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1. Executive Summary

Argo float technology is well established as a means of recording physical parameters in three dimensions in the open ocean and has been extended to coastal waters and biogeochemical sensors. The objective of JELAB is to expand the capacities of advanced Argo-type floats (e.g.ProvBio, BioArgo and Arvor-Cm) particularly for coastal applications by extending available payload. JELAB will be aimed to increase the instrumentation payload first with a camera system capable of imaging in the water column and on the sea floor. Sea-floor imaging and sensing during benthic parking will add a powerful new dimension to integration of surface to bottom biogeochemical measurements. Owing to a need to operate throughout the Cretan Sea a greater depth rating (2000 m) will be necessary. This extra payload development will be transferred in the near future to other applications such as water sampling. The JELAB floats will be based on commercially available software and hardware. HCMR and Ifremer will jointly contribute to these new developments. Operational performance of JELAB floats will be tested and validated in large-scale basin facilities and at sea.

An autonomous programmable dual camera system with LED lighting panels rated to 2000 m depth has been developed to meet the JELAB specification for a light-weight module capable of being carried on board an ARGO profiler float. Camera 1 is a profiler designed for imaging particles in the water column and Camera 2 looks downward to image areas of the sea floor.

2. Introduction

The use of autonomous instrument packages has greatly enhanced the capability for oceanographic observations. The need for costly ships is greatly reduced by avoiding the need to remain continuously on station while instruments are lowered on a wire or towed through a region of interest (Pollard, 1986[i]). Autonomous systems can be divided into four categories, profilers, gliders, landers and autonomous underwater vehicles (AUVs).

Profilers and gliders are small enough that they can be handled from small boats avoiding the use of large ships altogether and often can be considered disposable with no need for recovery after missions which may last many months. Profilers are floats equipped with a variable buoyancy system that enables them to make a controlled descent to a pre-determined depth, usually 1000 m, followed by ascent to the surface where data gathered during the dive or series of dives are transmitted to shore by a radio signal usually via satellite (Gould [ii]). Surface location is also transmitted in the data stream or determined by doppler location (CLS ARGOS). The ARGO global network of *ca*. 3000 floats routinely transmits data on salinity, temperature and depth (pressure) throughout most of the global ocean and in the Mediterranean Sea has contributed to understanding of deep-water formation (Poulain et al. 2007[iii],Smith et al. 2008[iv]).

Gliders are a development of the basic profiler through the addition of fins that create lift enabling the package to glide obliquely over significant horizontal distances during descent and ascent. The glide angle is varied by moving a ballast weight (usually the battery back) to and fro relative to the centre of buoyancy. Combined with buoyancy control this enables the vertical and horizontal speed to be controlled. A typical dive cycle takes about 6 h with descent down to 1000 m with a horizontal movement of about 6 km (Rudnick, 2016[v]). The sensor suite and data transmission are similar that those in the profiler floats, but the glide programme can be adjusted by a shore-based operator to ensure appropriate spatial coverage.

Landers are designed to descend to the sea floor where they can remain for hours or up to one year gathering data. Recovery is by shedding ballast, typically by acoustic command from the surface whereupon the lander ascends to the surface by virtue of positive buoyancy. Landers can carry a wide range of sensors including cameras, chemical sensor probes that enter the sea floor, sonars and samplers of various kinds (Priede & Bagley 2000[vi], Tengberg et al. 1995[vii], Brandt et al 2016[viii]) and have been used down to full ocean depth (≈11 km) where access for conventional submersibles is difficult (Jamieson et al. 2009[ix]). Landers are generally static but have the advantage that they can obtain long term time-series data (Smith et al. 1998[x], Smith et al, 2013[xi]). Some benthic “Rovers” or “Crawlers” can move across the sea floor to increase the sampling area or to investigate sea floor features of interest (Henthorn et al. 2010[xii], Purser et al. 2013[xiii]).

