A cost-efficient low-weight autonomous profiler for measurements in polar coastal waters and other regions with strong density gradients

Lucas M. Sandby\textsuperscript{a,b}, Jens E.B. Mejdahl\textsuperscript{a,b}, Simon H. Bjerregaard\textsuperscript{a,b}, Claus Melvad\textsuperscript{a,b}, Søren Rysgaard\textsuperscript{b}

\textsuperscript{a}Aarhus School of Engineering, Aarhus University, Inge Lehmanns Gade 10, DK-8000 Aarhus C, Denmark
\textsuperscript{b}Arctic Research Centre, Department of Biology, Aarhus University, Ole Worms Allé 1, DK-8000 Aarhus C, Denmark

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abstract

The rapid warming of our planet has resulted in accelerated melting of ice in polar regions. Currently we have limited knowledge on how, where and when the surface meltwater layer is mixed with the underlying ocean due to lack of observations in these remote areas. We present a lightweight (17 kg) and low-cost (€6000) instrument for autonomous profiling across the strongly stratified upper layer in Arctic coastal waters, freshened by the riverine input and meltwater from glaciers, icebergs, and sea ice. The profiler uses a specially designed plunger buoyancy engine to displace up to 700 cm\textsuperscript{3} of water and allows for autonomous dives to 200 m depth. It can carry different sensor packages and convey its location by satellite communication. Two modes are available: (a) a free-floating mode and (b) a moored mode, where the instrument is anchored to the seafloor. In both modes, the profiler controls its velocity of 12 ± 0.3 cm/s resulting in 510 ± 22 data points per 100 m depth. Equipped with several sensors, e.g. conductivity, temperature, oxygen, and pressure, the autonomous profiler was successfully tested in a remote Northeast Greenlandic fjord. Data has been compared to traditional CTD instrument casts performed nearby.

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Specifications table

| Hardware name                  | Arctic Research Centre Cost-efficient Ocean Profiler (ARC-COP) |
|--------------------------------|---------------------------------------------------------------|
| Subject area                   | Environmental, Planetary and Agricultural Sciences           |
| Hardware type                  | Field measurements and sensors                               |
| Open Source License            | \textsuperscript{c} CC BY 4.0                                 |
| Cost of Hardware               | \textsuperscript{c} €6000                                     |
| Source File Repository         | https://doi.org/10.17632/yc89ksvj8k.1                        |

\textsuperscript{c}E-mail addresses: lucassandby@gmail.com (L.M. Sandby), rysgaard@au.dk (S. Rysgaard)

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Hardware in context

The use of profiling floats for obtaining subsurface oceanographic observations have eliminated major seasonal bias in sampling in remote oceans [1,2]. Profiling floats, such as APEX, SOLO, PROVOR, and Navis, change their buoyancy in order to move vertically in the ocean, repeatedly collecting data spanning a range of depths [3]. Their prices range from 20 000€ to more than 100 000€. These autonomous drifting vehicles typically have aluminium pressure cases of about two meters length, use a pump to inflate an external oil bladder to increase buoyancy, are capable of making a few hundred profiles to a maximum depth of 2 000 m before battery exhaustion, and transmit their data to shore via satellite communication. Despite their success in offshore waters, there is a lack of data from coastal areas and in particular in polar coastal waters [4]. This is partly due to a limited buoyancy range of existing floats, which make them unsuitable for shallow coastal profiling with strong density gradients.

A low-cost, lightweight, and easy deployable instrument is needed for fjord and coastal autonomous profiling of oceanographic parameters, where strongly stratified conditions exist and where most freshwater (runoff) is present. The ARC-COP is a result of an interdisciplinary collaboration between the Arctic Research Centre and a team of Engineering students at Aarhus University. The purpose of the development is to increase the technical and economic feasibility of research in Arctic coastal areas with meltwater input from rivers, glaciers, icebergs, and sea ice. This allows researchers to obtain data with better spatial and temporal resolution of measurements in remote areas with difficult access.

Hardware description.

Our product requirements for the autonomous profiler and the results are outlined in Table 1. These have been set up to meet functional requirements based on the method House of Quality and MoSCoW analysis from Six Sigma. Today, oceanographic observations in remote coastal areas of the Arctic are provided from icebreakers, ice strengthened ships or from small research boats operated locally from coastal research stations. Increasing the number of observations during the active melting season could be facilitated with a new, lightweight, and low-cost instrument for autonomous profiling across the strongly stratified upper layer. Commercial profiling floats do not meet our product requirement with respect to volume displacement, weight, and cost.

The Arctic Research Centre Cost-Efficient Ocean Profiler (ARC-COP) (Fig. 1) is a profiling float with low-cost sensors and hardware. Utilizing user-defined settings loaded onto an SD-card, the ARC-COP dives autonomously according to the user-defined schedule, travelling to a maximum of 200 m depth. The profiler is turned on through the removal of the on/off magnet. While profiling, the temperature, pressure, and conductivity sensors samples with 1 Hz and stores the data on the SD-card. In addition, one of the two Aanderaa sensors (Aanderaa CT sensor or Aanderaa Oxygen Optode – see section 2.3) can be connected to extend the profiling datasets. When at the surface, the float has an integrated and bi-directional iridium-connection to send its location and engineering data, or to receive a command to stop profiling in order to be retrieved. Between dives, the float drifts at the surface in a deep sleep power saving mode.

The ARC-COP can be used in free floating mode or it can dive along an anchored mooring line, secured by its handles which can be safely opened and locked around the mooring line. Our design files and software are open source. The remainder of this section describes the hull, buoyancy engine, sensors, power, communication, wiring, and software systems.

Hull and skeleton

The centre hull and top are manufactured in EN AW-6060 aluminium. The hull is dimensioned as a pressure vessel via DS/EN 13445–3:2014 and both are validated for 20.11 bar [5] (relative pressure, 200 m depth in sea water with a density of 1025 kg m$^{-3}$) using FEA (Finite Element Analysis) buckling study with safety factor of 1.25. Hull thickness is 5 mm, anodized with a 20 μm surface layer and mounted Zn-anode to minimize corrosion during the mission period.

The top plate is equipped with a GPS/Iridium antenna and sensors (e.g. pressure, temperature, conductivity, oxygen) and is protected from collisions with ice with a cage. The bottom plate, which holds the buoyancy engine, and top are assembled by the welded-on flanges and the components are sealed with O-rings for waterproofing. A 4 mm stiffener plate is welded inside the hull and supports a gear plate on the buoyancy engine. The foot acts as a stand for the hull and is optimized based on CFD (Computational Fluid Dynamics) simulations [5] to create the lowest drag force and turbulence/pressure fields close to the sensors. Based on this flow analysis and due to space limitations the Aanderaa CT and Atlas C sensors are placed on the side of the hull with straps instead of with thread on the top as for the other sensors and hardware.

