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DEVELOPMENT OF THE WATERPROOF ENCLOSURE FOR TRACKING SYSTEM PITSTOP

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DEVELOPMENT OF THE WATERPROOF ENCLOSURE FOR TRACKING SYSTEM PITSTOP

RAZVOJ VODOTESNEGA OHIŠJA ZA SLEDILNI SISTEM PITSTOP

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AUTHOR’S DECLARATION

I, the undersigned, Blaž Bratuš, hereby declare that:

- the submitted project entitled Development of the Waterproof Enclosure for Tracking System PitStop is my original work done under the mentor’s guidance of Assoc. Prof. Dr. Miran Ulbin;
- the project has not formed the basis for the award of any degree, associateship, fellowship, or any other similar titles at any university or other institution of tertiary education;
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DEVELOPMENT OF THE WATERPROOF ENCLOSURE FOR TRACKING SYSTEM PITSTOP

Key words: waterproof enclosure, tracking system, PitStop, GPS tagging, open-source conservation, sea turtles

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ABSTRACT

The IUCN Red List of Threatened Species classifies six out of seven species of sea turtle as Threatened. Different tagging systems are being used to better protect and conserve the sea turtles and their habitats with the data gathered being essential to design better conservation strategies.

Tagging sea turtles can be quite expensive using the proprietary commercial tags. The aim of this project was to develop a reliable and affordable tracking system PitStop for monitoring threatened sea turtles. Different designs, materials and sealing methods were proposed and tested to find the optimal solution considering the performance, reliability and costs.

RAZVOJ VODOTESNEGA OHIŠJA ZA SLEDILNI SISTEM PITSTOP

Ključne besede: vodotesno ohišje, sledilni sistem, PitStop, GPS sledenje, odprtokodno ohranjanje prostoživečega živalstva, morske želve

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POVZETEK

Inštitut IRNAS Rače je organizacija, ki se specializira za hiter razvoj, prototipiranje in izdelavo učinkovitih ter cenovno ugodnih produktov in sistemov interneta stvari, tehnologije za ohranjanje prostoživečega živalstva pa so eno izmed pomembnejših strokovnih področij, na katerih delujemo. Na nas se je obrnila neprofitna organizacija Zoological Society of London (ZSL) iz Velike Britanije za pomoč pri razvoju sledilnega sistema PitStop za sledenje ogroženim morskim želvam.

Rdeči seznam ogroženih rastlinskih in živalskih vrst IUCN klasificira šest od sedmih vrst morskih želv kot ogrožene. V uporabi so različni načini označevanja in sledenja, ki pomagajo pri boljši zaščiti in varovanju morskih želv in njihovega naravnega okolja, zbrani podatki pa so ključni za načrtovanje boljših strategij za njihovo ohranitev.

Označevanje morskih želv s komercialno dostopnimi sledilniki je precej drago, saj se cene sledilnih sistemov gibljejo od 1200 pa tudi do 5000€. Cilj tega projekta je bil raziskati, če je mogoče enak učinek doseči tudi s pomočjo odprtokodnih principov in tehnologij ob znatno nižji ceni. Ohranjanje prostoživečega živalstva je namreč področje, na katerem bi lahko cenovno dostopne odprtokodne tehnologije pomenile velik napredek, saj ponujajo možnosti za veliko večji učinek, vendar pa je ponudba takšnih sistemov zelo omejena.

Cilj tega projekta je bil razvoj vodotesnega ohišja za zanesljiv in cenovno dostopen sledilni sistem PitStop za sledenje ogroženim morskim želvam. Predlaganih in preizkušenih je bilo več

možnih konstrukcij, več različnih materialov ter načinov tesnjenja z namenom najti najbolj optimalno rešitev ob upoštevanju učinkovitosti, zanesljivosti ter stroškov.

Glavne zahteve, ki jih je določal konstrukcijski zahtevnik so bile:

- *Zunanje dimenzije ne smejo biti večje od 150 x 150 x 50 mm.*
- *Masa sistema ne sme preseči 1000 g.*
- *Ohišje mora biti vodotesno do globine 100 m.*
- *Ohišje mora biti vzdržljivo in odporno na udarce.*
- *Odprtokodna konstrukcija.*

Sledilnik se na želvin oklep namesti s pomočjo steklenih vlaken in epoksidne smole. Sledilni sistem smo načrtovali tako, da zaradi svoje dvodelnosti omogoča, da se osnovna plošča trajno pritrdi na želvin oklep, medtem ko je mogoče sledilnik preprosto zamenjati. Zaradi tega je bil sistem tudi poimenovan PitStop, kar pri avto-moto športu pomeni postanek v boksih.

Pri načrtovanju ohišja je bilo potrebno upoštevati še nekaj omejitev. Ohišje je moralo biti dovolj veliko za vso elektroniko, po drugi stani pa je bil cilj narediti ohišje čim manjše, da bi bilo le-to tako čim manj moteče za želvo. Pomembna je bila tudi masa ohišja, z željo da bi sledilnik čim manj vplival na obnašanje želve je bilo potrebno celoten sledilnik narediti kar se da nevtralno ploven. Zaobljen dizajn je bil izbran, da bi s tem zmanjšali možnost, da bi se želva zapletla v ribiške mreže, prav tako pa je bil s tem zmanjšan vodni upor, ki bi oteževal plavanje.

Prva verzija ohišja je bila narejena s pomočjo 3D tiskalnika, prototip pa je služil za ovrednotenje primernosti konstrukcije. Ko je bilo potrjeno, da je ohišje primerno, dovolj veliko za vso potrebno elektroniko, način pritrjevanja na želvin oklep pa deluje kot načrtovano, je bilo na rezkalnem stroju izdelanih 15 ohišij, da se jih preizkusi tudi v praksi. Raziskovalci organizacije Zoological Society of London so v sodelovanju z Univerzo v Exeterju in s fundacijo Principe Trust sledilnike leta 2016 preizkusili na otoku Principe v Gvinejskem zalivu ob obali Afrike. Sledilniki so bili nameščeni na pet želv.

Pri nadaljnjem razvoju je bila ob nekaj izboljšavah sledilnika razvita tudi kamera, ki omogoča poleg spremljanja lokacije želv tudi snemanje posnetkov. Vendar pa je bilo zaradi določenih

težav s tesnjenjem odločeno, da je potrebno pred naslednjo verzijo sledilnikov preizkusiti različne materiale ter različne načine tesnjenja. Preizkusili smo štiri različne materiale in štiri različne načine tesnjenja, testi pa so obsegali tako preizkus tesnjenja, odpornosti na udarce, kot tudi vzdržljivosti pri visokem pritisku.

Pri projektu smo skozi štiri iteracije, preizkuse in testiranja razvili PitStop GPS sledilnike ter PitStop kamere, primerne za raziskave morskih želv, saj so se izkazali za vzdržljive, zanesljive ter cenovno dostopne. Sledilniki in kamere so bili nato v letih 2017 in 2018 preizkušeni še na otoku Principe, na Cipru, v Keniji ter v Gvineji-Bissau. Raziskovalcem je uspelo pridobiti tako podatke o gibanju označenih morskih želv kot tudi podvodne posnetke, ki dajejo pomemben vpogled v obnašanje morskih želv ter v nevarnosti, ki jim pretijo. Sledilni sistem PitStop se je izkazal kot dobra alternativa komercialno dostopnim sledilnikom. Odprtokodne tehnologije in izmenjava znanja so lahko raziskovalcem pri ohranjanju prostoživečega živalstva v veliko pomoč, pridobljeni podatki pa so ključni za načrtovanje boljših strategij za ohranitev ogroženih živalskih vrst, kot so na primer morske želve.

CONTENTS

1 INTRODUCTION

Institute IRNAS Rače is an organisation that specializes in rapid development, prototyping and manufacturing of effective and affordable hardware products and IoT systems, with the conservation tech being one of the important fields of expertise. We work in collaboration with conservation specialists to develop technologies to improve wildlife monitoring and protection by evaluating the technology available and suggesting better, more cost-effective and optimized solutions for the particular challenge. Most of the work done is published under open-source licenses that enable the sharing of knowledge. [4] [5]

At IRNAS we were approached by Alasdair Davies, Technical Specialist with Conservation Technology Unit at the Zoological Society of London (ZSL) to help develop a tracking system for monitoring threatened sea turtles, with the special focus on green sea turtles. The project is a collaboration between Arribada Initiative, founded by Alasdair Davies, Zoological Society of London, Principe Trust, and is financially supported by Shuttleworth Foundation. [6] [7]

Six out of seven species of sea turtle are classified as Threatened by the IUCN Red List, two of them as Critically Endangered, one as Endangered and three as Vulnerable, with the green sea turtle classified as Endangered. Different tagging systems are being used to better protect and conserve the sea turtles and their habitats. Data gathered is essential to recognize their movements and the behaviour, the information necessary to design better strategies for their conservation and the protection of their habitats.

Tagging sea turtles can be quite expensive using the proprietary commercial tags, which can cost up to 5000€. Although well suited for the job and used extensively, we wanted to explore how new advances in open source technologies and manufacturing could achieve the same results, but at a dramatically reduced cost. Conservation is an area in which low cost and open technology can make a substantial difference offering the potential to scale-up monitoring efforts. Despite that, access to affordable, open and customisable conservation technologies is often limited.

The aim of this project was to develop a reliable and affordable tracking system PitStop for monitoring of threatened sea turtles. This paper describes the development and testing of the enclosure for the tracking system. The system needed a robust waterproof enclosure capable of protecting the electrical components inside at great depths, GPS and satellite connectivity, pressure sensor and salt water switch. Different designs, materials and sealing methods were proposed and tested to find the optimal solution considering the performance, reliability and costs.

2 SEA TURTLE CONSERVATION

2.1 Wildlife conservation

Human presence, increasing exploitation of natural resources, intensive agriculture and industry growth can be damaging to nature and can lead to environmental degradation. Wildlife conservation aims to protect and preserve wild plant and animal species and their habitats.

The origins of the wildlife conservation are dating back to 1662 with the paper Sylva by John Evelyn [8] in which he drew the attention to the importance of conserving the forests as the timber resources in England at that time were becoming seriously depleted. At the beginning of the 19th century the British government began managing the forests in British India to reduce the risks of wildfires and to preserve the growth of small teak trees as an important resource. The conservation was then revived in the mid-19th century with a forest conservation programme based on scientific principles, the first such project in the world.

In the United States, wildlife conservation appeared in the political debates at the end of 19th and at the beginning of the 20th century with president Theodore Roosevelt as one of the most influential environmentalists and conservationists in the American history. Roosevelt granted the federal protection to land and wildlife, established the United States Forest Service, five national parks, 18 national monuments, 51 bird reserves, four game preserves and 150 national forests. He concurred with the statement from Gifford Pinchot, the first Chief of the United States Forest Service, "to make the forest produce the largest possible amount of whatever crop or service will be most useful, and keep on producing it for generation after generation of men and trees" [9]. His view on conservationism remained dominant for decades.

Environmentalism reappeared in the 1970s with the creation of the Environmental Protection Agency in the United States. In 1973, the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) was signed to protect endangered plants and animals and to prevent the global trade of wildlife. Since then, the convention was ratified by 183 parties, 182 countries and the European Union, being one of the largest conservation agreements created. In 1980, The World Conservation Strategy was prepared by the International Union for Conservation of Nature (IUCN) to provide "both an intellectual framework and practical guidance for the conservation actions necessary" [10]. The strategy contains the objectives of conservation and requirements for their achievement, priorities for national actions, and priorities for international actions.

Many countries have government agencies and non-government organizations that were founded to work in the field of the wilderness preservation. They help creating and implementing policies and laws to protect the wildlife as well as to educate and raise awareness. There are also numerous other independent non-profit organizations that promote various wildlife conservation causes. [11] [12]

When assessing conservation status of a species, many criteria have to be considered. There are several different systems in use that classify the species into groups with regard to the risk of extinction. The IUCN Red List of Threatened Species is widely recognized as the most comprehensive approach for evaluating the conservation status of plant and animal species. It classifies the species into nine groups – Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) and Not Evaluated (NE). Species classified as Critically Endangered, Endangered, or Vulnerable are referred to as Threatened species. The categories of the IUCN Red List are graphically represented in Figure 2.1. [13] [14]

Figure 2.1: The IUCN Red List of Threatened Species categories. [15]

2.2 Sea turtles

Sea turtles are reptiles that can be found in all oceans except for the polar regions. There are seven existing species of sea turtles: green sea turtle, loggerhead sea turtle, Kemp's ridley sea turtle, olive ridley sea turtle, hawksbill sea turtle, flatback sea turtle and leatherback sea turtle. The species are measuring mostly 60 to 200 cm and weighing 25 to 700 kg with the leatherback being the largest species of sea turtle.