AUVs or autonomous underwater vehicles are powered vehicles capable of travelling long distances at typical speeds of 1-2 $m.s^{-1}$ navigating automatically in three dimensions. These are sophisticated platforms capable of executing a survey mission and returning to a predetermined pick up point at an appointed time (Millard et al. 1998[xiv]). This is expensive technology but with improving reliability (Griffiths et al. 2003[xv]) is finding increasing application in biological surveys of the sea floor using on-board camera systems (Milligan et al. 2016[xvi]). Systems such as Autosub are capable of carrying a wide variety of scientific payloads including sonars and biogeochemical sensors (NOC 2019[xvii])

Landers and AUVS are generally relatively heavy technology with a weight (in air) >100 kg requiring a ship and lifting equipment for handling whereas profilers and gliders are lightweight and can be deployed and recovered from small boats. There is a general trend towards expanding capabilities of profilers and gliders to a wider range of sensors and types of missions that can be accomplished. This requirement is recognised in the BIO-ARGO and BIO-GEO-CHEMICAL-ARGO (BCG-ARGO) initiatives within the ARGO programme and implementation of the ARGO-oxygen programme. André et al.(2010[xviii]) have demonstrated the concept of a “virtual mooring” with their Arvor-C system, a coastal autonomous float that can park on the sea floor, ascend through the water column and return to a resting position on the sea floor. Arvor-C was developed from commercially available ARGO hardware and potentially overlaps with missions currently accomplished using landers.

Concept of JELAB is to bring the diverse sensing capabilities of AUVs and landers to light-weight ARGO-like profiler floats. A similar approach has been developed by Marini et al. (2013[xix], 2015[xx]) with the Guard 1 autonomous camera system designed for acquisition and recognising images of gelatinous zooplankton. This is a descendent of video plankton profilers designed for lowering on a CTD vertical wire (Picheral et al. 2010[xxi]) or towed through the water (Davis et al. 1992[xxii]). The Guard1 system can be enclosed in various styles of instrument housing and is small enough to carried on board an ARGO profiling float. GUARD 1 is very versatile and has been successfully deployed o an oceanographic tower where automated image recognition of fishes and other organisms was demonstrated (Marini et al. 2015). JELAB is complementary to the Guard1 system but uses a somewhat different design approach.

A parallel development in marine science instrumentation has been the increased use of new technologies for tracking marine animals such as sharks, tunas, whales and dolphins (Priede, 1984[xxiii], Priede & Miller, 2009 [xxiv], Block et al. 2011[xxv]). For these studies a wide range of light-weight instrument packages have been developed capable of being attached to animals. This resulted in the interesting proposal by Fedak (2003[xxvi]) that marine animals can be used as cost-effective oceanographic sampling platforms measuring conductivity, temperature, depth and other parameters. Instruments such as cameras attached to Great White sharks (Jewell et al. 2019[xxvii]) have followed a different pattern of development from conventional oceanographic packages and it is this technology that is being used in JELAB to achieve the performance required in small robust units.

The JELAB Concept.
The central concept of JELAB is to add imaging capability to an ARGO float as shown in Fig 1.

A horizontal or profiling camera is intended to image particles in the water column and a vertical camera to image the sea floor. The concept of the mission is for a profiling float capable of descending to 2000 m maximum depth, corresponding to the maximum depth of the Cretan Sea (Fg 2) The system should be able to operate in five modes: 1 - hover in mid water at a set depth, 2 - Descend through the water column at a defined speed, 3 - Hover above the bottom at a set altitude. 4 - Rest on the bottom, 5 - Ascend through the water column at a defined speed. It was anticipated that it would not be possible to telemeter imagery data to shore so mission times are restively short so that the float does not more through great horizontal distances and can be recovered for downloading of the imagery and data.

During a mission several cycles (up to 10) can be done between surface and the sea floor (or above the sea floor, up to 2000m depth) . It is assumed a ship is nearby the experiment area: the float is recovered at the end of the mission and can be easily redeployed. During descent, drift and ascent, the profiling float manages the video acquisitions, depending on pre-programmed times or depth, or on a bio-geochemical external event, like a bloom. The detection of such an event can also have an impact on the behaviour of the float: interruption of the ascent and repositioning with a focused monitoring in the bloom area for example. When the JELAB comes at surface, it sends technical data to the data centre. Snap shots or video sequences and photos remain stored in the camera subassembly, and are not transmitted in real time. They will be retrieved when the float will be recovered.