The hull contains a laser cut skeleton, fastened to the top that carries all the electrical components such as the custom designed PCB-Arduino shield. The construction is designed in sections to make assembly and maintenance easier, in accordance with the design guidelines which includes Poka-Yoke (mistake proofing) [5]. The SubConn connectors are selected to easily connect the conductivity sensor and optional sensor (see Table 3), although lower cost alternatives are available [6].
Buoyancy engine

The buoyancy engine has been designed in order for the float to profile to 200 m depth in strong density gradient waters. Often this upper ocean layer contains most freshwater with a density of 1006 kg m\(^{-3}\) whereas the deeper waters have a higher density of up to 1028 kg m\(^{-3}\) – primarily determined by the salinity in Polar regions [7].

The buoyancy engine itself consists of 40 different elements (excluding fasteners etc.) of which 19 are custom machined parts. The construction and the main components are shown in Fig. 2.

The engine is a separate element that is mounted to the bottom which is bolted to the main hull. The final piston design shown in Fig. 2 is able to displace a volume of \(V_{\text{control}} = 700\text{cm}^3\) of water. The volume of the float is \(V_{\text{float}} = 17L\).

For the sum of the buoyancy force and gravitational force to be zero the following must apply:

\[
P = D g q
\]

where

\[
p = \text{density of water in kg m}^{-3}
\]

\[
g = 9.81 m s^{-2}
\]

Table 1

| Product requirement | Achieved? |
|---------------------|-----------|
| Deployment | From small vessel | ✔ |
| Handling | 1 person | ✔ |
| Endurance | 100 profiles to 200 m | ✔ |
| Operation | Continuously free floating or mooring | ✔ |
| Profiling velocity | 0.1 to 1 m/s | ✔ |
| Shipping | Zarges Box \((100 \times 45 \times 45 \text{ cm})\) | ✔ |
| Air temperature | –30 to 40 °C | ✔ |
| Water temperature | –2 to 20 °C | ✔ |
| Water density | 1006 to 1028 kg m\(^{-3}\) | ✔ |
| Ice | Can measure –2 to 20 °C | ✔ |
| Waves | Calm weather, < 2 m | ✔ |
| Dimensions | < 100 \times 45 \times 45 \text{ cm} | ✔ |
| Weight in air | < 20 kg | ✔ |
| Volume | > 500 cm\(^3\) | ✔ |
| Mission duration | 1 month | ✔ |
| Measured parameters | Conductivity (C), Temperature (T), Pressure (P) \(\div\) depth (D)\(^1\) | ✔ |
| Maximum depth | 200 m | ✔ |
| Sampling frequency | 1 Hz | ✔ |
| GPS position | ± 0.7% FS (full scale) \(\times\) 140 mbar at 20 bar (equivalent to approx. 200 m depth) | ✔ |
| Pressure accuracy | ± 0.1 °C | ✔ |
| Temperature accuracy | ± 1 000 \text{μS/cm} | ✔ |
| Conductivity accuracy | ± 3 m for satellite connection | ✔ |
| Transfer data | >100 km | ✔ |
| Internal memory | > 1 month of data | ✔ |
| Color | Highly visible yellow for protection cage and red flag | ✔ |
| Ease of operation | Possible to operate by a person without any coding or mechanical skills | ✔ |
| Orientation | Vertical autonomous profiling | ✔ |
| Fixed position | Possible to do fix position | ✔ |
| Profiling | Can withstand collision with sea floor and ice | ✔ |
| Position | GNSS | ✔ |
| Energy | Internal battery | ✔ |
| Communication | Iridium | ✔ |
| User inputs | Possibility to cancel mission from the distance | ✔ |

\(^1\) Conductivity (C), Temperature (T), Pressure (P) and depth (D) are measured and sent to the user. C, T, P and Oxygen level is possible to measure.

Relationship between pressure \((P, \text{ in kPa})\) and depth \((D, \text{ in m from water surface})\) is as follows:

\[
P = D g q
\]

where \(q = \text{density of water in kg m}^{-3}\) and \(g = 9.81 \text{ m s}^{-2}\)
Given the neutral buoyancy weight of the float is $m_{\text{float}} = 17.3\,\text{kg}$ we gain a density of the float between $\rho_{\text{min}} = 998\,\text{kgm}^{-3}$ and $\rho_{\text{max}} = 1040\,\text{kgm}^{-3}$.

$$\rho_{\text{min}} = \frac{m_{\text{float}}}{V_{\text{float}} + \frac{V_{\text{control}}}{2}}$$

$$\rho_{\text{max}} = \frac{m_{\text{float}}}{V_{\text{float}} - \frac{V_{\text{control}}}{2}}$$

The densities can be changed by reducing/increase amounts of batteries and/or weights. It can also be adjusted by changing the neutral position of the piston.
As the satellite communication is sensitive to skin effect due to submergence in water, the risk of failed telemetry in waves can be reduced by having neutral buoyancy, when the piston displaces a volume of 300 cm³ (or even less). This example gains a new minimum density of \( \rho_{\text{min,new}} = 988 \text{kgm}^{-3} \).

A summary of the specifications of the buoyancy engine is listed below.

- The DC-motor and its internal planetary gear is further reduced by a 4.5:1 gear ratio which applies a maximum torque of 12.64 Nm to the spindle. This is converted to a linear movement to withstand the water pressure at the 200 m depth.
- As the spindle rotates, the piston mounted on the spindle nut moves outwards or inwards to change the volume (density) of the float with a total of 700 cm³.
- The centre of gravity (CoG) is on average placed \( z = 77 \text{mm} \) below the centre of buoyancy (CoB) which ensures vertical stability, even in waves. The stability momentum is calculated in the following dependent on delete \( \theta \) which is the angle of heel [8].

\[
M_{\text{upr}} = m_{\text{float}} \cdot g \cdot z \cdot \cos(\theta) \approx 13 \text{Nm} \cdot \cos(\theta)
\]

- The spindle is kept in place by a tapered roller bearing (upwards, which is most crucial due to the pressure) and the POM gearwheel.
- The piston moves within an anodized aluminium cylinder which is mounted on the outside of the bottom with a single O-ring.
- The U-cup seals the wet side from the dry side of the moving piston.
- To avoid rotation of the piston, linear rails are added to the piston which is guided by two roller bearings on the cylinder.
- The entire structure is held by the 386 g weight-optimized gear plate which is mounted to the bottom by stiffeners. The gear plate is validated using FEA (Finite Element Analysis) with a safety factor of 1.25.
- The stiffeners are bolted all the way through the POM-bottom securing maximum strength.
- The stiffeners are supported by a stiffener plate which is welded to the hull. This plate is also a wall between the gears and the cables and other objects.
- The stiffener plate as well as the stiffeners are analysed using FEA with a safety factor of 1.25.
- The ratchet wheel/brake system allows for the motor current to be cut, thereby reducing energy-usage. A small servo controls the ratchet brace.