It takes decades for sea turtles to reach sexual maturity. During the mating season, mature sea turtles can migrate thousands of kilometres to reach breeding sites, where after the mating female sea turtles go to the shore to lay eggs. On the shore female digs a hole in the sand with her hind flippers in which she then lays her clutch that typically contains 50 to 350 soft-shelled eggs, depending on the species. The female refills the nest with the sand to camouflage it and then returns to the sea, leaving the eggs unattended. Sea turtles have a relatively low offspring survival rate. It is estimated that out of a 1000 sea turtle eggs only 2 sea turtles will survive to reach sexual maturity. [16]

The green sea turtle (Chelonia mydas) was one of the first sea turtle species studied. It can be found throughout tropical and subtropical seas around the world with two major subpopulations in the Atlantic and Pacific Oceans. It is estimated that it inhabits the waters of more than 140 countries. Adult green sea turtles are measuring 78 to 112 cm and weighing 68 to 190 kg on average but can reach 150 cm and weigh 315 kg or even more. Most of their time is spent at depths up to 30 m but they can reach depths of over 150 m as well [17]. They typically swim at 2,5 to 3 km/h. Green sea turtles can swim more than 2600 kilometres between feeding and nesting sites. Females often return to the beaches where they hatched to lay their own eggs. The nesting process takes about an hour to an hour and a half and the female does this three to five times in one season every two to four years. [18]

Figure 2.2: A green sea turtle off the coast of Gili Islands, Indonesia.

The IUCN Red List of Threatened Species classifies six species of sea turtle as Threatened, two of them as Critically Endangered, one as Endangered and three as Vulnerable. The flatback sea turtle is classified as Data Deficient which means that there is insufficient information available for a proper assessment of conservation status. The green sea turtle is classified as Endangered by the IUCN Red List.

Although many of the threats to sea turtles are natural, there are also many that have been increasing with the growing presence of humans. It is illegal to hunt most species in many countries, but sea turtles are still caught worldwide, mainly for food. Beside hunting, a large contributor to sea turtle deaths is also a bycatch as a result of imprecise fishing methods. Some changes to fishing techniques were introduced to reduce the bycatch, for example larger hooks and traps from which sea turtles can escape. A major threat is also poaching of sea turtle eggs with a big demand for eggs on the black market. Other major threats also include climate change, loss of habitat and nesting areas due to beach development, oil spills and marine pollution, entanglement in abandoned fishing nets, and different plastic debris which may be mistaken for food. [16] [19]

2.3 Sea turtle conservation efforts

Human presence causes both intentional and unintentional threats to sea turtles. In recent decades, sea turtles have moved from unrestricted exploitation to global protection. Global initiatives as well as individual countries have passed laws and treaties to provide protection for endangered sea turtles.

Many conservation efforts have been undertaken to restrict turtle trade and consumption. In most countries it is illegal to hunt, collect, harm or kill sea turtles or their eggs. Many countries also have laws to protect their nesting areas.

Turtle conservation education has been growing in both size and efficiency. Rehabilitation centres have been established to help protect the local sea turtle populations. A tourism industry that exploited sea turtles has been replaced by a sustainable tourism that promotes sea turtle conservation where tourists can come and visit the nesting grounds, turtle shelters or turtle hatcheries.

Several changes to fishing techniques and new types of turtle-safe fishing equipment have been introduced to lessen the number of sea turtles killed by fishing incidents, such as larger hooks and fishing nets with turtle excluder devices that have reduced sea turtle bycatch in shrimp nets by 97 percent. An example of a fishing net with turtle excluder device can be seen in Figure 2.3. [16] [19] [20]

Figure 2.3: Loggerhead sea turtle escapes from fishing net through a turtle excluder device. [21]

For proper evaluation of the progress of conservation programmes sea turtle populations have to be adequately studied. Most information on sea turtle populations are based on counting nests on beaches, which does not provide an accurate data about the whole population. A report from United States National Research Council released in 2010 concluded that more detailed information on sea turtles' life cycles, such as birth rates and mortality, is essential for understanding and predicting trends in sea turtle populations [22].

2.3.1 Tagging sea turtles

Sea turtles spend the majority of their life in the water, but most of the conducted researches are based on counting nests on the beaches. This does not provide an accurate data about the whole sea turtle population nor does it provide any data regarding feeding, mating and migrating of the turtles. For proper understanding of the sea turtles' behaviour at sea, different tagging techniques are used to identify individuals and help tracking the sea turtles.

Tagging can help study turtles' feeding habits, mating and nesting habits, migration patterns, distribution, population trends, and growth rates. The information collected can be used to develop better conservation programmes and to better protect the sea turtles.

There are several different tagging methods used to tag sea turtles: flipper tagging, passive integrated transponder (PIT) tagging, GPS tagging, satellite tagging, sonic and radio tagging, genetic tagging, living tagging and others.

Flipper tagging

Flipper tagging is the most common method used to mark sea turtles. Tags are usually modified livestock tags, made from either plastic, steel or titanium. They are attached by piercing through the turtle's flipper using a tag applicator. They each contain a unique identification number and are used for visual identification. The flipper tags are inexpensive, easy to attach and easy to see but are on the other hand not permanent and can increase the chance of entanglement in fishing nets. The limitation of these tags is also that only visual identification is possible, either by a diver in the sea or an observer on the beach. An example of the flipper tag is shown in Figure 2.4.

Figure 2.4: Titanium Flipper Turtle Tag with applicator. [23]

PIT tagging

Passive integrated transponder (PIT) tags contain a small microchip which transmits a unique identification number when scanned with a dedicated scanner. The tags are about the size of a grain of rice and are implanted under the turtle's skin. The advantage of these tags is their size, they are less harmful to the turtles and last a lifetime. The main drawbacks are the higher cost than the flipper tags, they are harder to spot and require a special scanner to read the data. Similar to the flipper tags, the identification of the PIT tags is also possible only by an observer on the beach. An example of the flipper tag is shown in Figure 2.5.

Figure 2.5: Trovan ID-100A PIT tag with implanter and transponder reader. [24] [25] [26]

GPS and satellite tagging

GPS and satellite tagging are another methods used for tracking sea turtles, much more advanced compared to flipper and PIT tagging. While flipper and PIT tags only provide the data when a diver or an observer spots the turtle, the GPS and satellite tags continuously gather data about the location, dive time, depth and water temperature. The location can be measured using either GPS or the satellite communication and provides the information about the actual turtle movements and migrations. A turtle with a satellite tag will transmit the data to the passing satellite when the turtle surfaces with the data immediately available to the researchers while GPS tags can either send the data via the satellite communication or it can be stored locally on the tag and retrieved with the tag. Gathered data provides much more detailed insight into the sea turtles' behaviour and movements. The main drawbacks of these tags are their limited lifespan of less than one year and a high price in the range of 1000 to 5000€ per tag [27]. An example of the GPS tag can be seen in Figure 2.6.

The GPS and satellite tags are attached to the carapace, the dorsal (back) part of the turtle shell. There are several options to attach the tag: gluing the tag to the carapace using fiberglass and epoxy resin, attachment with a tether, attachment with a harness and attachment using orthopaedic screws.

Figure 2.6: Wildlife Computers SPLASH10-BF GPS Tag. [28]

Other tagging methods

Other tagging methods include sonic and radio tagging with transmitters that use short range waves to transmit the location instead of a satellite communication, genetic tagging using the DNA samples of sampled turtles, living tagging with a grafting process that transfers the skin grafts from the light coloured plastron to the dark coloured carapace which will be visible throughout the turtle’s lifetime, and other methods using paint, a wire attachment, branding, notching or holes drilled in the carapace for the turtle identification. [29] [30]

3 OPEN SOURCE

Open source is a development model in which a product's source code, design, blueprints, and documentation are freely available to anyone. It is a design that can be freely used, changed, and shared in modified or unmodified forms by anyone.

The open source development model is very different from proprietary models. Open source encourages more users to freely use and improve the products and share the changes within the community. This also enables more frequent creations of derivative works and quicker advancements within those fields. [31] [32] [33]

3.1 Licensing

Free software licences before the 1980s were generally informal notices written by the developers. However, with the growth of the open source community, different licences had to be created to clarify the new copyright, licensing, and patent issues. There are many different licences under which the open source projects can be published. Some are more suitable for open-source software projects and some for open-source hardware projects. As some problems with license compatibility can lead to contradictions it is still an open question to create a universal set of licences under which the open source projects could be published.

Some licences restrict using the products for commercial purposes. These licences are not complying with the definition of the open source models and are therefore not considered open source. [31] [32] [33] [34]

3.2 History

Sharing of technological information is a lot older than the term open source. Examples can already be found at the beginning of the 20th century and even before but with the invention of the internet the community really started growing. The term open source was first proposed by a group of people within the free software movement in 1998. The term first referred to open-source software but was later adapted for open-source hardware as well. [31] [32]

3.3 Open-source conservation

There are several fields where the open-source model is being widely used, but it is not something that is generally mentioned when it comes to wildlife conservation. Despite that open source principles can help lower the costs associated with the conservation, make it widely available to anyone and expand its impact.

When it comes to conservation, collaboration between governments, agencies, non-government organizations and other independent non-profit organizations is crucial for developing adequate conservation strategies and for their success. Connecting organizations and researchers and increasing the cooperation in conservation can be one of the most powerful tools which can be achieved through open-source models.

There are three major applications of the open-source model when it comes to conservation, open-source software, open-source hardware and open data. The open-source software includes different tools and platforms that can enable researchers to better collect, manage and share the data gathered during the surveys. With the open-source hardware researchers can share their technical solutions and make their work accessible to others. Open data is the concept that the data should be freely available to anyone to access and use. If the data collected is publicly accessible to anyone rather than only a few, it can be revolutionary for the conservation efforts, it could speed-up researches, help avoiding duplication of work and save limited conservation resources. [31] [35]

4 TURTLE TAG DEVELOPMENT AND DESIGN FEATURES

Tracking sea turtles is very important, and the information collected are necessary to design better strategies for their conservation. Sea turtles are highly migratory animals that spend the majority of their life in the water. That is why surveys that are based on counting nests on the beaches are often not enough. It is necessary to use different tagging techniques to identify individuals, which can provide the researchers with crucial information, including feeding habits, mating and nesting habits, migration patterns, distribution, population trends, and growth rates.

By far the most extensive data can be gathered using GPS and satellite tagging methods that do not only provide the data when the turtle is spotted but continuously gather information about the location, dive time, depth and water temperature. GPS and satellite tags are much more advanced compared to other available tags for turtles, which is consequently associated with much higher costs. Basic satellite tags start at 1200€ with the more advanced GPS tags that can also measure depth and water temperature reaching prices as high as 5000€ per tag. This is preventing the conservation organizations with limited budgets to deploy the tags at a larger scale.

At Institute IRNAS we were tasked to develop reliable and affordable tracking system. The aim was to develop a GPS tag that could achieve the same results as the proprietary commercially available tags but at a lower cost. The goal was to use the open source principles and to make the design, blueprints and documentation freely available to anyone in order to achieve greater impact. That would enable the researchers to get the technology that was before too expensive and encourage them to freely use and improve the products and share the modifications within the community.

This paper describes the development and the testing of the waterproof enclosure that was developed for this tracking system. All the 3D modelling was done parametrically in computer-aided design (CAD) software programs in SolidWorks and Autodesk Fusion 360.

4.1 Technical requirements

The main technical requirements for the enclosure were:

- External dimensions must not exceed 150 x 150 x 50 mm.
- Weight of the system must not exceed 1000 g.
- The enclosure has to be waterproof up to a depth of 100 m.
- The enclosure has to be durable and impact resistant.
- Open-source hardware design.

The tracking tag is attached to a sea turtle by gluing the tag to carapace using fiberglass and epoxy resin. It was desired that the tag consists of two separate parts with one of the parts that can be permanently attached to the turtle's carapace and the other that can be easily replaced.

4.2 Proof of concept and first prototypes

There were a few things that we had to consider when designing the tag enclosure. The enclosure had to be large enough to fit all the necessary electronic while at the same time the goal was to make the tag as small as possible so that it does not affect the turtle's behaviour. The important consideration was also the weight since a too heavy tag might disturb the sea turtle. The tag had to be as neutrally buoyant as possible with a minimal weight in the salt water. The curved design was selected to reduce the chance of entanglement in the fishing nets and to reduce the drag in the water that would make the swimming for the turtle more difficult.