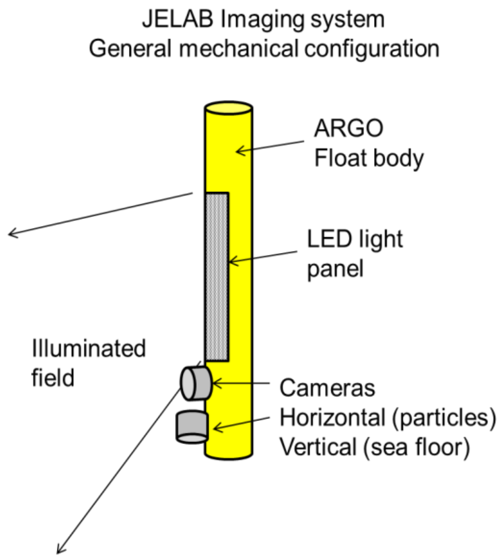


Figure 1. The initial JELAB concept with two cameras and a LED panel added to an ARGOS float.

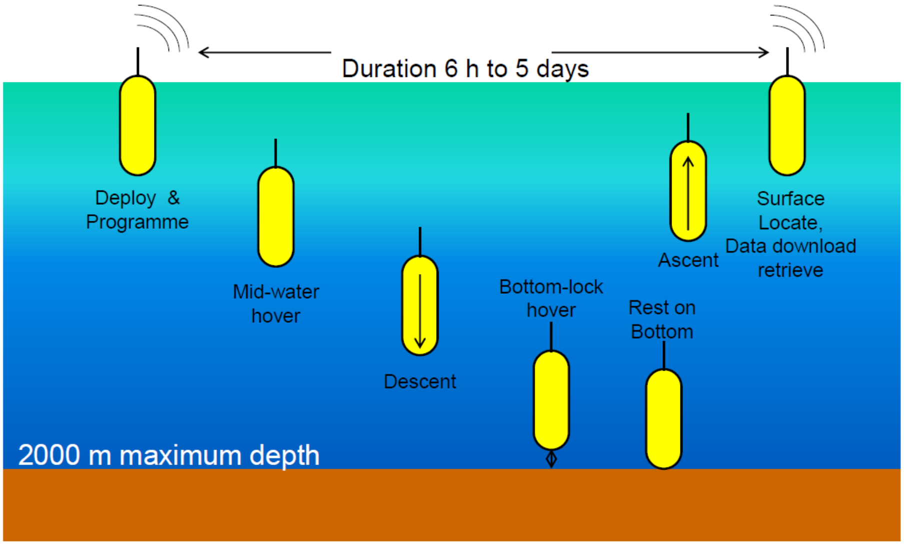


Figure 2. The JELAB mission concept.

At the outset of the project it was assumed that NKE Instrumentation would adapt a Provor float and provide the final JELAB float. NKE would consider the additional payload and the ability of the float electronics to interface with the payload. With Ifremer contributing to the writing of the specifications and providing the electronics driving the external payload and necessary interfaces with the float electronics. Following initial discussions in soon became apparent that the necessary adaptations of the Provor float to the JELAB mission were not possible within the limited resources available. Major re-engineering of the float would be necessary which NKE could not justify in the face of limited immediate market opportunities. The JELAB work package was therefore redefined to produce a compact autonomous camera and lighting system capable of being attached to an ARGO or PROVOR float but with no interfaces other than the mechanical attachment and an external battery supply.

3. Main report

JELAB1
A first version of the JELAB camera system was produced jointly with personnel at Oceanlab in the University of Aberdeen, Scotland who had developed a series of resin-embedded cameras for their own research. The result was single autonomous module with two camera and LED lighting arrays with internal microprocessor control based on two Raspberry Pi 2 Model B modules, capable of operating in time-lapse mode powered by external battery (Fig 3, 4). The assembly weighed 1645 g in air was 330 mm long and 100 mm wide. The unit was designed to be attached to the body of an ARGOS float using worm-drive hose clamps or heavy-duty cable ties. A battery pack in an aluminium alloy housing was also produced with 8 x 3.7 V cells providing 3400 mAh at 12V with dimensions 18.2 diameter and 650 mm length.

JELAB1 was completed in August 2016 and preparations began for first sea trials. Laboratory trials with programming and setting up of the system proceeded satisfactorily until on 7 December 2016 when the system failed. It is suspected that the cause may have been a capacitor failure on the UPS PICO Uninterruptable Power Supply. Precise diagnosis was not possible. In the meantime, the Oceanlab camera production facility had closed down and the personnel dispersed to other institutions. It was therefore not possible to order a replacement and/or additional units. Work then proceeded to development of JELAB2 system wholly designed and built in HCMR, Crete.