Apart from this piston design, other buoyancy engine systems have been considered. The most relevant of them are listed in Table 2. Among other theoretical methods are air pressure [9], shape memory alloys (SMA) [10], an osmotic pump inspired by marine animals [11], and an electrolysis bladder [12].

These methods have not been used in our study due to their impractical implementation as well as special components and complexity, leading to higher expenses – which is unattainable for a small production scale.

The buoyancy engine is controlled by the Arduino in order to change and regulate the float density dynamically during the ascend/descend. This secures a consistent velocity during the profile and makes it possible to lower the sampling frequency due to the controllable and possibly lower diving velocity.

**Sensors & hardware**

The most important sensors, including both the three standard sensors (temperature, pressure, and conductivity) as well as optional and auxiliary sensors are listed and described in Table 3. Hardware components are described in Table 4.

The standard ARC-COP includes a temperature, pressure, and conductivity sensor. These have been chosen due to their low-cost and versatility. In addition to these, the current mechanical, as well as electrical and software design, allows for either the Aanderaa Conductivity Sensor 4319 or Aanderaa Oxygen Optode 4835 to be mounted to the otherwise unused MacArtney connector.

All sensors sample with a frequency of 1 Hz and the data is sorted and stored with timestamps on an SD-card, which can be retrieved when the float is opened. Attached is an iridium module and a deep-sea antenna which allows for bi-directional transmission. The profiler is designed to dive according to a predefined schedule at user-defined times which are written in the settings file and stored on the SD-card.

**Wiring & PCB layout**

For the ARC-COP a custom 2-layer PCB has been manufactured. The PCB is designed as an Arduino shield so it can be directly attached to an Arduino Mega and fitted to the hull size – see Fig. 3.

The complete circuit diagram/schematic can be seen on Fig. 7.

The PCB entails the following main components listed below (see Fig. 3 for layout):
Table 2
Other buoyancy engine systems.

| Method                  | Description                                                                                                                                 |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Plunger and rolling diaphragm seal [13] | A piston is pushed directly out to the water to increase the volume and thereby decrease the density. This is most typically with a diaphragm seal to separate the wet outside and dry inside. |
| Hydraulic pump [14]     | A high-pressure hydraulic pump is used to inflate an external bladder with oil from an internal bladder and thereby increases the volume, and thus lower the density. Used in the float ALACE with an efficiency of 40–50%. |
| Single stroke hydraulic piston | A piston is used to push oil into an external bladder to change the volume and thereby the density. Used in the float Teledyne Apex with an efficiency of 22% [15]. To minimize the stroke-volume of the pump an internal reservoir can be used making it a multiple stroke hydraulic piston [14]. |

Table 3
Sensor description.

| Sensor                | Description                                                                                                                                 |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Temperature sensor    | The fast-response Blue Robotics temperature sensor [16] is used to measure temperature from −5 °C to 50 °C.                                      |
| Pressure sensor       | A 30 bar Blue Robotics pressure sensor [17] is used to estimate the depth and hereby calculate velocities and decide software case-selections.     |
| Conductivity sensor   | An Atlas K1.0 conductivity probe [18] and its EZO conductivity circuit is used to measure conductivity. From the conductivity salinity can be calculated in a range from 5 μS/cm to 200,000 μS/cm. To compensate for the temperature the value from the temperature sensor is used. A cast of ISO-PUR K 760 has been made with 3D-printed molds. |
| Optional sensors      | More sensors are, as of currently, implemented but are optional in the design. However, only one of these can be mounted at a time. Aanderaa Conductivity Sensor 4319 (electrical conductivity and temperature) [20]. Aanderaa Oxygen Optode 4835 (O2-concentration and temperature) [21]. |
| (Auxiliary) Leakage sensors | Two leakage sensors (P5 in BOM) are implemented. One is placed at the top of the skeleton, while the other is placed at the bottom of the buoyancy engine. These are coded as case-selectors which will enter the error state if leakage occurs. |
| (Auxiliary) IR sensor  | Measures the position of the piston in the buoyancy engine to be used for the controlling system/Arduino on buoyancy regulation. P6 in BOM. |

Table 4
Hardware description.

| Hardware              | Description                                                                                                                                 |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Communication/telemetry | Iridium Short Burst Data (SBD) [19]. The iridium network is used to transmit and receive data. Transmits: Position, battery percentage, engineering data (status). Receives (if any): Command to stop diving to enter error mode and be retrieved. For usage in non-remote areas, or with a ground station close by technologies such as LoRa, WiFi or RF could be used. We used RockBlock.rock7.com as platform/host. |
| Positioning system    | The GPS (GNSS) module (P4 in BOM) provides the time and position. To secure correct transmission of position and time – even in high waves, it is programmed to search for up to 5 min. |
| Data storage          | Settings, such as preferred diving times, diving depth and mission length, is written onto the SD card (P9 in BOM) before deployment. The CTD data, as well as engineering data (volume displacement, Iridium transmission data and software state-logging), is stored on the SD-card with a timestamp during the whole mission. |
| Battery               | 216Wh NiMH (4P10S Panasonic BK450A NiMH cells $= 1.2V/4.5Ah) with specially design housings formed around the piston cylinder. Other types such as Li-ion can be used as well. If Li-ion is to be used the BMC should allow 2A. Weight of batteries should be approx. 2500 g. |

Fig. 3. PCB design.
• A MAX232 IC for converting RS232 to UART for the Aanderaa sensors
• A 873 kOhm : 560 kOhm voltage divider for the battery measurements1
• A 3.3 to 5 V bi-directional logic level converter for all the components on the I2C-bus
• 4 Transistors for on/off configuration for the servomotor, SD-card reader, GPS, and LED
• In addition to these components, it also entails associated resistors, capacitors, and connectors as it can be seen on Fig. 7

Software

The Arduino programming language, which is similar to C, is used to program the Arduino Mega controlling the float. This gives access to a good range of inexpensive Arduino boards and compatible libraries and a large and helpful online community. The software is built up as a state machine consisting of 6 main states each with their own states and/or functions inside. These are described in Table 5 to give an overview of the structure and autonomy of the ARC-COP. Table 5 also includes the pseudo code conditions, describing how the different states are entered. Fig. 4 shows the topology of the software and components.