The electronic modules that had to be fitted inside the enclosure are:

- Mataki tracking device with dimensions of 43 x 21 x 7 mm and weight of 8 g
- Axivity AX3 3-axis logging accelerometer with dimensions of 35,4 x 24,2 x 8,9 mm and weight of 11 g
- i-gotU GT-600 GPS logger with dimensions of 46 × 41,5 x 14 mm and weight of 37 g
- LiPo battery with 1050 mAh, dimensions of 63 x 35 x 5 mm and weight of 29 g

The turtle tag that served as a proof of concept was 3D printed to evaluate the initial enclosure design. It consists of three parts, a shell, a lid and a gasket that ensures sealing. The shell and the lid were 3D printed using ABS plastic while the gasket was cut out of a rubber sheet. All parts are joined together using 14 stainless steel screws. Photos of the turtle tag are shown in Figure 4.1.

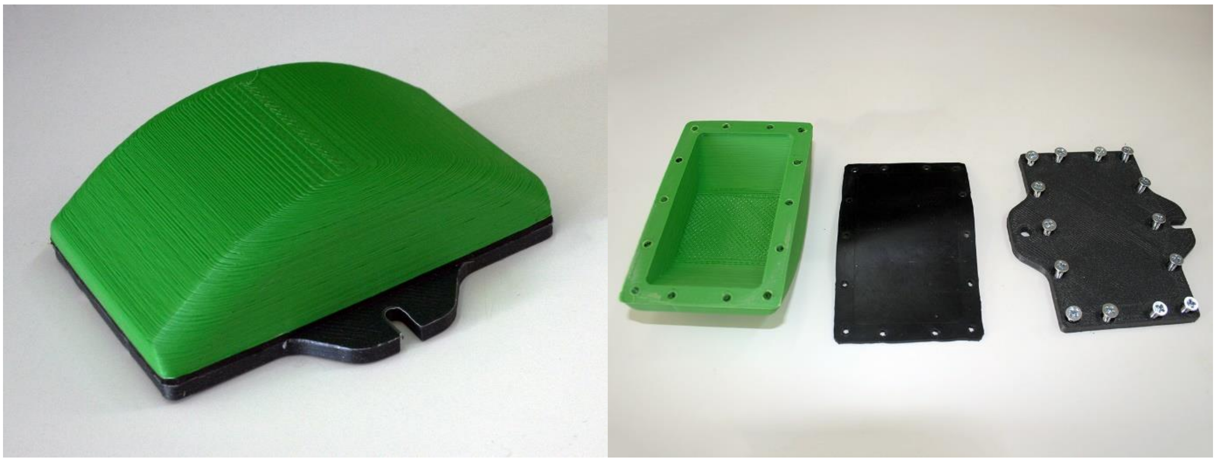

Figure 4.1: The first design of the turtle tag. On the left is an assembled tag and on the right three parts of the tag – a shell, a lid and a rubber sheet.

In the final version the shell was milled from acrylic. The lid and the seal were combined into one part. The polyurethane seal was cast and vulcanized by pouring resin directly onto a thin aluminium plate with the polyurethane layer providing sealing and aluminium plate providing required stiffness. The shell and the lid are joined together with the stainless steel screws which means that the tag can be recharged and repaired if necessary. We have also added another part, the base aluminium plate that can be permanently attached to the turtle’s carapace while the tag can be easily removed using just two screws. This means that the researchers can replace the tags without having to replace the fiberglass and epoxy resin as well.

Because of the design that enables researchers to quickly and easily “swap” a tag and replace it with a new one the tags were named PitStop Tags. The final version of the first generation PitStop Tags can be seen in Figure 4.2.

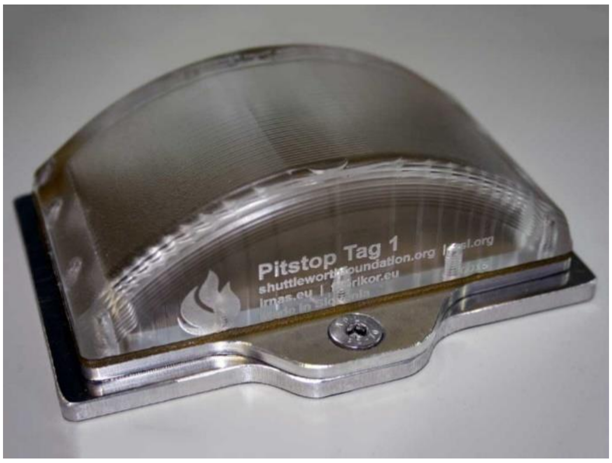

Figure 4.2: The final version of the first generation PitStop Tags.

The tag was optimized to be as neutrally buoyant as possible in the salt water. The weight of the tag enclosure is 300 g and the weight of electronics another 85 g. This adds to the total weight of 385 g in air and approximately 110 g in the salt water. The absolute density of the tag is 1,42 g/cm^3 which is a bit higher than the density of salt water at 1,03 g/cm^3.

We have manufactured a test series of 15 turtle tags that were then tested in a real-life scenario. The tags were tested in January 2016 on Principe Island off the coast of Africa in the Gulf of Guinea by Alasdair Davies from Zoological Society of London in collaboration with Principe Trust Foundation and researchers from the University of Exeter. Five tags were deployed with the first nesting green sea turtle returning after two weeks. A few photos of the tagging are shown in Figure 4.3.

Figure 4.3: Deploying the PitStop Tag on a green sea turtle on Principe Island. Photos taken by Alasdair Davies from Zoological Society of London.

4.3 The second generation and camera tags

In the new generation of turtle tags we have tried to improve the sealing of the enclosure. We have changed the seal; the new generation is using silicone gasket instead of polyurethane seal cast onto aluminium plate. The silicone gasket has proved to be more effective and easier and cheaper to manufacture.

In addition to the turtle tag we have also developed a turtle camera enclosure, an enclosure that enables the researchers to attach Raspberry Pi camera to the sea turtle. Thanks to the modular build turtle camera enclosure uses the same base plate as turtle tag and is therefore easily interchangeable. Screenshots of both PitStop GPS Tag and PitStop Camera Tag are shown in Figure 4.4 and Figure 4.5.

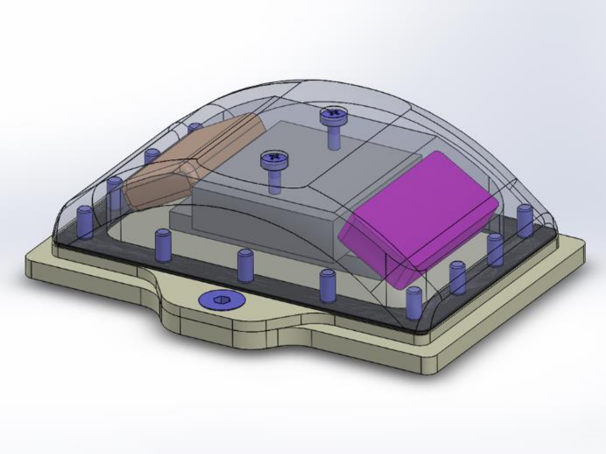

Figure 4.4: A screenshot of the new generation of PitStop GPS Tag in SolidWorks.

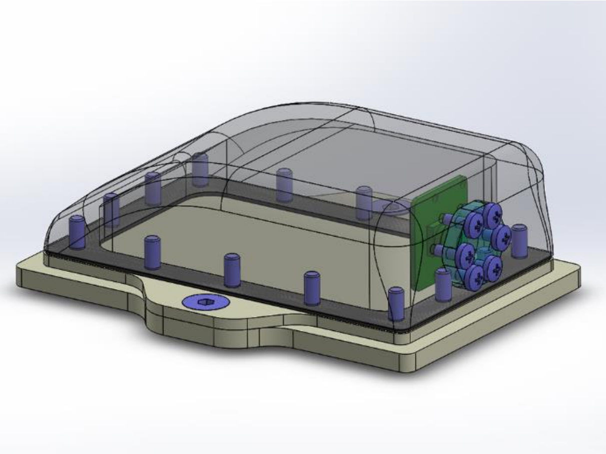

Figure 4.5: A screenshot of the new PitStop Camera Tag in SolidWorks.

There were some problems with the sealing during the testing of the first and the second generation of GPS tags as well as the camera tag. It was also assessed that because of its brittle failure and relatively low strength the acrylic is not the most appropriate material for the turtle tag enclosure shell. It was established that more testing needs to be done to assure the proper sealing, to select the suitable material and to optimize the design. All the testing that was preformed is described in detail in Chapter 6.

4.4 The final version of GPS and camera tags

The results from testing preformed and the feedback from test deployment showed a few necessary modifications to the turtle tags. It was determined that the most suitable material for the enclosure shell is polyoxymethylene (POM) plastic. The rubber O-ring string preformed the best and was chosen for the sealing. A fillet was created to round the edge of the base plate to reduce the chance of the fiberglass ripping.

There were also a few changes in electronics beside the changes in mechanical part of the tag. The new custom-built electronics was developed for the GPS tag. PiRA Zero power management electronics was added to the camera tag, together with the wireless charger and Axivity AX3 accelerometer. Pressure sensor was added to both GPS and camera tag, together with the salt water switch that can detect when the turtle surfaces for air.

The acryl that was also used for the camera window for the camera tag enclosure proved to be inappropriate choice as well. Aluminium cover was therefore designed to hold a glass window in place with the rubber O-ring seal to provide the sealing.

The electronic modules that had to be fitted inside the GPS enclosure are:

- Custom built GPS tracking electronics with dimensions of 60 x 35 x 9,5 mm and weight of 18 g
- Li-Ion battery pack 2x18650 with 7000 mAh, dimensions of 68 x 46 x 18,5 mm and weight of 99 g
- Pressure sensor TE MS5837-30BA
- Salt water switch with dimensions of 20 x 11 x 4,5 mm and weight of 5 g

The electronic modules that had to be fitted inside the camera enclosure, shown in Figure 4.6, are:

- PiRA Zero power management electronics with dimensions of 65 x 30 x 7,6 mm and weight of 11 g
- Raspberry Pi Zero W with dimensions of 65 x 30 x 7,9 mm and weight of 11 g
- Raspberry Pi Camera Module v2 with dimensions of 25 x 24 x 8,8 mm and weight of 3 g
- 2x Li-Ion battery 18650 with 3500 mAh dimensions of 68 x 46 x 18,5 mm and weight of 99 g

- Wireless charger with dimensions of 47 x 36 x 2 mm and weight of 12 g
- Axivity AX3 3-axis logging accelerometer with dimensions of 35,4 x 24,2 x 8,9 mm and weight of 11 g
- Pressure sensor TE MS5837-30BA
- Salt water switch with dimensions of 20 x 11 x 4,5 mm and weight of 5 g

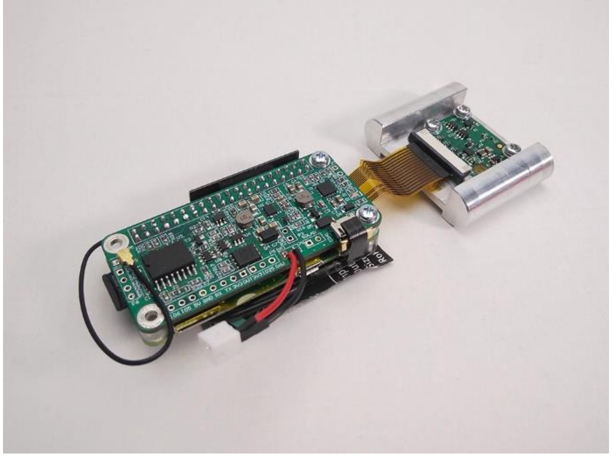

Figure 4.6: The electronics assembly of the PitStop Camera Tag.

While the electronics in the first version of the tags were merely placed inside the enclosure and covered with silicone, we have provided the mounting spots for each module in the new version. A few screenshots of both PitStop GPS Tag and PitStop Camera Tag are shown in Figure 4.7 and Figure 4.8, with the photos of assembled devices shown in Figure 4.9. Figure 4.10 shows a schematic diagram of the PitStop Camera Tag with all its parts and their purpose.

Figure 4.7: A few screenshots of the final version of PitStop GPS Tag in Autodesk Fusion 360. On the top is the assembled tag and on the bottom the inside of the enclosure with the mounting points for the electronic modules.

Figure 4.8: A few screenshots of the final version of PitStop Camera Tag in Autodesk Fusion 360. On the top is the assembled tag and on the bottom the inside of the enclosure with the mounting points for the electronic modules.

Figure 4.9: Photos of assembled PitStop GPS and Camera Tags.