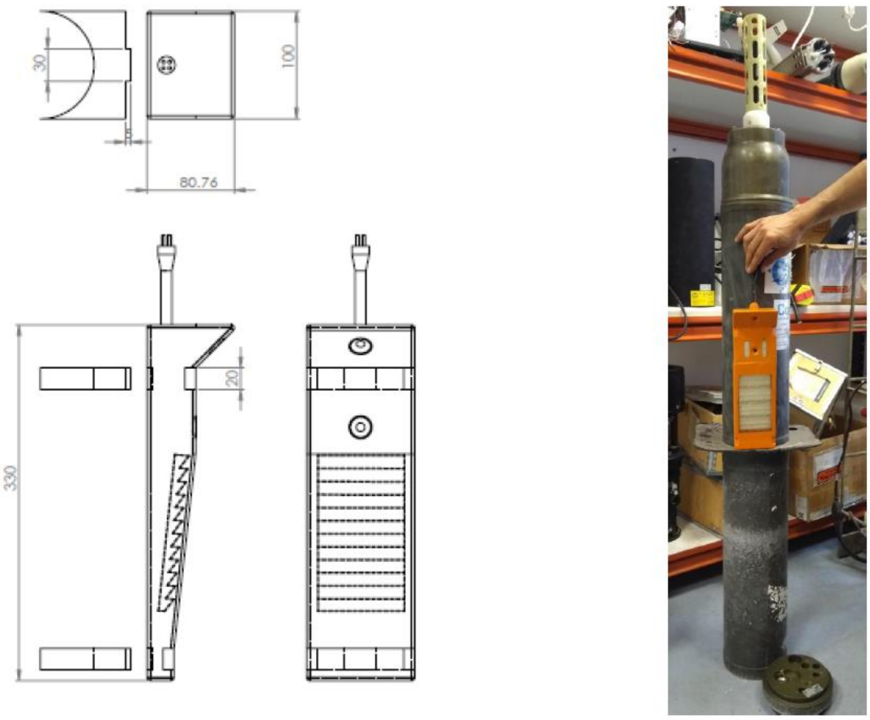


Figure 3. The JELAB1 camera assembly.
Left – mechanical drawing. Right – Prototype installed on an ARGO float.

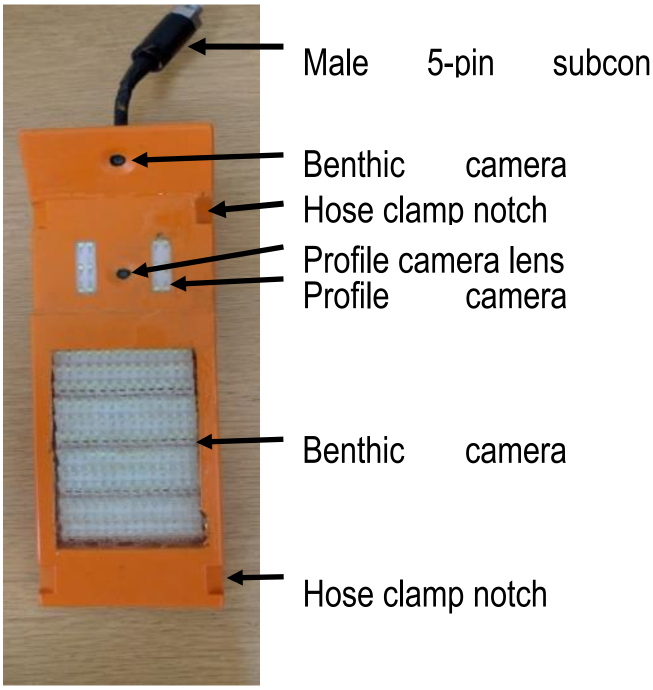


Figure 4. The JELAB1 camera assembly.
The cable connector at the top is for power supply input.

JELAB2

JELAB 2 tooks the JELAB 1 hardware as a starting point for the design and the possibilitie of basing the system on promising new cameras together with a much lower power consumption Arduino processor were considered such as the Arduino UNO - ARDUCAM 2MP: OV2640 and 5MP: OV5642.
The new Raspberry Pi Camera Module v2, was eventually chosen together with the new compact Raspberry Pi Zero W processor which is much smaller than the Raspberry Pi 2 Model B previously used. An Arduino processor was retained for overall mission management. Together with sensors this makes JELAB2 a much more flexible system than the JELAB1 prototype.