Power

The field test in Greenland (see section 7. Validation and Characterization) indicated a possible mission duration of approx. eight days, with seven dives to 20 m each day. This is based on a test of 16 h with five dives, where 8.3% of the battery capacity was used (based on voltage converted to discharge time). This is calculated according to the Panasonic BK450A discharge curve, given a discharge current of 840 mA and a cut-off at 1.1 V. The NiMh-cell can however be discharged to 0.9 V. This is a conservative calculation as the actual average discharge current will be significantly lower, but no data from the NiMH cell manufacturer is available. It is possible to lower the cut-off voltage but may result in power cessation and therefore not recommended, especially in the case of a potential emergency/error.

However, by periodically powering down the H-bridge (e.g. with a transistor), a power-consumption of 0.184 W on average is achieved during testing. With an average power consumption of 0.184 W and a 216 Wh Ni-MH battery package, the profiler can, as of currently, be deployed for over one month (39 days). This calculation accounts for one 200 m dive each day, as well as losses due to temperature (80% battery efficiency at 0°C in the hull [22]). The approximated power consumption for each state can be seen in Table 6. The field test result, as well as expected mission durations dependent on dives a day, are shown in Fig. 5. The expected mission duration is based on calculations assuming the H-bridge is being powered down.

Price

As a product, the ARC-COP acquires a unique position in the market with its lower price and better range of the buoyancy engine compared to existing floats. The low price is secured through simple mechanisms and manufacturing. The prices in Fig. 6 are based on a production of one to two units.

The largest expense is the manufacturing due to the custom components. This would potentially decrease with 20–30% were the production, for example, five to ten units. Presumably, this also makes it possible to acquire a bulk discount on the more expensive components. Furthermore, the GPS/Iridium antenna is too expensive, accounting for 12% of the total budget. This antenna is rated for 6000 m which is unnecessary but was chosen due to the limited market of existing antennas. The prices are given without VAT and the assembly time is not included. The components and their prices can be found in the BOM. The production price is calculated based on an average hourly wage of 500 DKK (approx. 67 EUR).

Usage summarized and alternative applications

The ARC-COP is a low-cost alternative to other profilers and floats also measuring CTD-data up to a 200 m depth. Its extended buoyancy design makes it unique when operating in areas with high density gradients, for example in polar regions. Additionally, its weight and simple design makes it easy to operate, including for researchers lacking extensive technical skills.

Ultimately, the aim of the float, and its relatively low price, is to make possible the deployment of multiple units, thus obtaining a higher spatial resolution of CTD measurements, as well as allowing for the risk of losing equipment in challenging environment. An example could be, that the ARC-COP is suited for profiling in the vicinity of glaciers where it is too dangerous to access by boats due the risk of rolling icebergs. Under these circumstances, deployment could be at the incoming current towards glaciers or by RC-controlled boats or heavy lift drones.

In general, it is well suited for underwater research, investigation, mapping or recording such as environmental research in fjords and estuaries.

1 For the recommended NiMH battery, the voltage divider should be changed to 560 kOhm : 300 kOhm.
In its essential form, the ARC-COP is a product designed to move sensors up and down the water column. This means that the CT-sensors could be replaced or supplemented to expand the possible research areas. Examples of other instruments are, but not limited to:

**Table 5**
Software states described.

| State              | Description (numbered in sequential order)                                                                 | Entered IF (pseudo)                                                                 |
|--------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Startup state      | 1. Checks for errors on battery level & SD-card.                                                           | (Always the first state after initialization)                                       |
|                    | 2. Runs initial settings and receive GPS position.                                                           | The on/off magnet is removed from the outer hull.                                  |
|                    | 3. Using the LED, gives indications to the user whether error has occurred, or everything is ready for deployment. |                                                                                     |
| Measure state      | Measures conductivity, temperature, pressure, and other potential parameters.                             |                                                                                     |
|                    | Calculates time based on last GPS-connection. After every 25 measurements (or if the state changes), the data is stored to SD-card and the average velocity is calculated. |                                                                                     |
| Change buoyancy state | 1. Measures position of the piston.                                                                           | Desired depth, or surface is reached (change direction or surface).                 |
|                    | 2. Performs a ramped-up extension or retraction of the piston.                                               | Velocity is too low (to increase velocity).                                         |
|                    | Contains multiple state conditions such as “surfacing”, “changing direction” and “increasing velocity”.    | Velocity is too high (to decrease velocity).                                       |
|                    | In case the water depth is shallower than the profiling range, the float will surface and continue profiling according to the schedule. |                                                                                     |
|                    | If the profiler cannot surface due to ice cover, it will enter error mode.                                  |                                                                                     |
| Send/receive state | 1. Attempts to receive GPS position.                                                                          | The ARC-COP has returned to the surface preceding a dive.                            |
|                    | 2. Attempts to transmit and receive data to/from the iridium network.                                       |                                                                                     |
|                    | The GPS and iridium will, if no connection, try to get a fix for two to five minutes each before entering the next state. |                                                                                     |
| Sleep state        | All possible hardware is shut down or put into sleep mode. The Arduino timer is still active in order to operate the wake-up time. | A send/receive state succeeded. More than three minutes until next dive.               |
| Error state        | 1. Surfaces the float.                                                                                       |                                                                                     |
|                    | 2. Raises a software error flag and continuously enters the send/receive state to provide the updated position for recovery. |                                                                                     |
|                    | 3. Blinks the light in order to locate the float when dark. This state is also used as a “recovery” state.    |                                                                                     |

![Fig. 4. Software topology.](image)

In its essential form, the ARC-COP is a product designed to move sensors up and down the water column. This means that the CT-sensors could be replaced or supplemented to expand the possible research areas. Examples of other instruments are, but not limited to:
Table 6
Approximated average power consumption in different states based on measurements and estimates from theoretical datasheets and calculations*.

| Software-State   | Power consumption                                           |
|------------------|------------------------------------------------------------|
| Measure          | ≈ 500 mW                                                   |
| Change buoyancy* | ≈ 19,000 mW at 200 m depth / 5,800 mW at surface          |
| Send/receive*    | ≈ up to 1,050 mW – depending on signal quality             |
| Sleep            | ≈ 90 mW                                                    |

Fig. 5. Expected mission duration to 200 m assumed modification on the H-bridge and including environmental conditions.

Fig. 6. Price overview (W/O VAT) - Total price € 6,016.
- Camera for recording or time-lapse.
- Oxygen optode
- pH sensor
- Irradiance (PAR) sensor
- Fluorometer
- Turbidity sensor

It should be noted, that by adding features, the energy budget will change. Furthermore, the float density should be accounted for. We do see a high potential of reducing the energy usage by both electrical and software optimization. During spring 2021 this is one of more tasks that we will work on (see section 7.3 for more information).

In addition to the improvements, we expect to deploy ARC-COPS in Danish estuaries during summer/fall 2021 to measure temperature, salinity, and oxygen levels.

