. These two channels imitate those of the insect and its neuron.

VERSION 2-LEARN

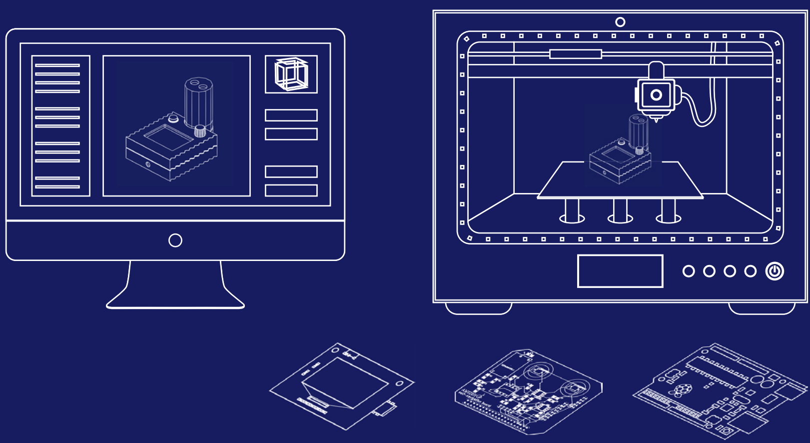




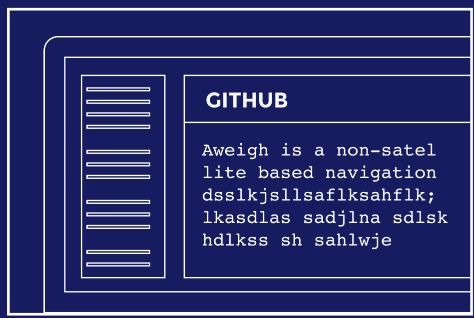
GATHER TOOLS



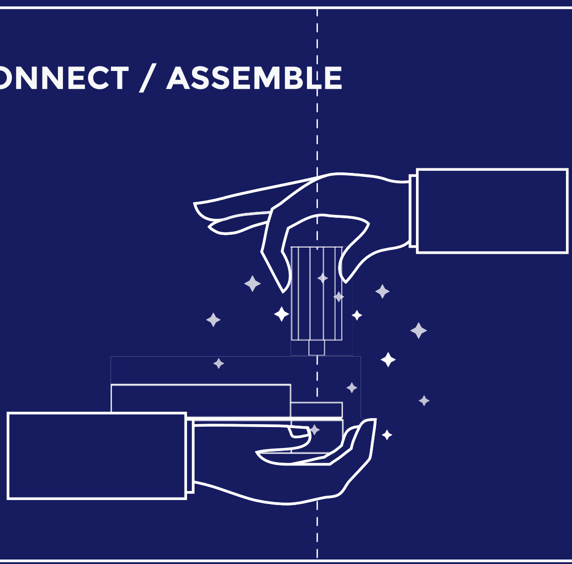
PRINT / GET COMPONENTS ON WEBSITE



DOWNLOAD / PROGRAM

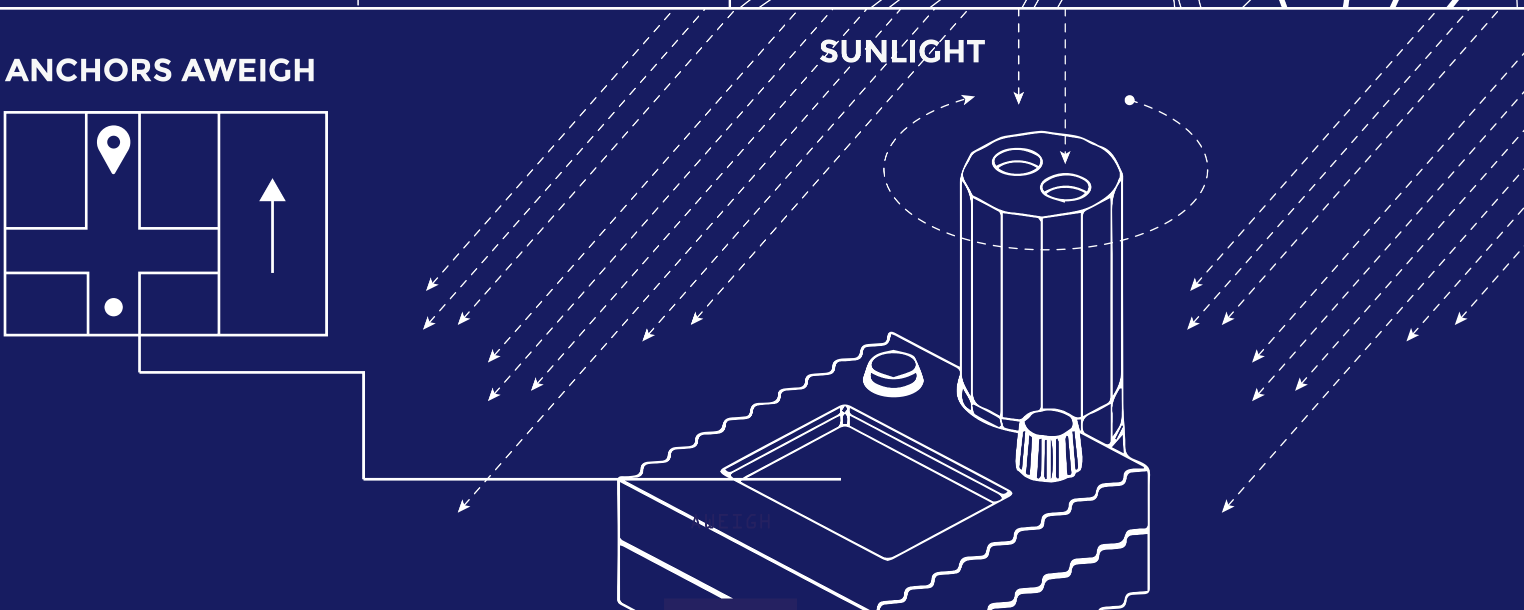


CONNECT / ASSEMBLE



CUSTOMISE

ANCHORS AWEIGH

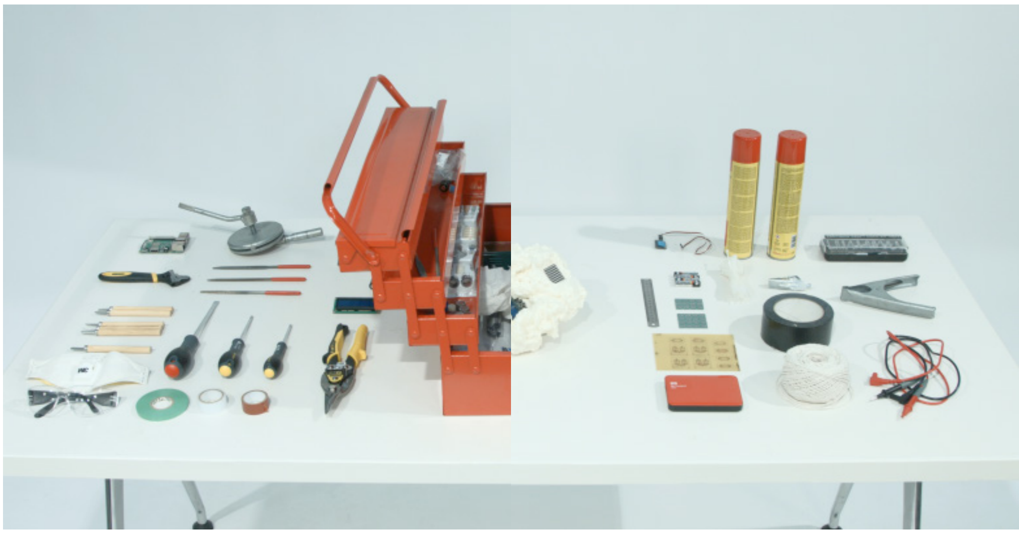


VERSION 3-DEVELOP

" I like that Aweigh is open-ended. It supports a kind of continuous search and questioning. "

J. , STACKOVERFLOW ENTHUSIAST

Aweigh - Version 3 was created for users like J. who appreciate the challenge and the freedom to build their own digital devices. All of Aweigh's necessary components are simple electronics, which can be found in standard forms or are included in other devices situated in environments as mundane as your living room or your kitchen. The technology was developed so that each part of a device can be found and constructed from several sources, objects, environments - unlike GPS navigation, which has a single point of failure. We hope that Version 3 users will develop and upload their own implementation method , showing how day-to-day users of ubiquitous technologies can directly influence the shape of digital infrastructure. These users are invited to contribute to Aweigh's public repository.