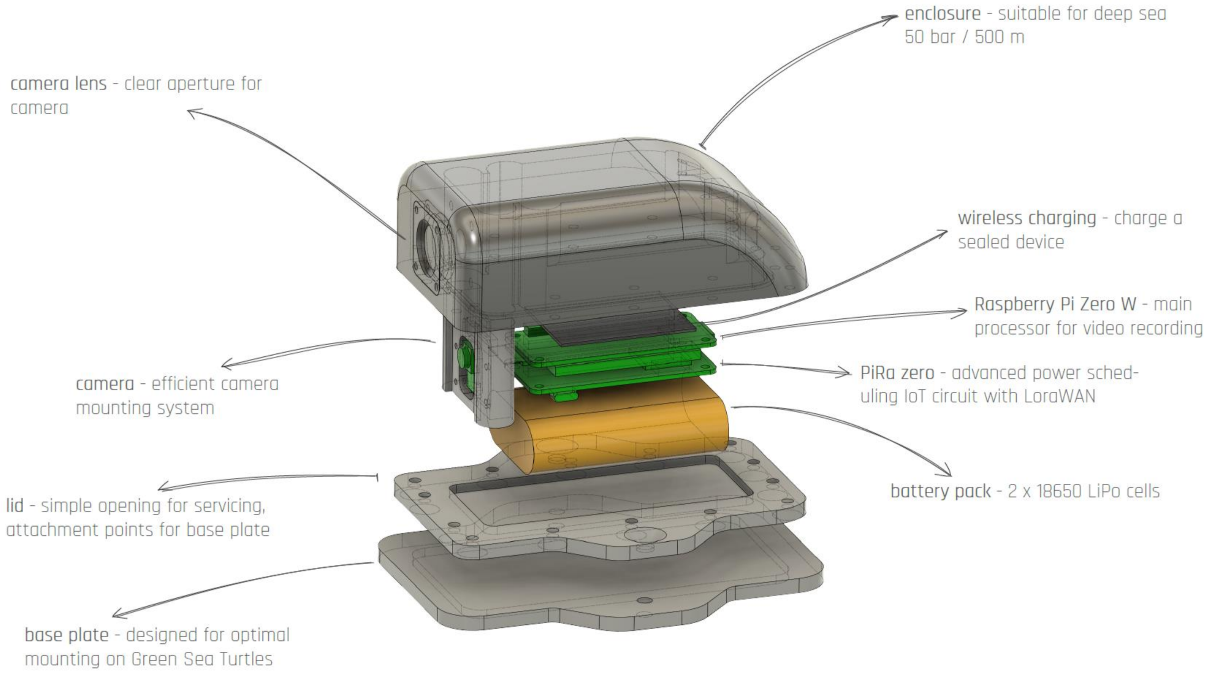

Figure 4.10: Schematic diagram of the PitStop Camera Tag showing all the parts and explaining their purpose.

The PitStop GPS Tag enclosure with lid has dimensions of 124 x 70 x 38,5 mm and a weight of 292 g while the PitStop Camera Tag enclosure with lid has dimensions of 124 x 70 x 44 mm and a weight of 360 g. The dimensions of the base plate are 134 x 112 x 5 mm with a weight of 108 g. This brings the total weight of the PitStop GPS Tag together with the electronics and the base plate to 522 g in air and approximately 169 g in the salt water, and the total weight of the PitStop Camera Tag to 620 g in the air and approximately 206 g in the salt water. The dimensions and weight can also be seen in Table 4.1.

Table 4.1: Dimensions and weight of PitStop GPS and Camera Tags.

	Enclosure dimensions	**Enclosure weight**	**Tag dimensions**	**Tag weight in air**	**Tag weight in water**
PitStop GPS Tag	124 x 70 x 38,5 mm	292 g	134 x 112 x 43,5 mm	522 g	169 g
PitStop Camera Tag	124 x 70 x 44 mm	360 g	134 x 112 x 49 mm	620 g	206 g

Nesting green sea turtles will lay clutches of eggs three to five times in one season, returning to the beach every 10 to 14 days. The first time in a season when a turtle comes to the beach the researchers attach the base plate to its carapace using fiberglass and epoxy resin. After the fast-acting epoxy resin cures they attach the PitStop Camera Tag using two screws. When the turtle returns to the beach after 10 to 14 days, they remove the camera tag to retrieve the footage and to charge the batteries and replace it with a freshly charged tag. When the turtle returns to the same beach the third time, they replace the camera tag with the PitStop GPS Tag, which will then gather the data until the turtle returns to the same beach in the next nesting season. The PitStop system with "swappable" tags allows the researchers to quickly replace the tags without having to use the fiberglass and epoxy resin each time.

The first series of ten PitStop Camera Tags was deployed in December 2017 on Principe Island by Alasdair Davies from Arribada Initiative in collaboration with Insitute IRNAS Rače and Principe Trust Foundation. The second series of ten tags was deployed in July 2018 in Kenya. A rugged protective case with ten PitStop Camera Tags can be seen in Figure 4.11. Several successful taggings have resulted in a lot of video material. The photos, videos and gathered data from the tagging are shown in Chapter 5.

Figure 4.11: Rugged protective case with ten PitStop Camera Tags, ready for deployment.

4.5 Lite version of GPS tag

While the standard PitStop GPS and Camera Tags proved to be reliable and suitable for deployment on larger adult green sea turtles, the researchers have expressed a desire for a smaller and lighter tag that could be used for tagging smaller sea turtles as well. It was unfortunately not possible to reduce the size of camera tag since it was already optimized to be as small as possible. On the other hand, the GPS tag was designed to have the same footprint as the camera tag which means that it was still possible to reduce its size. The battery used was replaced with a smaller LiPo battery Cellevia Batteries LP654050 with 1500 mAh, dimensions of 50 x 40 x 6,5 mm and weight of 30 g.

We were able to reduce the size of the GPS tag enclosure from 124 x 70 x 38,5 mm to 94 x 64 x 26,5 mm and at the same time reduced its weight from 292 g to 160 g. This represents the size reduction of more than 50% and the weight reduction of more the 45%. This bring the total weight of the PitStop GPS Lite Tag together with the electronics to 213 g in air and approximately 77 g in the salt water. A few screenshots of PitStop GPS Lite Tag are shown in Figure 4.12, with the photo of assembled device shown in Figure 4.13. The dimensions and weight can also be seen in Table 4.2. Dimensions and weight of the PitStop GPS Tag are without the base plate for both tags to be more comparable.

Figure 4.12: A few screenshots of the PitStop GPS Lite Tag in Autodesk Fusion 360. On the top is the assembled tag and on the bottom the inside of the enclosure with the mounting points for the electronic modules.

Figure 4.13: A photo of assembled PitStop GPS Lite Tag.

Table 4.2: Dimensions and weight of PitStop GPS and GPS Lite Tags. Dimensions and weight of the PitStop GPS Tag are without the base plate.

	Enclosure dimensions	**Enclosure weight**	**Tag dimensions**	**Tag weight in air**	**Tag weight in water**
PitStop GPS Tag	124 x 70 x 38,5 mm	292 g	124 x 70 x 38,5 mm	414 g	123 g
PitStop GPS Lite Tag	94 x 64 x 26,5 mm	160 g	94 x 64 x 26,5 mm	213 g	77 g

The first series of ten PitStop GPS Lite Tags was deployed in June 2018 in Cyprus by Alasdair Davies from Arribada Initiative in collaboration with Zoological Society of London and researchers from the University of Exeter. A few photos of the tags deployed are shown in Figure 4.14. The second series of twenty-five tags was deployed in August 2018 on Poilão Island in Guinea-Bissau.

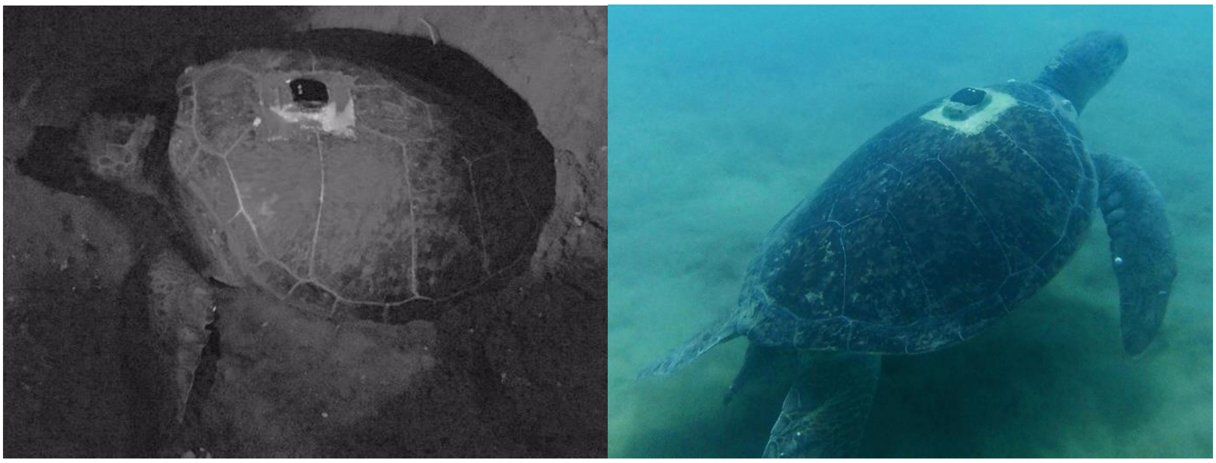

Figure 4.14: PitStop GPS Lite Tag, deployed on a green sea turtle in Cyprus. Photos taken by Julia Haywood from University of Exeter.

5 RESULTS OF TAGGING

The first deployment of PitStop Camera Tags in December 2017 on Principe Island was a big success. We received several hours of video material that demonstrated that camera tags are working properly. The tags proved to be a great alternative to proprietary commercial tags. A few photos, taken by the PitStop Camera Tags during the test deployment in December 2017 of the coast of Principe Island, can be seen in Figure 5.1.

The data and the footage that was retrieved from the tags was also very useful for the researchers. Not only does the data help with monitoring the green sea turtles, the videos can give a rare insight into behaviour and interaction between the sea turtles, and the dangers that threaten them, all critical to implementation of informed conservation strategies. The researchers are also able to observe the changes to the ocean environment, presence of plastic debris and marine pollution.

The very important aspect of the videos and photos taken is also a possibility to use them for publicity. The images can be a powerful tool to promote the sea turtle conservation and raising awareness.

Figure 5.1: A few photos that were taken by the PitStop Camera Tags in December 2017 of the coast of Principe Island. Photo credit to Arribada Initiative.

The second tagging was a deployment of PitStop GPS Lite Tags in June 2018 in Cyprus. The main purpose of this survey was to test the GPS tracking as well as the pressure sensor. The lite version of the tracking tag was used because the green sea turtles in the Mediterranean are generally smaller.

The sea turtles were tagged on Alagadi Turtle Beach in Cyprus when they first came to the beach to nest. To minimize the impact of the tag on a turtle no base plate was used, and the tags were directly attached to the turtle’s carapace using fiberglass and epoxy resin. When the turtle returned to the beach the tag was removed and the data retrieved. The acquired locations mean that the test was a success and that the tags are a suitable substitute for much more expensive proprietary commercially available tags. A map showing the movements of the first turtle that returned to the beach is shown in Figure 5.2.

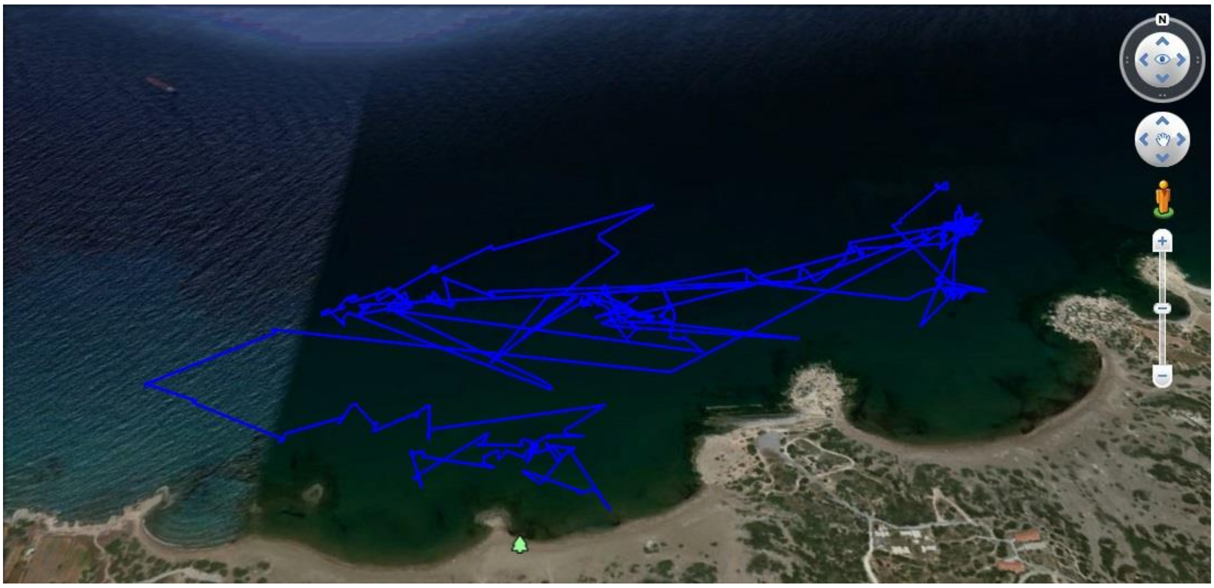

Figure 5.2: A map showing the movements between the first and the second nesting of the first turtle that returned to the beach of the coast of Cyprus. Image credit to Arribada Initiative.