The JELAB2 design.
The JELAB camera system (Fig 5) uses two independent cameras, each with its own LED lighting array. Camera 1 is a near-field (profiler) camera and has two small LED arrays and the Camera 2 is the far-field (benthic) camera with a single high-power LED array. Raspberry Pi Camera Module v2 are used, incorporating a Sony IMX219 8-megapixel sensor which is capable of high definition video, still shots and time-lapse sequences. Each camera is controlled by its own dedicated Raspberry Pi Zero W single-board computer with wireless LAN capability (802.11 b/g/n). Each Raspberry Pi has an SD card slot with a 32 GB memory card installed for storing of images; the capacity of this card can be varied to depending on mission requirements. Images are downloaded via the Wifi LAN which also allows the Raspberry Pi to be reprogrammed for each mission. The LED light panels are activated in synchrony with the camera. To avoid excessive quiescent power consumption of the Raspberry Pi the overall

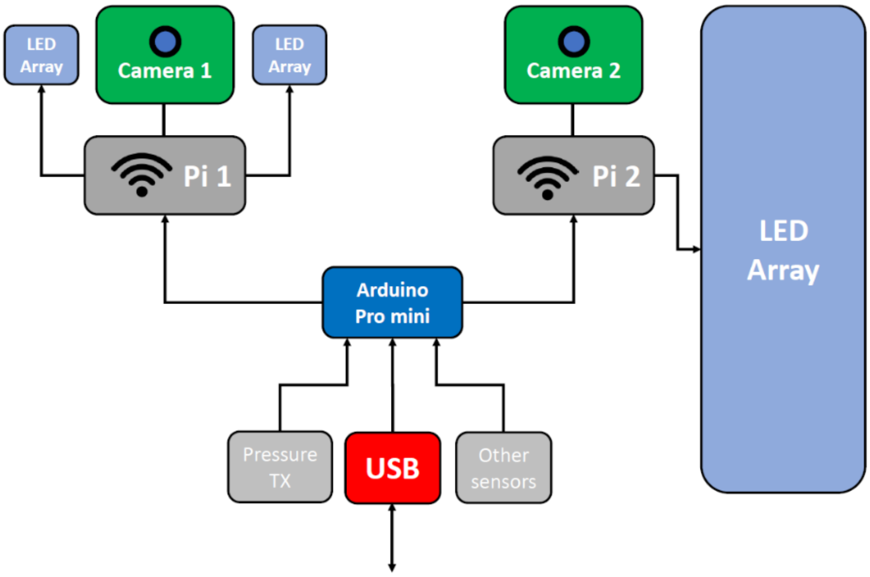


Figure 5. JELAB2 camera schematic

mission schedule is controlled by an Arduino Pro Mini microcontroller board, which is programmed via the USB connector. The Arduino is also capable of taking analogue and digital inputs from sensors such as pressure, temperature and light. In the prototype, a pressure sensor is used to trigger mission commencement (Fig. 6).

The system is designed to operate from a Li-ion single battery pack with a nominal output of 14.8V. The pack is made up of 40 Panasonic NCR18650B cells each with a nominal voltage of 3.7V. These are arranged in 4 series of 10 parallel rows wired to a 4S 40A Li-ion Lithium Battery 18650 Charger PCB BMS Protection Board. The capacity of this battery pack can be changed by adding to or reducing the number 4 series cell units according to the nature and duration of the mission. For functioning of the components of JELAB, three different voltages are