With the access to our open-source code and design parts, we see a high potential for researchers to add or rewrite features specifically to their usage. One example could be that by tracking the float position, which can be done as of now but improved in resolution by minor software changes, the free-floating mode could be used to track surface currents.

**Design files**

The design files are uploaded within folders([https://doi.org/10.17632/yc89ksvj8k.1](https://doi.org/10.17632/yc89ksvj8k.1)). A readme-file is in each folder. These folders are containing subfolders which will be described in the following. The subfolders contain from a few to more than 20 files within each.

**See the design files in the upload (Source file Repository)**

**001 - Construction parts (CAD)**

The outer construction is primarily made of EN AW-6060 aluminium and POM (polyoxymethylene). Machining such as turning, milling and CNC-machining is necessary to achieve the fine tolerances necessary to withstand the pressure at 200 m depth. Other minor components are made using rapid prototyping manufacturing methods. The files are in five different categories:

- **003 Buoyancy engine**: The construction consists of 19 different parts primarily machined in aluminium. It is split between 15 unique designed parts and 4 customized standard components.
- **004 Hull**: The centre hull is a ø170mm x 5 mm x 600 mm aluminium tube with welded flanges and a stiffener plate. The top is manufactured in aluminium, the foot is 3D-printed in PLA (Polylactic Acid) and the bottom is machined in POM.
- The vent plug is included in the design files, but it is considered more relevant to use this for an extra SubConn connector to be used for charging.
- **005 Electronics and standard components**: All the standard bought components and electronics are in this folder to be shown in the CAD-assembly and give an overview of the construction and placement of components.
- **006 Internal skeleton**: The skeleton consists of 3 laser cut POM layers and M4 rods (simplified for CAD).
- **009 Rapid prototyping**: The internal skeleton and other minor components are 3D-printed in the biodegradable bioplastic PLA or laser cut in POM.
- **Extra**: (007 Technical drawings): For the manufactured parts the technical 2D-drawings are attached.

(1) It is recommended to open the file “Float_assembly_stp” and from here opening the different parts. This gives the best overview of the whole construction.

**002 - Software**

The software of the ARC-COP is coded in the Arduino-language using the “Visual Studio Code” code editor. A main.cpp file entails the general coding such as presets and case-selection / state machine structure. However multiple libraries have been made or modified. These include the following list:

- **MS5837.h** communicates with Blue robotics Bar 30 sensor ([https://github.com/bluerobotics/BlueRobotics_MS5837_Library/blob/master/MS5837.h](https://github.com/bluerobotics/BlueRobotics_MS5837_Library/blob/master/MS5837.h))
- **TSYS01.h** communicates with Blue robotics Celsius Fast-respons temperature sensor ([https://github.com/bluerobotics/BlueRobotics_TSYS01_Library](https://github.com/bluerobotics/BlueRobotics_TSYS01_Library))
- **TimeLib.h** handles time when there is no GPS connection ([https://github.com/PaulStoffregen/Time/blob/master/TimeLib.h](https://github.com/PaulStoffregen/Time/blob/master/TimeLib.h))
- **Grove.h** measures leakage on the grove sensors
- **buoyMotor.h** controls the motor when buoyancy is changed
SharpIR.h measures and filters the distance signal from the IR sensor. Changes are made to the original SharpIR.h
(https://github.com/guillaume-rico/SharpIR).

sparkfunSD.h handles all communication with the SD breakout board. Based on SD.h (https://github.com/arduino-libraries/SD/).

Subsea.h handles the different signaling actions on the Blue Robotics Subsea LED.

ConductAtlas.h handles communication with the Atlas conductivity module. Based on the sample code from
(https://atlas-scientific.com/files/Arduino-I2C-EC-sample-code.pdf).

gpsZOE.h communicates with the GPS module. Based on a SparkFun Ublox library (https://github.com/sparkfun/SparkFun_Ublox_Arduino_Library).

Sleep.h controls sleep function for the Arduino. Based on the LowPower.h library (https://github.com/rocketscream/LowPower/).

BatteryMeasure.h measures the voltage on the battery and converts it to percentage.

Iridium.h communicates with the iridium module. Based on IridiumSBD.h (https://github.com/mikalhart/IridiumSBD/).

Aanderaa.h communicates with the Aanderaa conductivity or oxygen sensor through RS232 using the MAX232.

Extensive comments are written in the code.

It is recommended to open the following as stated in the readme file: Visual Studio Code -> File -> open folder -> choose
the folder "001 BOOI_v2 - Bente_Birger" From here the relevant libraries can be opened.

003 - PCB & circuit schematic

This folder contains the following subfolders/elements:

- PCB_schematic: a pdf of the circuit schematic. This is previewed in Fig. 7. It entails all the circuits and with Dupont
  connectors sensors can be directly connected to the main board. If an Aaanderaa or other sensor is used, it requires its own
  fuse separate/in extension to/from this circuit.
- Float_Main_PCB: containing the KiCAD data. This includes the following files:
  - Float_Main_PCB.kicad_pcb: The KiCAD PCB layout
  - Float_Main_PCB.sch: The KiCAD circuit schematic

The 2-layer PCB is designed in KiCAD with the components described in section 2.4. The signal tracks have a general
width of 0.381 mm (15 mils) but for the lines carrying more power a width from 0.762 mm to 1.016 mm has been used.

004 - Other files

Other files include the settings.txt that need to be uploaded to the SD-card for the software to read the correct settings.

Bill of materials

The most important materials/components are described briefly in the following. The complete list can be seen in the
“Design Files and BOM” attachment.

| Designator | Component | Quantity | Cost per unit (EUR ex. VAT) | Total cost (EUR ex. VAT) | Source of materials | Material type |
|------------|-----------|----------|----------------------------|--------------------------|---------------------|--------------|
| P1         | BlueRobotic Temperature | 1        | € 39.19                     | € 39.19                  | Blue Robotics       | Other        |
| P2         | BlueRobotic Pressure     | 1        | € 47.02                     | € 47.02                  | Blue Robotics       | Other        |
| P3         | Atlas Conductivity kit (K1.0) | 1        | € 140.42                   | € 140.42                 | Atlas Scientific    | Other        |
| P4         | SparkFun GPS Breakout - ZOE-M8Q (Qwiic) | 1        | € 29.39                    | € 29.39                  | SparkFun Electronics| Other        |
| P7         | RockBLOCK 9603 - Iridium SatComm Module | 1        | € 163.28                   | € 163.28                 | SparkFun Electronics| Other        |
| P10        | Trident GPS + iridium antenna | 1        | € 687.65                   | € 687.65                 | Trident Sensors     | Other        |
| P12        | Micro Motors: E192.12.125–125:1 12 VDC | 1        | € 85.28                    | € 85.28                  | Elfa distrelec      | Other        |