List of all the components

DC power booster

Capacitors - 2 x 100 uF, 3 x 1000 pF, 3 x 1 uF, 1 x 150 uF, 1 x 0.1 uF, 1 x 10 uF

Resistors - 4.53k, 100k, 820k, 330k, 2 x 5k

Logarithmic op amp

Analog to digital converter (ADC)

Unity gain op amp

2 x Blue enhanced photodiode

Magnetometer

Accelerometer

Real-time clock module or other time-keeping mechanism

Shaft

Gears

Casing

Power supply

Processor - minimum 8-bit

Memory card

Buttons

Potentiometer

Display, motors, or LEDS

List of handy equipment

Soldering iron and solder

3D printer

Lasercutter

Masking tape and duct tape

Scissors, exacto-knife

Multimeter or oscilloscope

Power Supply

Computer

microUSB cable

PROCESS

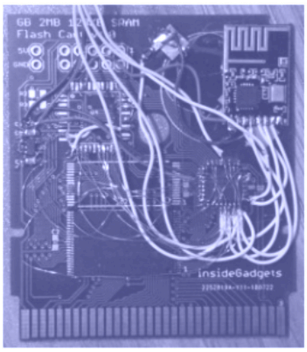
This specific process description is inspired by insideGadget's hack of a Nintendo Gameboy into a wireless controller.

Step 1 - Collect all components and materials. Polarisation sensors can be found in most screens, processors in smart devices, memory cards in cameras, ADCs in sensing devices, accelerometers in phones, logamps in speakers. In this example, a custom Gameboy Color cartridge is made: flash chip to store the ROM, ATmega48PA microcontroller, and Gameboy buttons for controls.

Step 2 - Gather relevant tools. This will depend on the specific components you choose to use and the objects that you might decide to take apart.

Step 3 - Research prior art and find examples. A few people have made custom Gameboy cartridges, while others have implemented their own controllers that are compatible with the same joystick interface. Some of these references will have the correct Vendor ID & Device ID.

VERSION 3-DEVELOP




```
struct{
  union {
    uint8_t data;
    struct {
      uint8_t X:2;
      uint8_t Y:2;
      uint8_t B:1;
      uint8_t A:1;
      uint8_t SELECT:1;
      uint8_t START:1;
    };
  };
} reportBuffer;
...

if(usbInterruptIsReady()){
    reportBuffer.data = 0x05; // Center pad, little endian
    ...
    reportBuffer.A = 1;
    reportBuffer.Y--;
    ...
    usbSetInterrupt(&reportBuffer, sizeof(reportBuffer));
```

Step 4 - Use GBDK Program to make the ROM. See multi-game loader code. This program listens for key inputs and outputs them to an address with the data we specify.

Step 5 - Choose a memory address to write to and program the inputs as you wish.

Step 6 - Make the polarisation sensor by etching the PCB according to Aweigh's self-navigation board schematic found here.

Step 7 - Test polarization sensor with any other processor and work out the calibration needed using the mathematical relationships described here.

Step 8 - Solder the flash chip, sensor cicruit, and data lines. A good example of a project turning a Gameboy into a wireless joystick is described here.

Step 9 - Carefully remove the current Gameboy Color display and replace with anoth er LCD of your choice, connected to an Atmega48 board.

Step 10 - Implement a communication protocol between the cartridge and the microcontroller. This can be done physically or wirelessly through a receiver - some people have done this with an nRF24L01 receiver.

Step 11 - Program a simple GUI for the display, taking into account each step described by the algorithm found here.