6 TESTING OF THE ENCLOSURES

After the development and test deployments of first versions of turtle tags a need has arisen for a more detailed testing of the tag enclosures before the new iteration of the tag design. Firstly, there were some problems with the sealing and furthermore the acrylic proved to be not the most appropriate material for the turtle tag enclosure shell because of its brittle failure and relatively low strength. We have therefore conducted a series of tests to assure the proper sealing, to select the suitable material and to optimize the design.

6.1 Endurance test

The sea turtles regularly clean their shells by rubbing them against the rocks. Because of the turtle's weight this can create a lot of force to the turtle tag that is attached to the turtle's carapace. We tested the endurance of the cases to see if the tested cases can withstand a hit with such high force. Our goal was to see which material absorbs most force at the given shape and which one would break the easiest.

The enclosures made from different materials that we tested were:

- Acrylic enclosure shell with the weight of 88 g
- Polyoxymethylene (POM) enclosure shell with the weight of 102 g
- Oilamid enclosure shell with the weight of 83 g
- Polyamide 6 (PA6) enclosure shell with the weight of 83 g

We have built a pendulum like construction to try to simulate a scenario of a turtle hitting the tag enclosure against a rock. The pendulum featured a 73 cm long lever with a screw supported by two ball bearings as axis of rotation to reduce the friction. The pendulum was mounted on top of the workbench using a two-part holder. At the other end there was a backplate mounted on the lever, with two long screws where the weights could be put on to increase the momentum of the swing. The weight of the lever was 1,715 kg and the weight of the backplate 0,710 kg. We have also used six different weights that were in different configurations able to deliver from 0,825 to 19,110 kg of load. A small sphere opposite of the backplate was designed to hit the target enclosure. The enclosures were held in place using a vice, mounted to the heavy wooden block on the ground. A board with angle scale showing 10°, 20°, 30°, 40°, 50°, 60° and 67° was added to easily determine the force hitting the enclosure. The test equipment can be seen in Figure 6.1.

Figure 6.1: A pendulum like construction that was used to test the endurance of different turtle tag enclosures.

To test the enclosures to see which material absorbs the most force and which one would break the easiest we let the pendulum crash into the cases with different loads from different angles. We pulled the pendulum up to a certain angle and let it crash into the tested enclosure. After the first crash and a ricochet we stopped the pendulum to prevent it from crashing again. We tried to keep the number of hits as low as possible, so the case wouldn't break because of the number of hits rather than the force of the hit. We started with smaller loads and lower angles to get an approximation of what the cases can handle and then worked our way up.

After each test we have also calculated the angular momentum required for each enclosure to break. We have used the angle from which the pendulum hit the tag enclosures and the total weight to calculate the momentum. Angular momentum L is proportional to moment of inertia I and angular speed ω: [36]

$$L = I\omega \tag{6.1}$$

Because $I = r^2 m$ for a single particle and $\omega = \frac{v}{r}$ for circular motion, angular momentum can be expanded and reduced to:

$$L = rmv \tag{6.2}$$

Where:

r – radius of rotation
m – mass of the body
v – linear (tangential) speed at the radius

In our case the angular momentum was therefore calculated as:

$$L = rmv = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v \tag{6.3}$$

Where:

$l = 0{,}70\ \mathrm{m}$ – length of the lever
$r_l = \frac{l}{2} = \frac{0{,}70\ \mathrm{m}}{2}$ – distance from the pivot point to the centre of mass of the lever
$r_w = 0{,}65\ \mathrm{m}$ – distance from the pivot point to the centre of mass of the backplate and the weights
$m_l = 1{,}715\ \mathrm{kg}$ – mass of the lever
$m_b = 0{,}710\ \mathrm{kg}$ – mass of the backplate
m_w – mass of the weights
α – angle of the pendulum when released
$h = (1 - \cos\alpha) \cdot l$ – height of the pendulum when released
$v = \sqrt{2gh}$ – linear (tangential) speed at the radius just before the collision

The acrylic case broke very fast without any weights on the pendulum. The testing results are shown in Table 6.1, calculated angular momentums required for the enclosure to break in Equation 6.4 and Equation 6.5 while the broken enclosure can be seen in Figure 6.2.

Table 6.1: The results of testing of the acrylic enclosure shell.

Angle / **Load**	**20°**	**30°**	**40°**
0 kg	ok	ok	**broken**

$$L = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v = \frac{0{,}70\ \mathrm{m}}{2} \cdot 1{,}715\ \mathrm{kg} \cdot 1{,}36\ \frac{\mathrm{m}}{\mathrm{s}} + 0{,}65\ \mathrm{m} \cdot (0{,}710\ \mathrm{kg} + 0\ \mathrm{kg}) \cdot 1{,}36\ \frac{\mathrm{m}}{\mathrm{s}} = \mathbf{1,44}\ \frac{\mathbf{kgm^2}}{\mathbf{s}} \tag{6.4}$$

Where:

$\alpha = 30°$

$h = (1 - \cos\alpha) \cdot l = (1 - \cos 30°) \cdot 0{,}70\ \mathrm{m} = 0{,}094\ \mathrm{m}$

$v = \sqrt{2gh} = \sqrt{2 \cdot 9{,}81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 0{,}094\ \mathrm{m}} = 1{,}36\ \frac{\mathrm{m}}{\mathrm{s}}$

$m_w = 0\ \mathrm{kg}$

$$L = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v = \frac{0{,}70\ \mathrm{m}}{2} \cdot 1{,}715\ \mathrm{kg} \cdot 1{,}79\ \frac{\mathrm{m}}{\mathrm{s}} + 0{,}65\ \mathrm{m} \cdot (0{,}710\ \mathrm{kg} + 0\ \mathrm{kg}) \cdot 1{,}79\ \frac{\mathrm{m}}{\mathrm{s}} = \mathbf{1,90}\ \frac{\mathbf{kgm^2}}{\mathbf{s}} \tag{6.5}$$

Where:

$\alpha = 40°$

$h = (1 - \cos\alpha) \cdot l = (1 - \cos 40°) \cdot 0{,}70\ \mathrm{m} = 0{,}164\ \mathrm{m}$

$v = \sqrt{2gh} = \sqrt{2 \cdot 9{,}81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 0{,}164\ \mathrm{m}} = 1{,}79\ \frac{\mathrm{m}}{\mathrm{s}}$

$m_w = 0\ \mathrm{kg}$

Figure 6.2: Acrylic enclosure shell tested broke without any load at 40° angle.

Since the acrylic enclosure broke very easily we were also very careful when testing the POM enclosure and therefore slowly increased the load and the angles, but the enclosure held up more than expected. It finally broke under a large load at a maximum angle. The testing results are shown in Table 6.2, calculated angular momentum required for the enclosure to break in Equation 6.6 while the broken enclosure can be seen in Figure 6.3.

Table 6.2: The results of testing of the polyoxymethylene (POM) enclosure shell.

Angle / **Load**	**30°**	**40°**	**50°**	**67°**	**67°**
0 kg	-	-	-	ok	-
1,140 kg	ok	ok	ok	ok	-
1,965 kg	-	-	ok	ok	-
2,900 kg	-	-	ok	ok	-
4,040 kg	-	-	-	ok	-
9,025 kg	-	-	ok	ok	**broken**

$$L = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v = \frac{0{,}70\ \mathrm{m}}{2} \cdot 1{,}715\ \mathrm{kg} \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} + 0{,}65\ \mathrm{m} \cdot (0{,}710\ \mathrm{kg} + 9{,}025\ \mathrm{kg}) \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} = \mathbf{20{,}0}\ \frac{\mathbf{kgm^2}}{\mathbf{s}} \tag{6.6}$$

Where:

$$\alpha = 67°$$

$$h = (1 - \cos\alpha) \cdot l = (1 - \cos 67°) \cdot 0{,}70\ \mathrm{m} = 0{,}426\ \mathrm{m}$$

$$v = \sqrt{2gh} = \sqrt{2 \cdot 9{,}81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 0{,}426\ \mathrm{m}} = 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}}$$

$$m_w = 9{,}025\ \mathrm{kg}$$

Figure 6.3: Polyoxymethylene (POM) enclosure shell tested broke after a series of tries under 9,025 kg of load at 67° angle.

We tested both oilamid and PA6 enclosures with the same load as the POM enclosure but they both survived the crash. We have then increased the load to the maximum that we were able to fit on the pendulum’s backplate, but we could not break the enclosures. The testing results are shown in Table 6.3 and Table 6.4, calculated angular momentums required for each enclosure to break in Equation 6.7 and Equation 6.8 while the tested enclosures can be seen in Figure 6.4 and Figure 6.5.

Table 6.3: The results of testing of the oilamid enclosure shell.

Angle / Load	67°
7,650 kg	ok
9,025 kg	ok
12,635 kg	ok
19,110 kg	ok

$$L = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v = \frac{0{,}70\ \mathrm{m}}{2} \cdot 1{,}715\ \mathrm{kg} \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} + 0{,}65\ \mathrm{m} \cdot (0{,}710\ \mathrm{kg} + 19{,}110\ \mathrm{kg}) \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} = \mathbf{39{,}0\ \frac{kgm^2}{s}} \tag{6.7}$$

Where:

$\alpha = 67°$

$h = (1 - \cos\alpha) \cdot l = (1 - \cos 67°) \cdot 0{,}70\ \mathrm{m} = 0{,}426\ \mathrm{m}$

$v = \sqrt{2gh} = \sqrt{2 \cdot 9{,}81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 0{,}426\ \mathrm{m}} = 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}}$

$m_w = 19{,}110\ \mathrm{kg}$

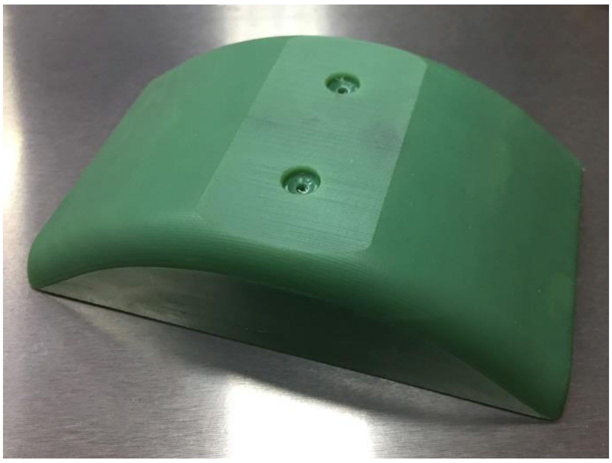

Figure 6.4: Oilamid enclosure shell tested wouldn’t break even under the maximal load.

Table 6.4: The results of testing of the polyamide 6 (PA6) enclosure shell.

Angle / **Load**	**67°**
19,110 kg	ok

$$L = r_l \cdot m_l \cdot v + r_w \cdot (m_b + m_w) \cdot v = \frac{0{,}70\ \mathrm{m}}{2} \cdot 1{,}715\ \mathrm{kg} \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} + 0{,}65\ \mathrm{m} \cdot (0{,}710\ \mathrm{kg} + 19{,}110\ \mathrm{kg}) \cdot 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}} = \mathbf{39{,}0\ \frac{kgm^2}{s}} \tag{6.8}$$

Where:

$$\alpha = 67°$$

$$h = (1 - \cos\alpha) \cdot l = (1 - \cos 67°) \cdot 0{,}70\ \mathrm{m} = 0{,}426\ \mathrm{m}$$

$$v = \sqrt{2gh} = \sqrt{2 \cdot 9{,}81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 0{,}426\ \mathrm{m}} = 2{,}89\ \frac{\mathrm{m}}{\mathrm{s}}$$

$$m_w = 19{,}110\ \mathrm{kg}$$

Figure 6.5: Polyamide 6 (PA6) enclosure shell tested wouldn’t break even under the maximal load.

Looking at the results it's clear that acryl isn't appropriate for this application because it already broke without any load on the pendulum. The other materials endured a lot heavier loads, they were all surprisingly strong and exceeded our expectations, especially the oilamid and PA6 enclosures, making them all a suitable choice for tag enclosures. When we also considered the price and the machinability of all the materials we have chosen the POM plastic to be the most appropriate for the PitStop Tag enclosures. Although it wasn’t the strongest of the materials it is definitely strong enough, and it has a better machinability than the oilamid or PA6 which is why it was selected as our first choice. The comparison of the materials tested can be seen in Table 6.5.