(continued on next page)
| Designator | Component | Quantity | Cost per unit (EUR ex. VAT) | Total cost (EUR ex. VAT) | Source of materials | Material type |
|------------|-----------|----------|----------------------------|--------------------------|---------------------|--------------|
| P13        | Ball Screw Spindle - Rollco FSCR1605C5-300-P0-L-D0-D0 U-cup, CH23-080/3 NBR | 1 | € 139.75 | € 139.75 | Rollco | Metal |
| P14        | Rachet servo Hitce HS-85MG | 1 | € 19.59 | € 19.59 | SparkFun Electronics | Metal (Steel C45) |
| P16        | Rachet servo Hitec HS-85MG | 1 | € 19.50 | € 19.50 | Maedler | Steel C45 |
| P17        | 22370100 Ratchet Brace | 1 | € 10.40 | € 10.40 | Maedler | Metal (Metal C45) |
| P18        | 22378000 Ratchet wheel | 1 | € 19.50 | € 19.50 | Maedler | Metal (Metal C45) |
| P19        | 21888116 Spur Gears, Steel C45 Hardened 16 (m1.5) | 1 | € 32.50 | € 32.50 | Maedler | Steel C45 |
| P20        | 29511072 Spur Gears, POM, 72 (m1.5) | 1 | € 16.90 | € 16.90 | Maedler | Polymer (POM) |
| P26        | Panasonic accupack NiMH 12 V/4,5Ah (BK450A cells) | 4 | € 39.52 | € 158.08 | Actec | Other |
| P27        | Arduino Mega | 1 | € 11.48 | € 11.48 | Ardu shoppen | Other |
| P28        | Subcon MCBH3F | 1 | € 165.36 | € 165.36 | MacArtney | Other |
| P29        | Subcon MCIL3M | 1 | € 48.43 | € 48.43 | MacArtney | Other |

**P1-P3:** CTD-sensors used as described in Table 3  
**P4:** GPS breakout board as described in Table 4  
**P7:** Iridium module as described in Table 4  
**P10:** Antenna used for GPS and iridium. An alternative should be found to this due to the high price. It comes with U.FL or SMA connector.  
**P12:** 12 V DC motor used to drive the piston. Nominal torque of 3 Nm and internal gearing of 125:1. Rotational speed of 24–32 rpm.  
**P13:** Spindle used to convert the rotational movement of the motor to a linear movement of the piston.  
**P14:** U-cup which seals the wet outside from the dry inside using an inexpensive standard component. Can be found in many sizes as it is normally used for hydraulic systems. An alternative could be a more expensive diaphragm seal.  
**P16:** Servo motor used to activate/deactivate the P17 ratchet brake.  
**P17:** Design files: Maedler 22370100 Ratchet brace (modified) – used with P18 as brake for the piston  
**P18:** Design files: Maedler 22378000 Ratchet wheel (modified) – used with P17 as brake for the piston  
**P19:** Design files: Maedler 21888116 (modified) – Directly attached to the motor. In Steel C45  
**P20:** Design files: Maedler 29511072 (modified) – Attached to the piston coupling. In POM.  
**P26:** 12 V NiMH Batteries custom packed to fit into the hull. Li-ion batteries should be implemented for better battery density, but the NiMH makes it a flexible solution for prototyping as no BMS (Battery Management System) is necessary.  
**P27:** Arduino Mega. Many alternatives are available. An example could be the ESP8266 using less power in deep sleep and with WiFi implemented [23]  
**P28:** Subcon MCBH3F female connector directly fastened to the 100004–003 Top flat Iridium.  
**P29:** Subcon MCIL3M male connector. This is casted together with the P3 Atlas sensor using P40 Hardening rubber for sensor cable mold.  

**Build instructions**  
The ARC-COP should be assembled in sections before assembling the hull.  
The figures (e.g. Fig. 8) can be used as instructions/guides, but the full assembly file (Float_assembly) is a CAD file showing all components and placements.
Production:

These general instructions must be followed during the entire assembly:

- P30-P33 O-rings must be lubricated pre-assembly using P35 Molykote 111.
- Use A4 stainless steel bolts/nuts
- Aluminium bolts can be used to avoid galvanic corrosion and thus the need of an anode.
- Please see the attached technical drawings belonging to the part/assembly

Sub-assembly welds

1. 100004-001 Centre with 100004-011 Stiffener plate
   a. Tip: Mount the stiffener plate on the buoyancy-engine and loosely mount the buoyancy engine in the hull to control correct position of the plate
2. 100004-001 Centre with 100004-003 Flange_bottom and 100004-007 Flange_top
   a. Tolerances on the end face of flanges need to be machined after this step (!)
3. 100003-003 Cylinder and 100003-006 Cylinder_flange
   a. Tolerances on the inner face of the flange need to be machined after this step (!)
   Test: Do a pressure-test to secure that all welds are watertight (we did a 2 bar, 1-hour test). An air-pressure test can be done as well.
4. 100003-012 Stiffener leg and 100003-010 Stiffener bottom.

Anodizing (hard anodizing, minimum 25 μm) of the following parts

1. Hull assembly (welded 100004–001 Centre)
2. Top (100004–003 Top_flat_Iridium)
3. 100003–013 Stiffener fastener
4. Buoyancy engine cylinder (100003–003 Cylinder assembly)

Sub-assembly – Top & skeleton

1. Top: 100004–003 Top_flat_Iridium must be assembled with sensors (P1–P3), connectors (P28,P29: SubConn), LED (P8), protective cage (100009–037 Beskyttelse_Bente_birger) etc.
   a. Remember O-rings (P30-P33) for all components.
2. Skeleton: PCB must be soldered (if not ordered with components) – see circuit diagram and PCB-file for components and placements.
   a. For prototyping, two mini switches have been inserted. These are used when uploading new software or decoding/analyzing.
   i. One between the pins marked with 1 on Fig. 9 to disconnect the USB-port (power saving).
   ii. One between pin 3.3 V on the P27 Arduino (marked with 2 on Fig. 9) and the 3.3 V line on the PCB to easily switch between power to the P27 Arduino from the 3,3V DC-regulator or from the USB-port.
3. Skeleton: The different layers in the skeleton must be assembled individually from the bottom up (e.g. the middle layer with the Arduino Mega (P27) is fastened and PCB is plugged in).
4. Skeleton: The layers are being held together by three M4 threaded rods and with 3D-printed “spacers”.
5. If not bought, cables and connectors are made, and all components are connected
   a. VCC is marked directly on the physical PCB. Use the PCB-layout file to see all connections/interfaces
6. Skeleton is mounted to the top with a 3D-printed spacer as seen on Fig. 10.