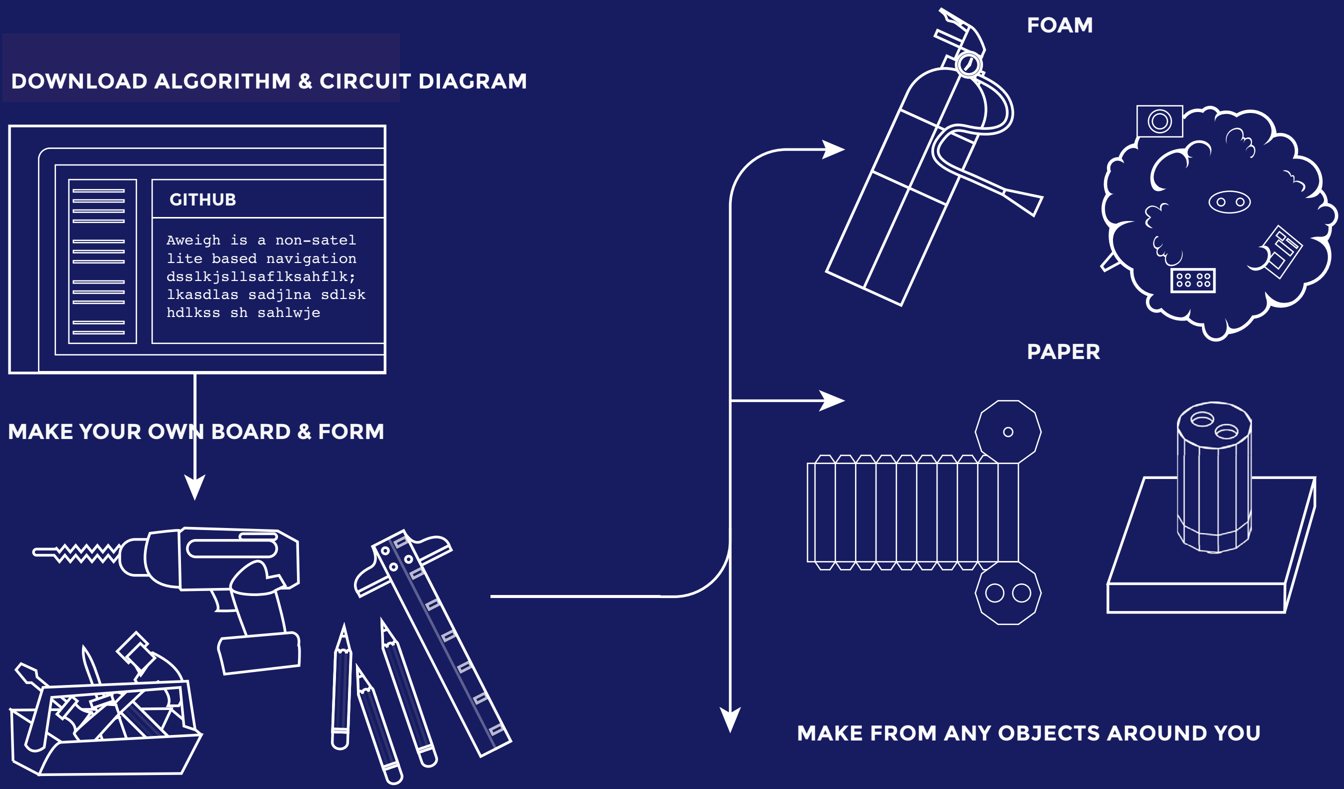
Step 12 - Run the entire system and troubleshoot any communication issues between the three parts: the cartridge reads polarization values, the Gameboy is used to control the device, and the ATmega48 is used to process and display information.

Step 13 - Encase all parts in the Gameboy Color and plug the custom cartridge in.
Step 14 - Level the device, take the readings, find position, enter destination.