Table 6.5: Comparison of strength, machinability and costs of the materials tested.

	Angular momentum at fracture	**Machinability**	**Costs (relative)**
Acryl	$1{,}90\ \frac{\mathrm{kgm^2}}{\mathrm{s}}$	Good	1
Polyoxymethylene (POM)	$20{,}0\ \frac{\mathrm{kgm^2}}{\mathrm{s}}$	Excellent	1,4
Oilamid	$39{,}0\ \frac{\mathrm{kgm^2}}{\mathrm{s}}$ *	Poor	1,3
Polyamide 6 (PA6)	$39{,}0\ \frac{\mathrm{kgm^2}}{\mathrm{s}}$ *	Poor	1,1

* We were not able to break the enclosure, not even when we have increased the load to the maximum that we were able to fit on the pendulum’s backplate.

6.2 Sealing test

Green sea turtles spend most of their time underwater at depths of up to 30 m, but they can reach depths of over 150 m as well. It is crucial for the tag enclosure to be able to withstand the pressure and remain fully waterproof when continuously exposed to depths of more than 100 m to protect the electronics inside.

We have used a pressure container to test different sealing options, a photo of which can be seen in Figure 6.6. The pressure container was connected to an air compressor capable of providing pressure up to 10 bar. The container was half-filled with water. The tested enclosures were assembled and put on the bottom of the container fully covered with water. Weights were put over the cases to ensure the negative buoyancy. The cases were tested under 9 bar of pressure for 15 minutes, equivalent to the depth of 90 m. After the test they were taken out of the container, carefully wiped dry and disassembled to check for leaks.

Figure 6.6: Pressure container, used for sealing tests.

The different cases and different sealing methods that we tested, shown in Figure 6.7, were:

- Polyoxymethylene (POM) enclosure shell with foamed polyurethane O-ring string
- Polyoxymethylene (POM) enclosure shell with rubber O-ring string
- Polyoxymethylene (POM) enclosure shell with silicone gasket
- Oilamid enclosure shell with silicone gasket
- Polyamide 6 (PA6) enclosure shell with silicone gasket
- Acrylic enclosure shell with a polyurethane sealing layer cast on an aluminium plate

Most of the enclosures also had two screws on the top of the enclosure shell. Those two screws provide a contact for a salt water switch. Self-sealing screws APM Hexseal Seelskrews were used to provide a reliable seal [37]. The self-sealing screws were also tested to confirm the sealing.

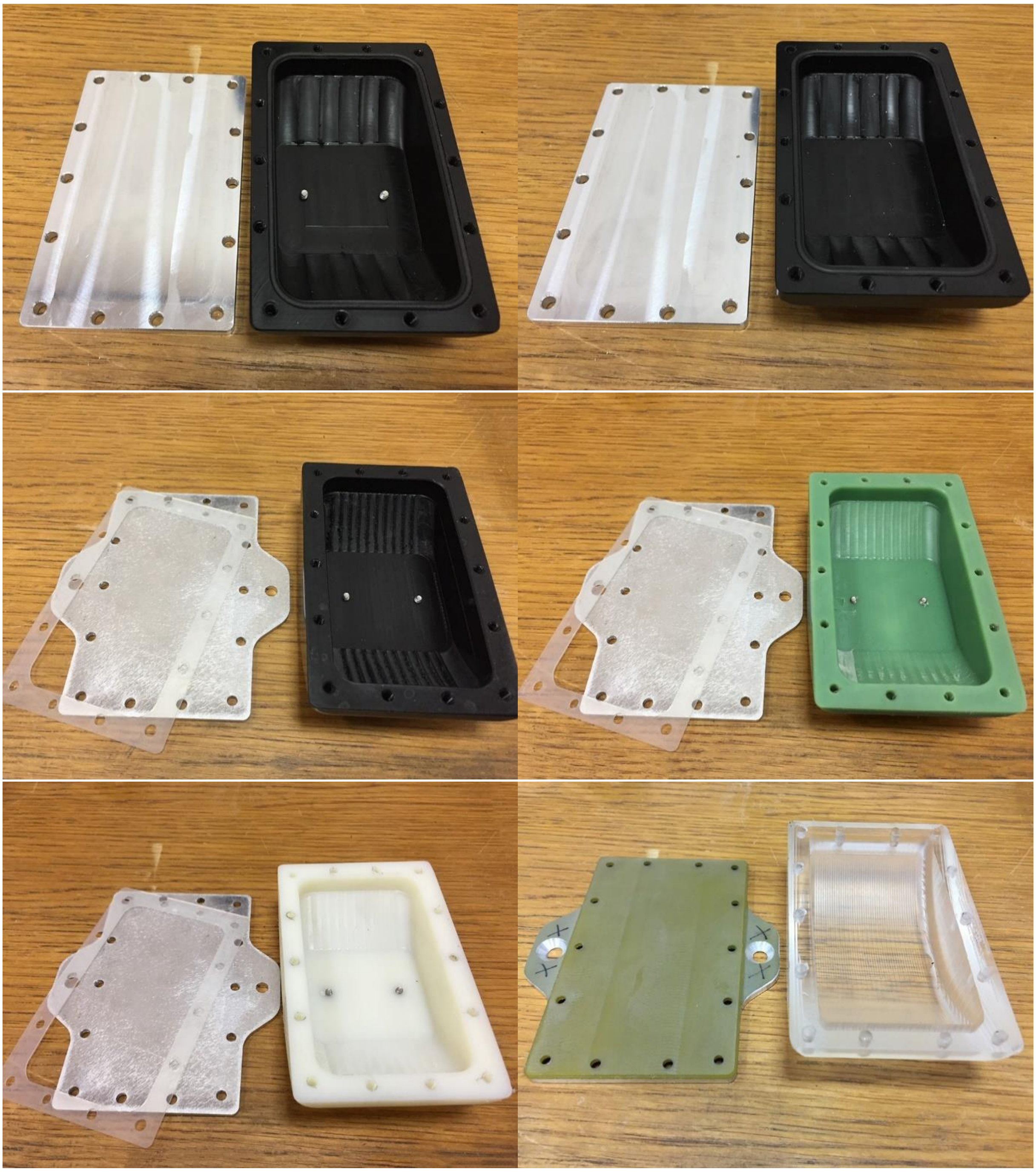

Figure 6.7: Different cases and sealing methods tested. From top left to bottom right: POM with foamed polyurethane O-ring string, POM with rubber string, POM with silicone gasket, oilamid with silicone gasket, PA6 with silicone gasket, acrylic with a polyurethane layer on an aluminium plate.

Of all the cases and sealing methods tested the only combination that stayed completely dry was POM enclosure shell with rubber O-ring string. We tested this combination both with and without the two self-sealing screws for the salt water switch on the top of the case. The acrylic shell with a polyurethane layer on an aluminium plate and POM shell with foamed polyurethane O-ring string preformed the worst with a lot of water inside while all three enclosures with silicone gasket had just a few drops of water inside. We have concluded that the most effective sealing method is a rubber O-ring string. The photos of the enclosures tested can be seen in Figures 6.8 to 6.14.

Figure 6.8: Polyoxymethylene (POM) enclosure shell with foamed polyurethane O-ring string was wet on the inside and on the lid. When the case was disassembled the water was flowing out, so it can be assumed that there was a lot of water inside.

Figure 6.9: Polyoxymethylene (POM) enclosure shell with rubber O-ring string was the only combination that stayed completely dry. For this test there were no self-sealing screws for the salt water switch on the top of the case.

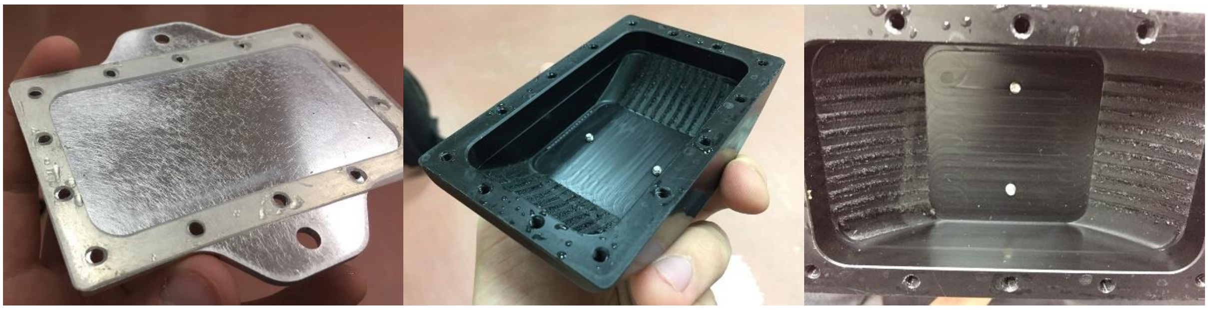

Figure 6.10: Polyoxymethylene (POM) enclosure shell with silicone gasket had just a very small wet spot inside.

Figure 6.11: Oilamid enclosure shell with silicone gasket was the wettest of all cases with a silicon gasket whit big wet spots inside.

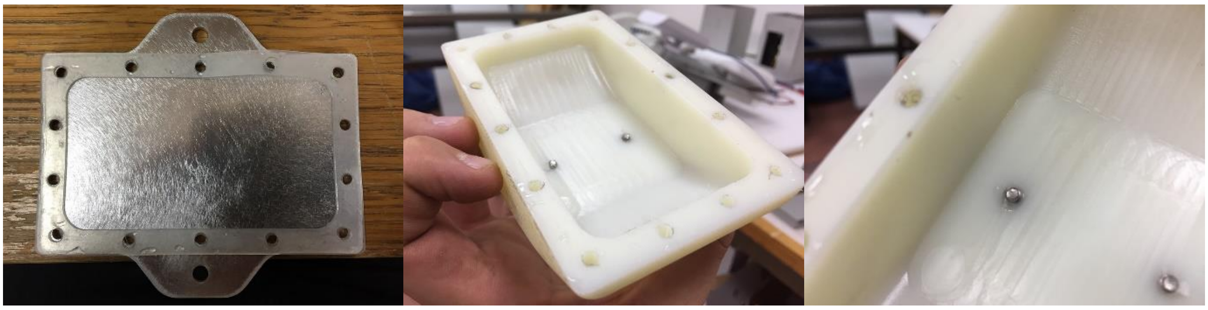

Figure 6.12: Polyamide 6 (PA6) enclosure shell with silicone gasket had just a very small wet spot inside.

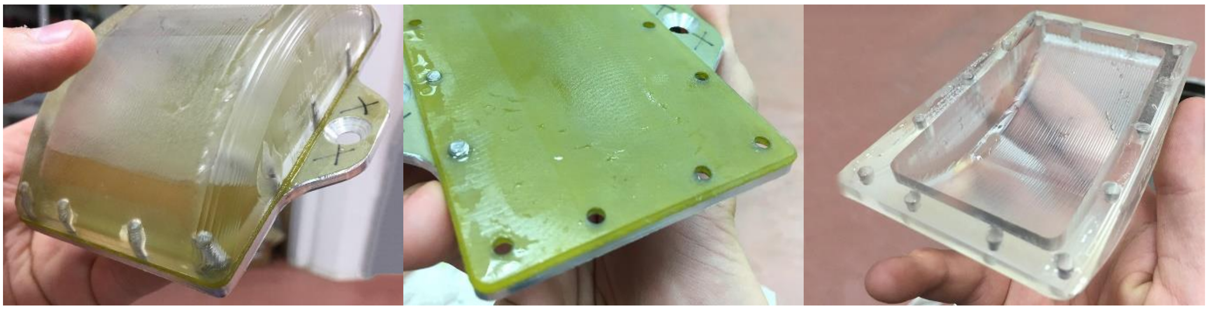

Figure 6.13: Acrylic enclosure shell with a polyurethane sealing layer cast on an aluminium plate preformed the worst, it was already visible from the outside that a lot of water penetrated the case.

Figure 6.14: The second test of polyoxymethylene (POM) enclosure shell with rubber O-ring string, this time with two self-sealing screws for the salt water switch on the top of the case. The enclosure stayed completely dry even on the second try with the self-sealing screws.

The first sealing tests were conducted to find the most suitable material and sealing method. Polyoxymethylene (POM) plastic was selected as the most appropriate material and the rubber O-ring string as the most effective sealing method. In the first tests the cases were tested under 9 bar of pressure which was easily achieved with an air compressor with the selected combination then subjected to further testing.