Sub-assembly – Buoyancy engine (see Fig. 2)

1. Insert all 100003–013 Stiffener fastener parts in the 100004–004 Bottom and screw down all the 100003–5004 Stiffener
   a. Secure P32 O-rings are correctly placed and lubricated
2. Mount the 100003–5001 Cylinder ass with 100004–004 Bottom
   a. Secure P31 O-rings are correctly placed and lubricated
3. Mount the P24 RS PRO, 1-row roller bearing on the 100003–5001 Cylinder ass

Gear plate:

1. Mount 100003–007 Bearing house together with the 30203 bearing the 100003–009 Gear plate
2. Place the 100003–011 Spacer bushing upon the 100003–007 Bearing house
3. Mount the P12 Micro Motors E192-12-125 (P12) on the 100003-009 Gear plate and mount the Maedler 21888116 modified gear on the motor.

4. Mount the 100009-001 IR holder on the 100003-009 Gear plate and mount the P6 IR sensor

5. Fasten the 100003-009 Gear plate to the 100003-013 Stiffener fastener.

**Assemble and insert the piston:**

6. Mount the two 100003-014 Piston guide on the 100003-004 Piston with countersink screws
7. Place P14 U-cup, CH23-080/3 NBR in the groove on 100003–004 Piston
8. Assemble the 100003–016 Spindle and 100003–015 Spindle coupling
   a. Be aware this is an interference fit. Heat and/or pressure is needed.
9. The spindle nut from P13 Ball Screw Spindle is fastened to the 100003–004 Piston
   a. Make sure that the orientation for the P6 IR proximity sensor is not obstructed/interfered with any object on the spindle nut or elsewhere.
10. The feather key is placed in the 100003–015 Spindle coupling groove

Continue the assembly of the gear plate:

11. Mount the Maedler 22378000 Ratchet wheel (modified)
12. Mount the 100003–021 Ratchet brace house, Maedler 22370100 ratchet brace modified, 100003–022 Ratchet pin together with the P15 Sodemann T024-300-250L spring on the 100003–009 Gear plate.
   a. The spring (P15) must be shaped manually to fit into the structure and pre-tensioned
13. Mount the P16 HS85MG servo on the 100003–009 Gear plate
   a. The connection between the P16 HS85MG servo and Maedler 22370100 ratchet brace modified can be made with a wire/flexible cable
14. Mount the 100003–023 Ratchet wheel bushing on top of the Maedler 22378000 Ratchet wheel (modified)
15. Mount the Maedler 29511072 (modified) POM gear and fasten this to the 100003–015 Spindle coupling

Batteries:

1. Batteries are fastened in the bottom with the battery brackets. For this prototype P26 NiMH batteries are used.
2. The batteries have been custom made to fit exactly into the hull and use the volume most efficiently. The exact shape is shown in 007 Technical drawings - Battery_weld.

Complete assembly – Final hull

1. Mount the 100004–004 Bottom with the buoyancy-engine to the 100004–003 Flange_bottom
   a. Ensure that the O-rings are correctly placed.
2. Route the cables from the Buoyancy engine through the stiffener plate to the top
3. Mount the foot on the bottom (extra-long bolts can be used, so an extra nut can be used to fasten the foot)
4. Mount the 100009–034 Magnet_hull_holder and insert the magnet
5. Connect cables to the skeleton
6. (!) Update P9 SD-card with correct settings
7. (!) Charge battery
8. Insert skeleton with top
9. Fasten all bolts and mount the anode
   a. Remember electrical connection between all aluminum parts
10. Mount protection cage and flag
11. Connect sensors to SubConn plugs

Operation instructions

Pre deployment

1. Charge batteries
2. Write preferred settings to the SD-card using the upload file (settings.txt – an example is included in the file to see formatting etc.).
   a. Depth [XXXX] (meters of depth from 0000 to 0200)
   b. Amount of dives [XXXX] (number recommended 0000 to 0024)
   c. Specified times of diving [HHMM]
3. Check the switches (if inserted at step 5.3 (2.a) Sub-assembly – Top & Skeleton)
4. Place a bag of silica gel in the hull – preferably on the skeleton
5. Insert SD-card and close the top
6. Inspect O-rings
7. Secure that all bolts are fastened

Deployment

1. Remove the magnet from the outer hull
2. Watch the LED for battery level (BL)
   a. 1 blink: BL < 30%
   b. 2 blinks: 30% < BL < 50%
   c. 3 blinks: 50% < BL < 70%
   d. 4 blinks: 70% < BL < 90%
   e. 5 blinks: 90% < BL
3. Grab the handles and place it in the water
   a. If moored(!): Open the one handle (bolt and nut) and attach it to the mooring line
   b. If in free-float mode: Deploy it to the ocean surface and leave it for profiling

Recovery

1. Send a “home” command to the ARC-COP or coordinate it with the float being at the surface (small and capital letters are acceptable)
2. Find ARC-COP – positions transmitted through iridium approx. every 5 min.
3. Use the handles to lift it into the boat
4. Place the magnet in the placement on the outer hull

Data retrieval

1. To avoid condensation let the float reach room temperature
2. Open the top, remove SD card and read the data on a separate computer.

Validation and Characterization

Field test

Two ARC-COP instruments were deployed in the Ella Ø fjord system (72.5°N, 25.5°W) in NE Greenland during August 2020. These fjords are several hundred meters deep and connect the Greenland ice sheet with the Greenland Sea (Fig. 11). The ARC-COP was deployed from a small boat. Two modes were applied: (a) a free-floating mode and (b) a moored mode, where the instrument was anchored to the seafloor. In both modes, the profiler was able to control its dives with a speed of $12 \pm 0.3$ cm/s, resulting in $510 \pm 22$ data points per 100 m dive with the low-cost Atlas sensor. In total, 18 profiles were obtained in the free-floating diving mode and the maximum dive was 200 m. Each profile took approximately 20 min (in total 40 min for down cast and upcast) and the instrument drifted 30–60 m between individual profiles due to sea currents. In the moored mode, the instrument was anchored to the sea floor by a 4 kg folding grapnel anchor, with a Ø3 mm Dyneema mooring line travelling through the handle of the ARC-COP and tightened to a 4-liter trawl float at the surface. Examples of test results are shown on Fig. 12.

In the free-floating mode, the ARC-COP revealed water temperatures of $> 7 \degree C$ in the surface of the water column, caused by intense, 24-hour solar radiation in this area during the summer period. The high surface temperature melted the sea ice, which together with runoff from the land, created a reduction of surface salinity, down to 27. Oxygen conditions in the surface layer were above atmospheric saturation due to high photosynthetic activity by phytoplankton activity in the pycnocline at around 20 m depth. After 20 m depth, temperatures fell below $0 \degree C$ due to the presence of Polar Water. Temperature reached $-1.7 \degree C$ at 80 m depth, approaching the freezing point of seawater. Below 80 m, temperature and salinity conditions started to increase due to underlying modified Atlantic Water. This is an interesting observation as it means that icebergs in the area will only melt very slowly in the upper 20 m, where temperature is above $0 \degree C$.