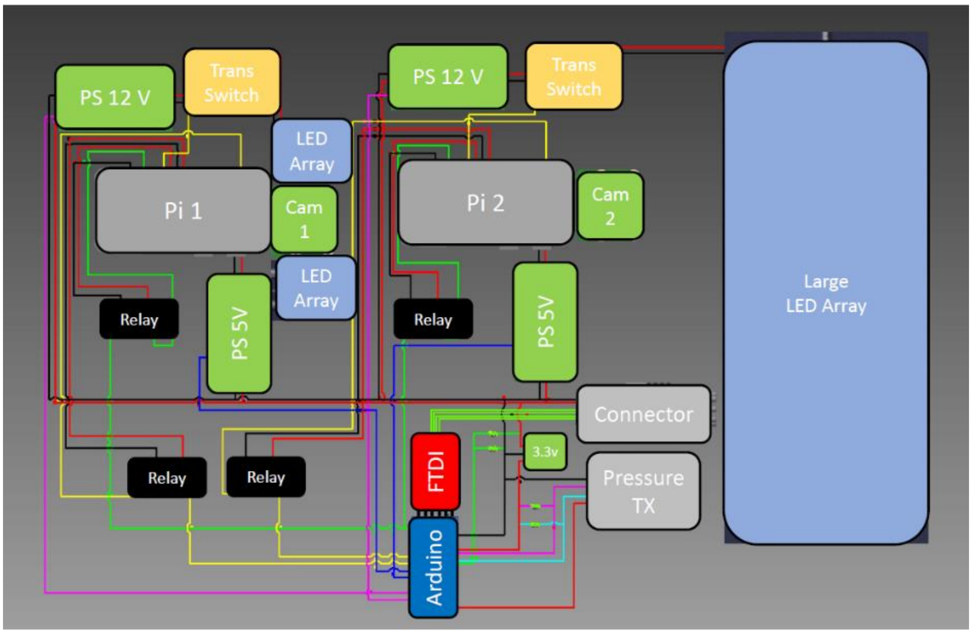


Figure 6. Hardware implementation of the JELAB2 system, showing power supplies. An external battery provides 14.8 V nominal via the connector.

required: 3.3V for the Arduino is provided by a Polulu 3.3V, 500mA step-down voltage regulator type D24V5F3: 5V for each of the Rasperry Pi's is provided by a Polulu 5V, 6A step-down voltage regulator type D24V60F5 : 12V for the LED arrays by a Polulu DC-DC Converter Step-up/Step-down 12V 2A. The 3.3 V Arduino board is chosen to be compatible with the Raspberry Pi inputs and the pressure sensor. For each LED array switching with fast rise and fall times is provided by an IRF540N n-channel MOS-FET driven by two NPN transistors. Reed relays short floating outputs to ground to avoid spurious switching.

The USB connection to the Arduino is implemented by an FTDI Basic break out board. Connection to the exterior is with four conductors through a Seacon MCBH 8-way bulkhead. Two conductors are used for the battery, leaving 2 spare pins for external sensors or other upgrades. The pressure sensor is a Keller Piezoresistive OEM Pressure Transmitter LD10 rated to 200 bar with a built-in I2C microcontroller interface that links directly to the Arduino (Fig. 7).

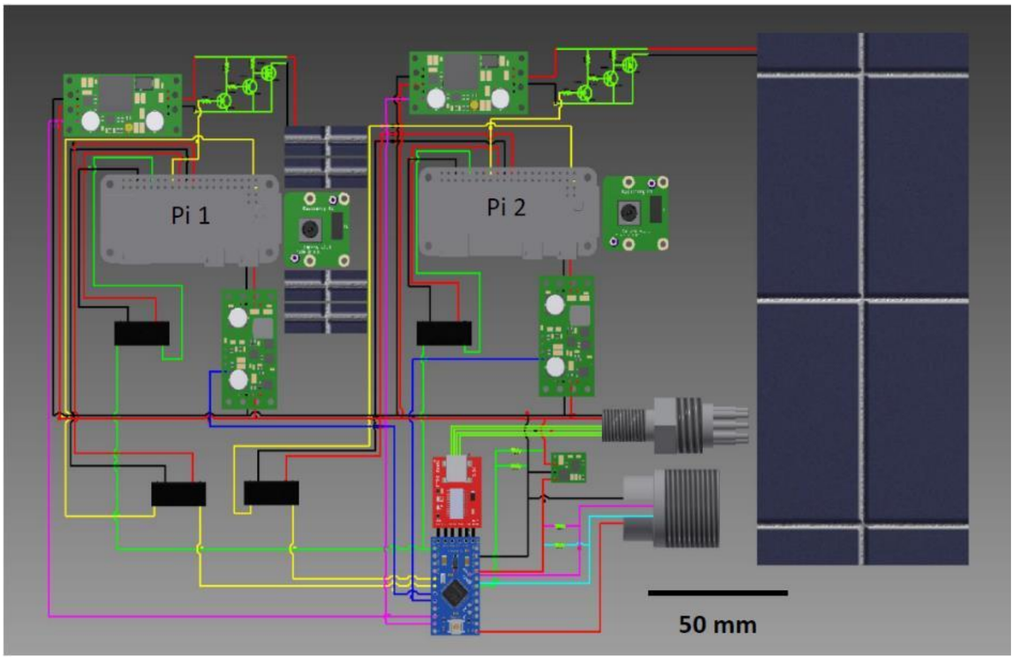


Figure 7. JELAB2 components (to scale) with their connections (not to scale).