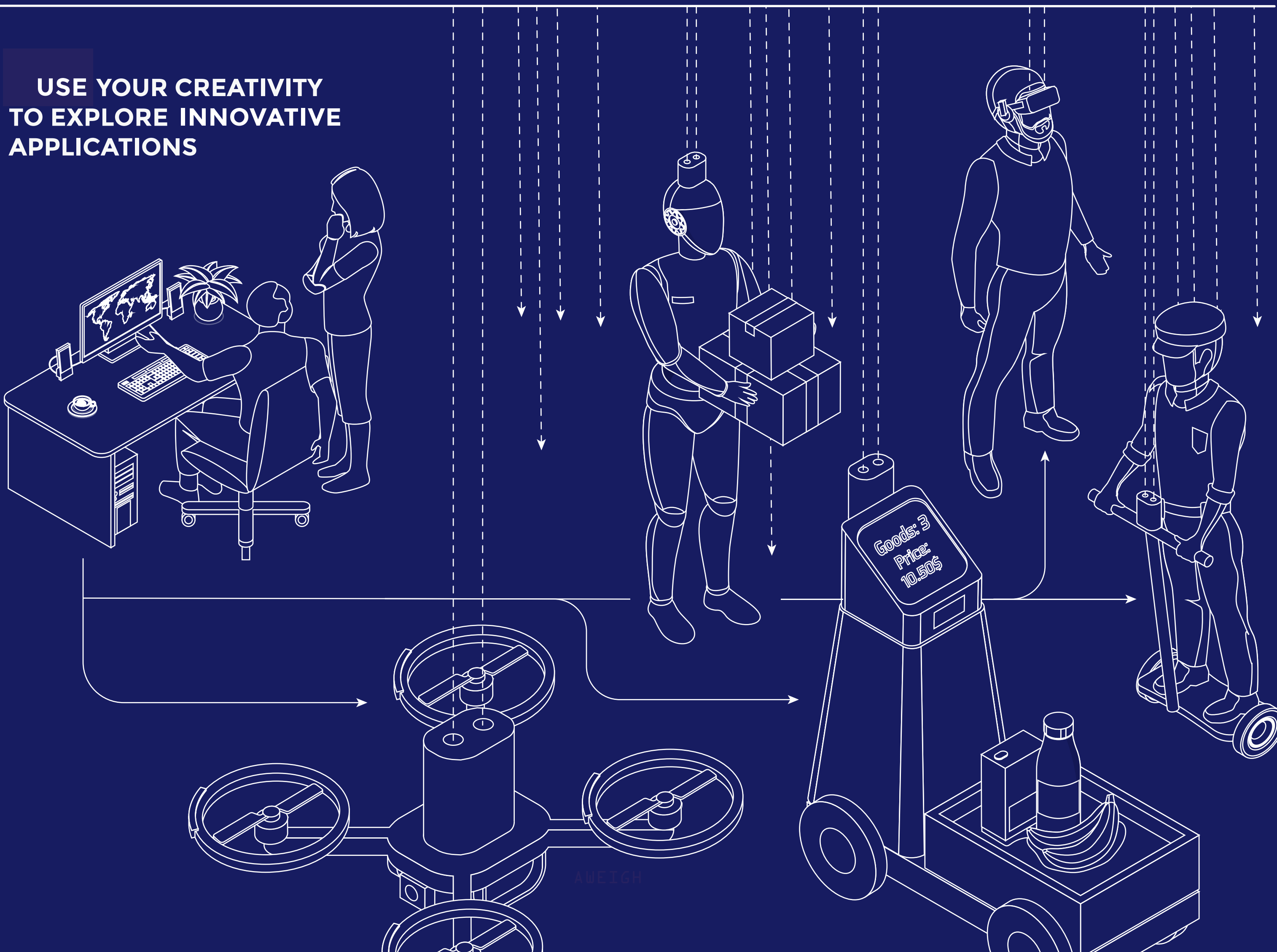
Step 15 - Anchors aweigh!