Fig. 11. (A) Study site for the ARC-COP in NE Greenland. (B) ARC-COP surfacing after a dive to 120 m water depth in Kempe fjord (red cross in A). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
ARC-COP vertical 1-m binned temperature and salinity measurements were compared with standard CTD casts (RBR-Concerto, Ottawa, Canada) nearby. No significant differences were observed for temperature (paired $t$-test, $p = 0.90$, $\alpha = 0.05$) and salinity (paired $t$-test, $p = 0.85$, $\alpha = 0.05$) between our parallel measurements (data not shown).

The ARC-COP performed well in the moored mode, where the instrument was anchored to the seafloor at 20 m water depth with a Ø3 mm Dyneema line. The line was loose and a few meters longer than the water depth. The instrument was programmed to dive every second hour in the upper water layers where the strongest temperature and salinity gradients exist (Fig. 13). The data show that the ARC-COP was able to dive at regular intervals and record temporal variability of temperature and salinity conditions from close to the bottom to the surface. The instrument reached the surface during each dive cycle. Conditions under the deployment ranged from relatively calm conditions ($3–5$ m/s and $\sim 0.2$ m waves) to more windy conditions ($8–10$ m/s and $\sim 1$ m waves). Hence, the instrument is well suited for studies of heat and freshwater conditions in relation to the summer thaw during which runoff from land, melting of sea ice and glaciers occur. For this prototype, conductivity, temperature, and oxygen sensors have been tested. In addition, other sensors measuring, for example, irradiance (PAR) and fluorescence can be mounted to expand measurements to phytoplankton biomass and net oxygen production. However, the robustness of ARC-COP for longer deployments is yet to be proven.

**Performance assessment**

The ARC-COP performed well in test deployments in Northeast Greenland in August 2020. Overall, the ARC-COP was easy to handle and operate from a small boat and it demonstrated its ability to autonomously measure profiles to a depth of 200 m in high density gradient waters. The ARC-COP showed not only potential but carried out actual measurements and transmissions of data during icy and windy conditions where manually operated CTD casts from a small boat were not feasible.

**Future improvements**

While commercial products likely provide superior performance in other areas, we have demonstrated that a low-cost float for arctic coastal areas can be constructed relatively easily with commonly used materials and can collect relevant scientific data. Overall, the ARC-COP satisfied all but one of the design requirements listed in Table 1. We suggest the following design improvements, which are already underway in our own laboratory.

**Energy**

The energy consumption should be reduced, which is possible by one or more of the following:

1. Removing all LEDs which have currently been used for prototyping purposes.
2. Power down or put to sleep all possible sensors.
   - **H-bridge**: To reduce power consumption, the H-bridge is, as of now, the most relevant component to optimize. This can be achieved by the following:
     - Implement a transistor on the power-supply line as seen for the GPS and other components.
     - Build/implement a custom H-bridge IC into the PCB [24].
   - **IR-sensor**: Implement a transistor. The IR-sensor should only be active while in “change buoyancy mode”.

![Fig. 12. Temperature (left), salinity (middle) and oxygen (right) conditions (atmospheric saturation, broken line & in situ values, line) in the water column of Kempefjord in Ella Ø. Three consecutive dives with the ARC-COP are shown from 23rd of August 2020.](image-url)
Depth-sensor: Powered down by inserting a transistor to cut power when not in use.
Temperature sensor: Powered down by inserting a transistor to cut power when not in use.
3. Use a more efficient microcontroller than the Arduino, or build a barebone (e.g. a Mega 2560 barebone).

User-friendliness (ease usage)
To increase user-friendliness, two things should be changed.

1. Wireless data transfer should be implemented to enable data retrieval without having to open the profiler top. Wi-Fi is currently our suggestion.
2. To enable reading of the data during surfacing, whilst avoiding the shielding of the aluminium hull, the connection should be established through the top.
   a. We have considered redesigning the top using a toggle latch lock instead of bolts. This will ease the opening.
3. Charge the batteries without opening the top. This can easily be done with a 2 pole SubConn plug (mcbh2f-g2). For this, the thread for the air vent could be removed and replaced by a 7/16–20 thread (in the CAD-files this has already been done).

Data collection and software
The software should be written so that the CTD measures while the buoyancy is being changed. This will increase the measurement resolution and can be done with multithreading (fake parallel execution) on the Arduino. Another solution could be using another or an additional microcontroller.
Furthermore, during long term missions, it may be necessary to “park” the float at a defined depth over a period of time to avoid ice, ships and more. This can be done only by software and should not be energy draining.

Price

Although the price is already much lower than commercial products, we envision multiple ways to reduce it further. First, an alternative to the 6000 m rated Trident GPS/Iridium antenna should be used. This could be a cast around a traditional antenna. Casting material could be the same as used for the Atlas sensor cable. If Wi-Fi is implemented, it should be considered whether Iridium is necessary for the given expedition/case.

A previous version was constructed with a POM hemispherical top, allowing for the possibility of acquiring signals through. However, the production price of this part exceeded the price of an external antenna and the signal quality was too unreliable due to a less stable height above water as a result of its hemispherical shape.

Conclusion

The low-cost profiling float, ARC-COP, rated to a depth of 200 m is designed, constructed, and successfully validated. The 17 kg lightweight float operates autonomously in arctic regions where and when it is not possible to do manual CTD-profiles. It measures conductivity, temperature, and pressure (CTD) as well as oxygen, with the possibility of adding other sensors. The ARC-COP acquired CTD-data through strong gradients of temperature and salinity in Northeast Greenland. It demonstrates the potential of a versatile, easily deployable, low-cost, and open-source profiling float which may enhance our understanding of the meltwater and ocean mixing related to the melting of sea ice and glaciers in the remote areas of Greenland.

Human and animal

Not relevant.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ohx.2021.e00207.

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Lucas Mogensen Sandby: Student, Mechanical engineering – Aarhus University

Jens Erik Byskov Mejdahl: Student, Mechanical engineering – Aarhus University

Simon Hald Bjerregaard: Student, Mechanical engineering – Aarhus University
Claus Melvad: Professor, Department of Mechanical and Production Engineering – Aarhus University, ORCID: 0000-0002-5720-6523, Research Areas: Mechatronics/robotics, Metrology & Sensor development

Søren Rysgaard: Professor, Arctic Research Center – Aarhus University, ORCID: 0000-0003-1726-2958, Research Areas: Arctic system science, physical, chemical and biological oceanography