For the next sealing tests under higher pressure we have made a new series of two enclosures, one PitStop GPS Tag and one PitStop Camera Tag enclosure. The goal was to test the finished enclosures under pressure of at least 20 bar, equivalent to the depth of 200 m. Polyoxymethylene (POM) plastic was used for the enclosure shell and the rubber O-ring string for sealing. The GPS tag also featured two self-sealing screws for the salt water switch on the top of the case and the camera tag featured an acrylic glass window with the rubber O-ring seal for sealing and an aluminium cover to attach it to the enclosure. The cases tested are shown in Figure 6.15.

Figure 6.15: PitStop GPS Tag and PitStop Camera Tag enclosures, tested at 10, 25 and 50 bar.

The second sealing tests were similar to the first tests since we used the same pressure container, but because of the higher pressure required, we could no longer use the same air compressor. Instead we used a high-pressure gas cylinder and a regulator. The gas cylinder contained nitrogen with a working pressure of 200 bar and a regulator capable of delivering up to 50 bar of pressure.

The container was half-filled with water. The enclosures that were tested were assembled and put on the bottom of the container fully covered with water. Weights were put over the cases to ensure the negative buoyancy. The cases were first tested under 10 and 25 bar of pressure for 15 minutes, equivalent to the depth of 100 and 250 m. The next test was conducted at 50 bar, equivalent to the depth of 500 m. Although not required, we wanted to see if the enclosures would survive this kind of pressure as well. The last test was conducted at 25 bars for a few hours to test longer exposure to high pressure. After each test cases were taken out of the container, carefully wiped dry and disassembled to check for any leaks.

Both GPS and camera enclosures stayed completely dry when tested under 10 and 25 bar of pressure for 15 minutes and even at longer exposure to high pressure at 25 bar for a few hours. The photos of the enclosures tested can be seen in Figure 6.16.

Figure 6.16: Both PitStop GPS Tag and PitStop Camera Tag enclosures stayed completely dry at 10, 25 and even 50 bar.

When tested at 50 bar, slight deformations were found on both aluminium lids and on camera enclosure shell. But despite the deformation, both cases stayed completely dry, even at 50 bar. The pictures of the enclosures that were put to test at 50 bar are shown in Figure 6.17.

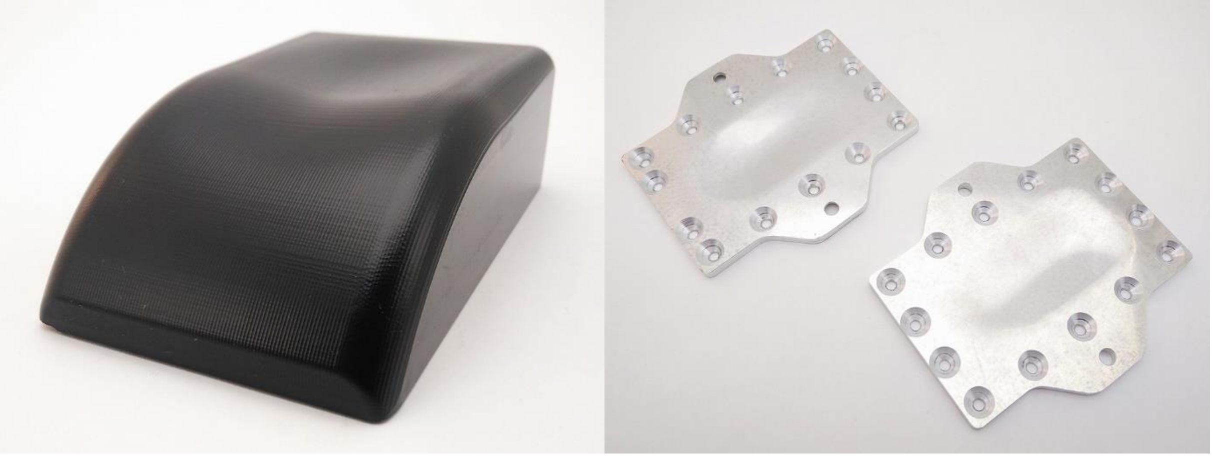

Figure 6.17: Permanent deformation that both aluminium lids and the camera enclosure shell have undergone when subjected to 50 bar.

Both cases passed all tests, even when they have undergone permanent deformation, they stayed completely dry. This confirms our choice of rubber O-ring string for the sealing.

We have also tested different O-ring groove dimensions to see which dimension is optimal to ensure reliable sealing. The cross section of the O-ring selected is 2 mm. The width of the groove was fixed to 2 mm and the depth of the groove was then altered. It was determined that the optimal depth for reliable sealing is 1,25 – 1,40 mm. With increasing the depth to more than 1,40 mm we have seen small leaks in certain cases as shown in Figure 6.18. On the other hand, there were some problems with the deformations and damages on the enclosures with the grooves shallower then 1,25 mm, as shown in Figure 6.19.

Figure 6.18: The turtle tag enclosures with the depth of O-ring groove of more than 1,40 mm had a few problems with small leaks in certain cases.

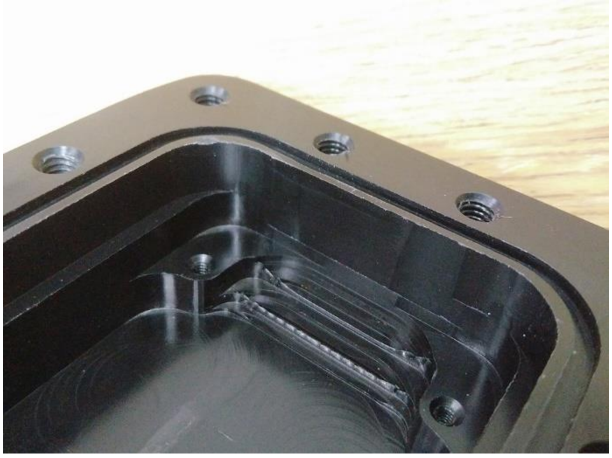

Figure 6.19: The turtle tag enclosures with the depth of O-ring groove of less than 1,25 mm had some problems with the deformations and damages on the enclosures.

6.3 Pressure sensor sealing test

The information about the depth is very important for accurate tracking of the sea turtles. A pressure sensor is used in the PitStop Tags to measure the depth which also had to be tested to confirm the sealing. Sealing tests of the pressure sensor were similar to the sealing tests of the PitStop Tag enclosures. A special enclosure was made from polyoxymethylene (POM) plastics with rubber O-ring string used for sealing. To seal the pressure sensor we have used an O-ring seal with the same dimensions and receptacle hole as prescribed in the pressure sensor data sheet, provided by the manufacturer. The dimensions and tolerances prescribed are shown in Figure 6.20. During the first two tests we used an aluminium plate to attach the pressure sensor. We have then designed a custom PCB which is also used to attach and connect the pressure sensor in the actual PitStop Tags. In the third test we then used this PCB to attach the pressure sensor. Both enclosures can be seen in Figure 6.21.

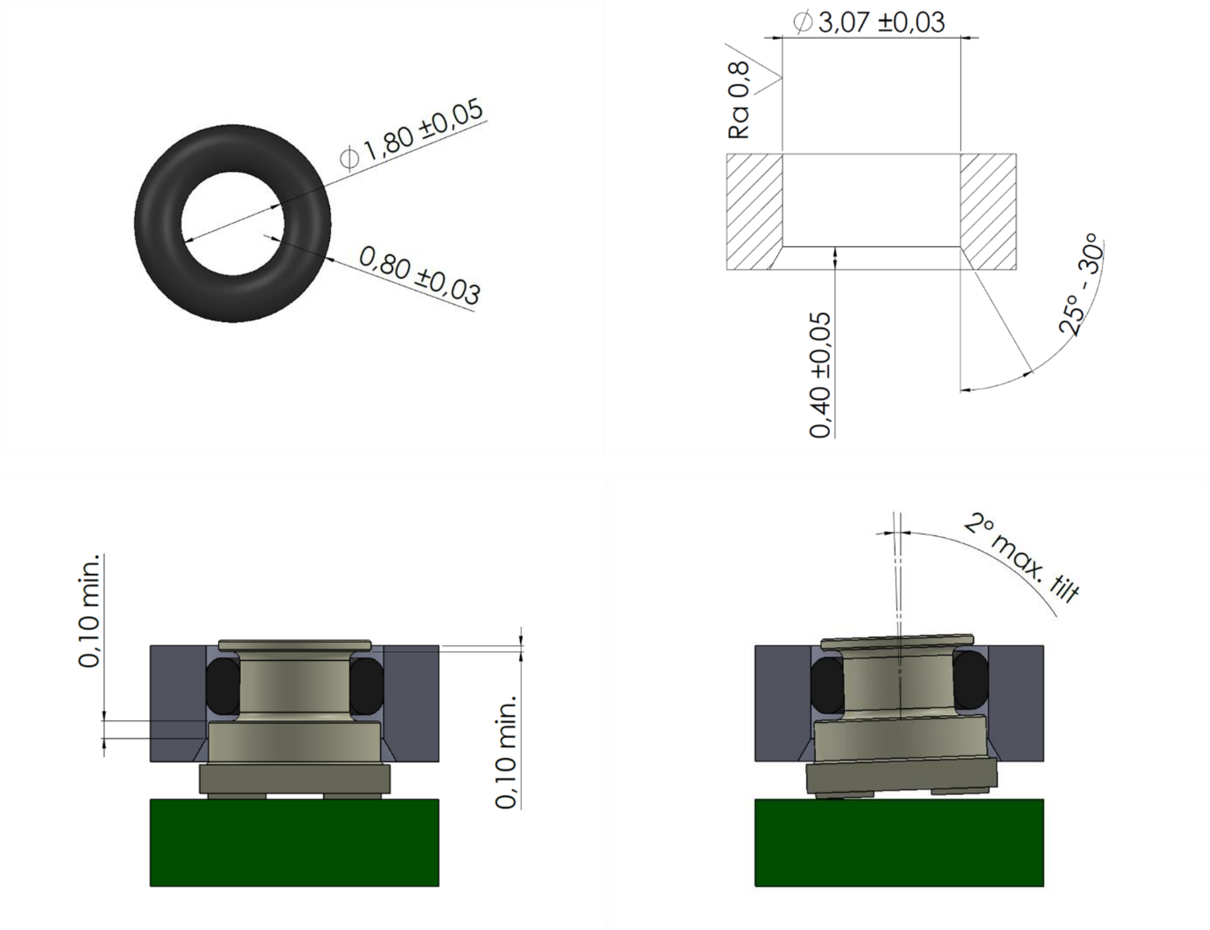

Figure 6.20: The prescribed dimensions and tolerances of seal and receptacle hole for pressure sensor TE Connectivity MS5837-30BA. [38]

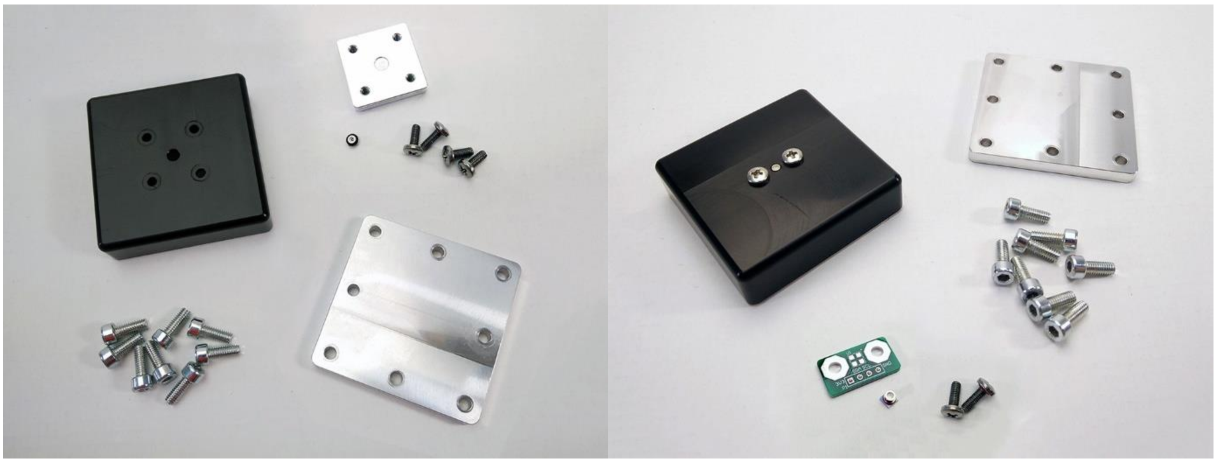

Figure 6.21: A special enclosure was made to test the sealing of the pressure sensor. On the first tests the pressure sensor was attached using an aluminium plate (left). A custom PCB was then designed that is also used to attach and connect the pressure sensor in the actual PitStop Tags (right).

The same pressure container was used for the tests as before. The pressure container was connected to an air compressor capable of providing pressure up to 10 bar. The container was half-filled with water. The enclosures that were tested were assembled and put on the bottom of the container fully covered with water. The cases were tested under 9 bar of pressure for 60 minutes, equivalent to the depth of 90 m. Afterwards they were taken out of the container, carefully wiped dry and disassembled to check for leaks.