VERSION 3-DEVELOP

MAKE YOUR OWN FORM



USE YOUR CREATIVITY TO EXPLORE INNOVATIVE APPLICATIONS



Examples of Variations 2 & 3

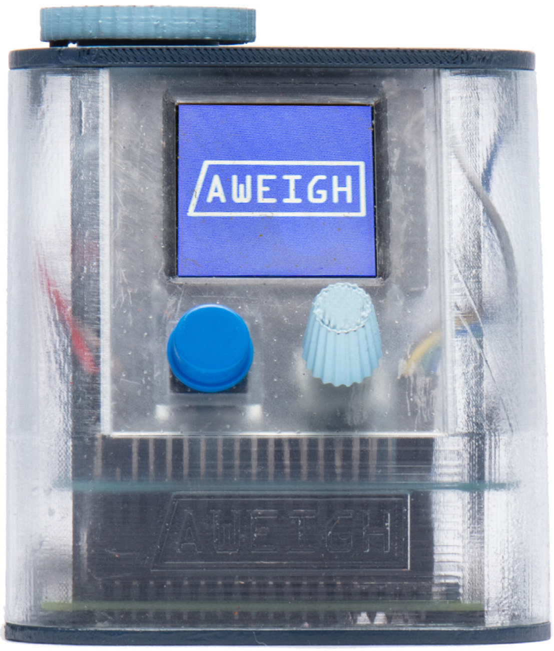
Here are some examples of the variations of models that can be made from variations 2 and 3 of Aweigh.

01

AWEIGH

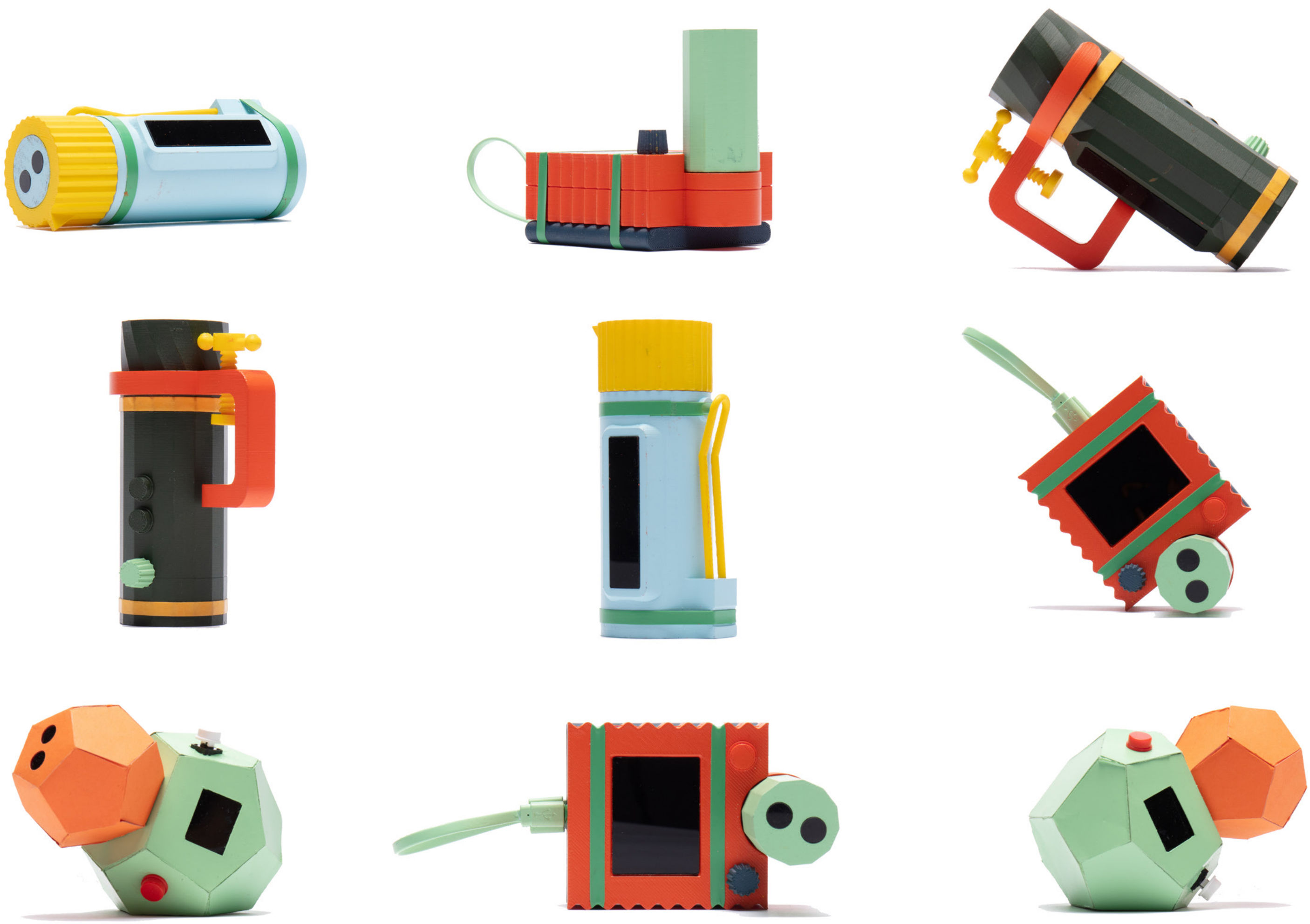
02

0 3



0 2

0 3



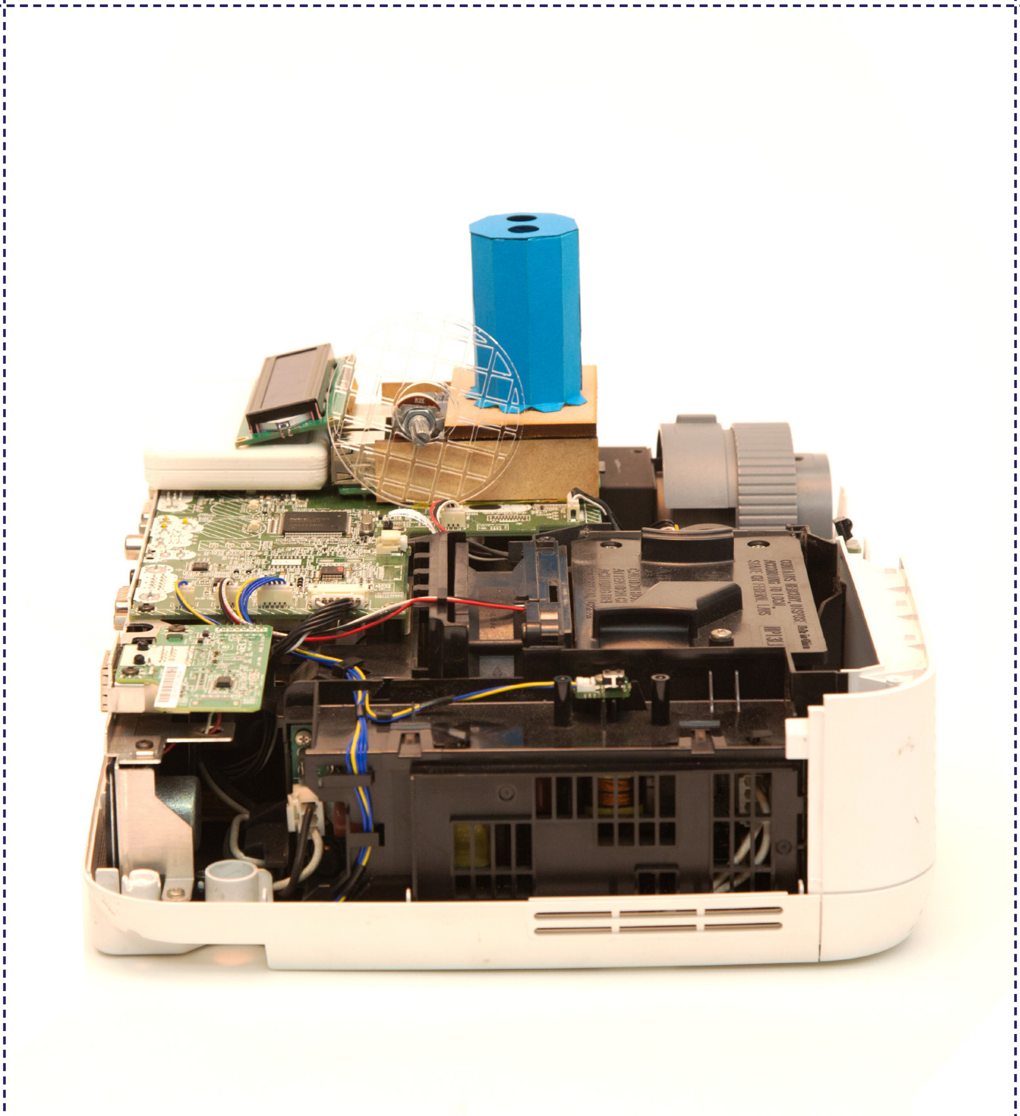
0 4

0 5

06

07

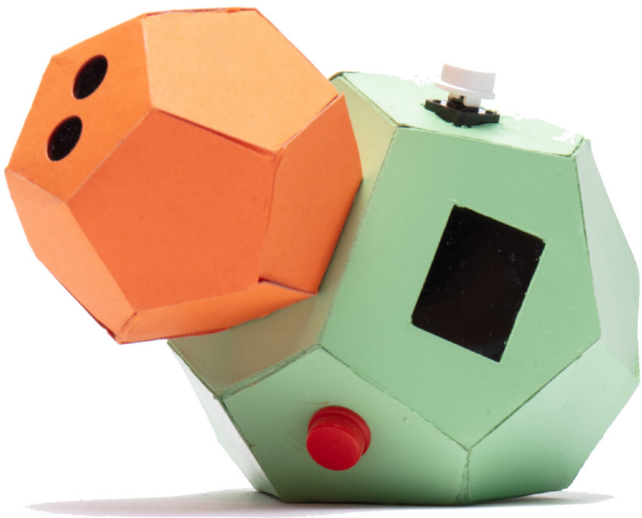
08



09

AWEIGH

10



Outro

Aweigh addresses the problems that we have identified with contemporary technology, but it does not solve them. The progression of technology cannot be so easily changed by a single device, it is changed by the mindset of individuals. Aweigh can be a starting point in reframing the way we think about complex technologies.

Technology is a big space, so we recognised the need to focus on a specific field of study. Our process was to find inspirations and alternatives from the obsolete or marginalised in nature and the past. We see Aweigh as not an endpoint or one-off device, but as the first in a series of possible alternative solutions to ubiquitous technologies; a series of solutions that shifts the vector of technological progression towards the individual's needs.

What direction will technology continue to progress? How reliant are we willing to let ourselves become? We ask readers to contemplate the technologies around them and question their understand and design.

Endnotes

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2. Wang, Y., Chu, J., Zhang, R., Wang, L., Wang, Z. (2015) A novel autonomous real-time position method based on polarized light and geomagnetic field Scientific Reports volume 5, Article number: 9725

3. The definition we are using for a black box is a device which can be used for the purposes intended by the maker of the device without any knowledge of its internal workings. Other possible uses for the device may exist but require knowledge of its internal workings.

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5. D., Herrlin, M., Lintner, W. 2016. United States Data Center Energy Usage Report. Lawrence. Berkeley National Laboratory, Berkeley, California. LBNL-1005775 .

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11. Merrick, R. (November, 2018). Brexit: UK faces potential £5bn bill for new satellite navigation system after May fails to remain part of EU Galileo project.

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13. More examples of obsolete navigation technologies can be found on our website www.aweigh.io

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17. https://julianoliver.com/output/ [date accessed 19.1.19]

Inspiring projects

Julian Oliver

Roel Roscam

Bill Gaver

Philipp Ronnenberg

LOW-TECH magazine https://www.lowtechmagazine.com/

People who have helped us

Jeff Gough

John Pottle & the Royal Institute of Navigation

Anarchist Federation

Aweigh, a project by
Flora Weil, Keren Zhang, Samuel Iliffe and States Lee.

The Aweigh team is a research collective of four designers and engineers, recently graduated from the Innovation Design Engineering programme held jointly between the Royal College of Art and Imperial College London. The group's mission is to empower individuals with the technologies they use. We engage and direct discussions around the development of contemporary technologies through propositional and investigative explorations of computational systems, their logistics, and the often invisible ways they shape our reality.

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