During the first test the pressure sensor was damaged when inserted into the special enclosure due to the incorrect O-ring size. Because of the damage the water was able to penetrate the pressure sensor and fully flooded the case. The sealing test was unsuccessful and therefore had to be repeated with the correct O-ring size and a new pressure sensor. Another test with a new pressure sensor and the correct O-ring was conducted. This time the case stayed completely dry as well as on the third test when a custom PCB was used to attach the pressure sensor. The photos of all three tests can be seen in Figures 6.22 through 6.24.

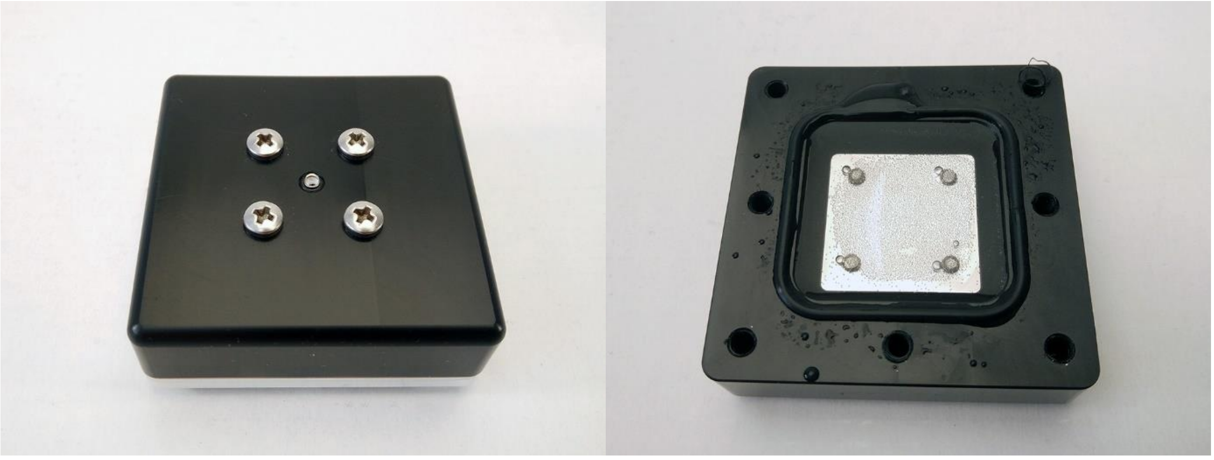

Figure 6.22: During the first test the pressure sensor was damaged, and the water was able to penetrate the pressure sensor and fully flooded the case.

Figure 6.23: The second test with a new pressure sensor and the correct O-ring size. The case stayed completely dry.

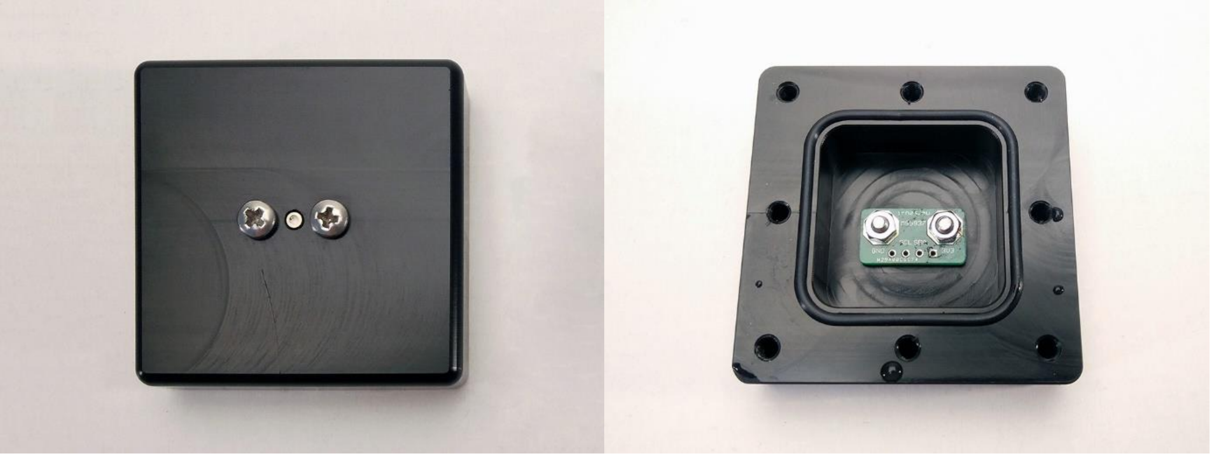

Figure 6.24: A custom PCB that is also used to attach and connect the pressure sensor in the actual PitStop Tags. The case stayed completely dry.

When assembling the enclosure with a pressure sensor it is crucial to be extra careful not to damage the pressure sensor which proved to be quite sensitive during the tests. There are several things to pay attention to in order to assemble and attach the pressure sensor reliably in the enclosure. The receptacle hole has to be of correct dimensions with the tolerances, lead-in chamfer and surface finish being very important. When soldered to the custom PCB the care has to be taken not to overheat the sensor. The O-ring seal that provides the sealing has to be coated with a suitable grease. And the last but not least when inserting the pressure sensor into enclosure it has to be precisely aligned with the receptacle hole. If those steps are precisely followed the pressure sensor seals perfectly.

6.4 High-pressure resistance test

When we were testing the sealing of the enclosures under high pressure during the sealing test we have noticed a large deformation when the enclosure was exposed to 50 bar of pressure. We decided to investigate that further. For these tests we have used PitStop Camera Tag enclosures made from polyoxymethylene (POM) with a weight of 208 g and polyethylene (PE) plastics with a weight of 144 g. POM was selected as the most appropriate in the endurance and sealing tests and the PE was selected because it is a material that we work a lot with. Because it has a lot lower density, enclosures made from PE therefore weigh a lot less and might have less impact on sea turtles' behaviour. Both camera enclosures made from POM and PE plastic are shown in Figure 6.25.

Figure 6.25: Polyoxymethylene (POM) and polyethylene (PE) enclosure shells that were tested for high-pressure resistance.

The tests were similar to all the previous testing. The same pressure container was used for the tests as before, connected to an air compressor capable of providing pressure up to 10 bar and to a high-pressure gas cylinders and a regulator, capable of delivering up to 50 bar of pressure. The container was half-filled with water. The enclosures that were tested were assembled and put on the bottom of the container fully covered with water. Weights were put over the cases to ensure the negative buoyancy. The POM cases were tested under 10 and 25 bar of pressure for 30 minutes while the PE cases were tested under 5 and 8 bar of pressure for 30 minutes, 1 and 16 hours. After each test cases were taken out of the container and wiped. The deformation was measured using a depth gauge.

The results of the testing are described in the next list. The photos of deformations on POM and PE cases can be seen in Figure 6.26.

- Polyoxymethylene (POM) enclosure shell at 10 bar of pressure for 30 minutes – there was no noticeable deformation.
- Polyoxymethylene (POM) enclosure shell at 25 bar of pressure for 30 minutes – there was no noticeable deformation.
- Polyethylene (PE) enclosure shell 5 bar of pressure for 30 minutes – we have measured a maximum 1,1 mm deformation at the top middle of the case.
- Polyethylene (PE) enclosure shell 8 bar of pressure for 30 minutes – we have measured a maximum 1,1 mm deformation at the top middle of the case.
- Polyethylene (PE) enclosure shell 8 bar of pressure for 1 hour – we have measured a maximum 1,6 mm deformation at the top middle of the case.
- Polyethylene (PE) enclosure shell 8 bar of pressure for 16 hours – we have measured a maximum 5,4 mm deformation at the top middle of the case.

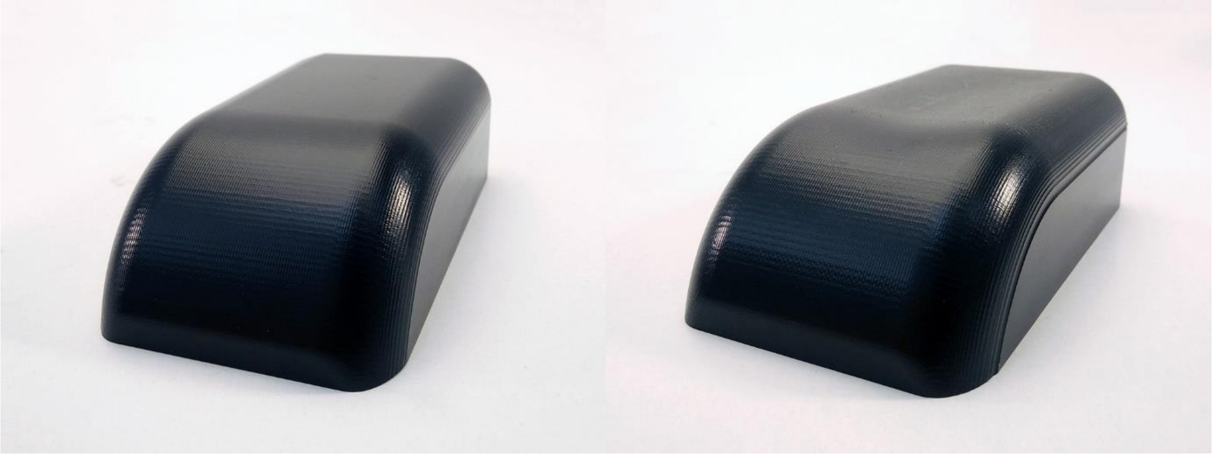

Figure 6.26: On the left is a polyoxymethylene (POM) enclosure shell with no noticeable deformation and on the right a polyethylene (PE) enclosure shell where a deformation can be clearly seen. On the picture is the enclosure that was subjected to 8 bar of pressure for 1 hour with a deformation od 1,6 mm.

While enclosure made from polyoxymethylene (POM) passed both tests, we have discovered that the enclosure made from polyethylene (PE) was a lot weaker. Tests under only 8 bar showed a large deformation and we have therefore concluded that PE is not suitable for PitStop GPS and Camera Tag enclosures if the design remains unchanged.

7 CONCLUSION

The aim of the project was to develop a reliable and affordable tracking system PitStop for monitoring of threatened sea turtles. Although proprietary commercial tags were available and are used extensively, high costs often make impossible for conservationists to use them on a larger scale. Our goal was to reduce the cost of tagging sea turtles using open source principles and technologies in order to achieve greater impact.

This paper gives an insight into the whole development process of the enclosure for tracking system PitStop. The tag enclosures were extensively tested to determine the best design, material and sealing method. Through four iterations of the design we have developed an enclosure, capable of withstanding the load and the pressure. Polyoxymethylene (POM) plastic was selected as the most appropriate material in a series of endurance and sealing tests and the rubber O-ring string as the most reliable sealing method.

The test deployments conducted show the progress we achieved with the improvements through the iterations of the tracking system and the data retrieved from the tags show its potential. The acquired GPS locations, sensor readings and video footage can help with monitoring, give an insight into behaviour and interaction between the sea turtles, and help identify the dangers that threaten them. All this is critical for implementation of informed conservation strategies, especially if the tags could be used on a larger scale.

With the PitStop tracking system we were able to dramatically reduce the cost of tagging sea turtles and offer affordable and customizable technology to researchers, with the final tags costing in the range of 200 to 800€, depending on the configuration. The PitStop Tags are a great alternative to proprietary commercial tags, able to provide the researchers both the data and the video footage. The PitStop Tags are already being used by researchers for sea turtle monitoring, but further testing, trials and test deployments should be conducted to confirm all the findings and to find possible changes that could still improve the design.

Following the open source principles, all the documentation and instructions are published and are freely available to anyone. This enables the researches to not only use the tracking system but to also modify and customize it to fit their needs.

Open source technologies and the sharing of knowledge have the potential to revolutionize the monitoring of species, and most importantly, help us use the data acquired to implement carefully planned and comprehensive conservation strategies that will ultimately protect and conserve endangered species such as the amazing green sea turtle.

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DECLARATION OF IDENTITY OF THE PRINTED AND THE ELECTRONIC VERSION OF THE MASTER'S THESIS

Faculty: Faculty of Mechanical Engineering, University of Maribor
Student: Blaž Bratuš
Study Programme: Master's Degree Study Programme of Mechanical Engineering
Master's Thesis Title: Development of the Waterproof Enclosure for Tracking System PitStop
Mentor: Assoc. Prof. Dr. Miran Ulbin

I, the undersigned, Blaž Bratuš, hereby declare that:

- the submitted project entitled Development of the Waterproof Enclosure for Tracking System PitStop is my original work done under the mentor's guidance of Assoc. Prof. Dr. Miran Ulbin;
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