LED panels.

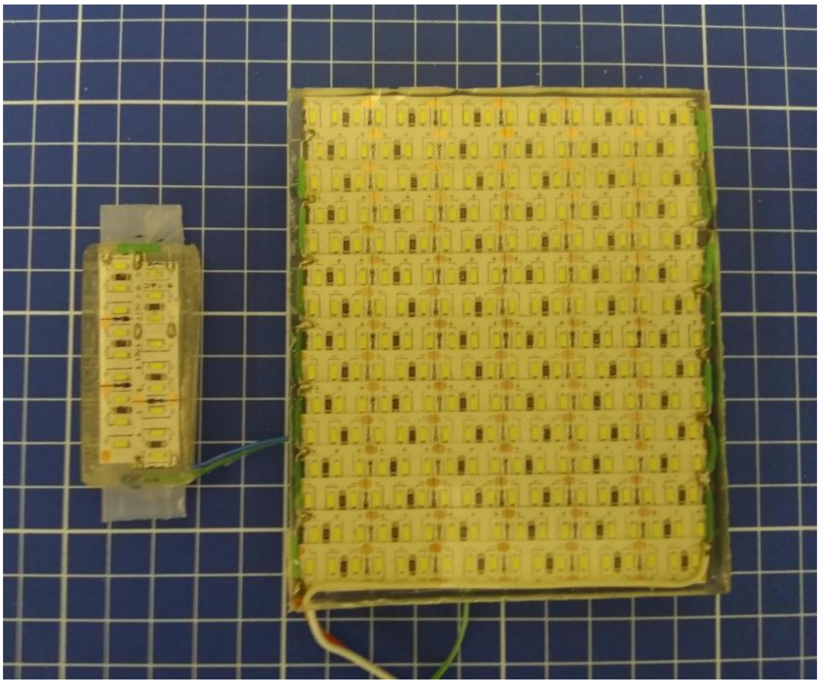
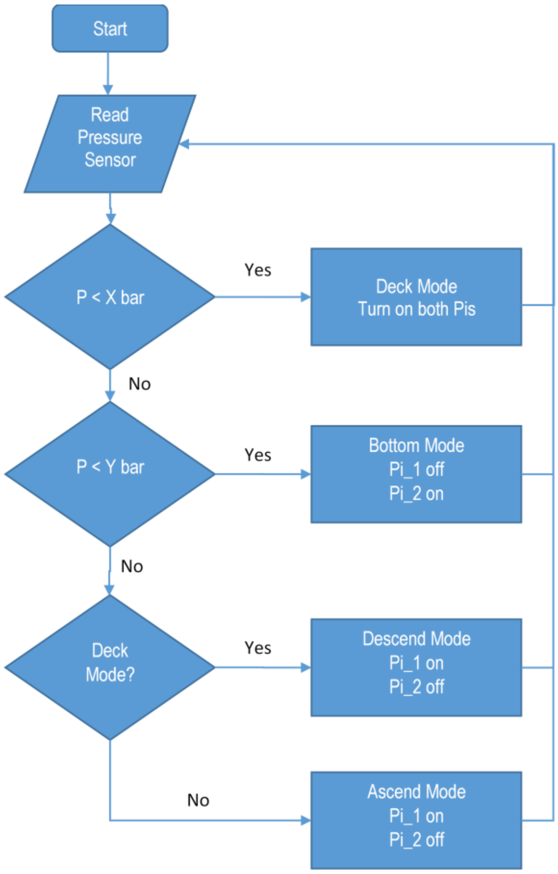


Figure 8. The JELAB2 LED panels.
Left, small near field panel (dimensions 22 x 52 mm), **right**, large far field panel (dimensions 94 x 110 mm) both 10 mm thick. Background grid 10mm.

Two kinds of LED arrays were developed, a small one for near field use and a large one for far field illumination. The panels are based on commercial off the shelf (COTS) LED strip lighting (SMD 3014 V-TAC). The near field panel has 18 LEDs which consume 1.6W at 12V producing *ca*. 150 lm at a colour temperature of 6400°K. Two near field panels are used in parallel on JELAB giving a total of 300 lm. The large array has 270 LEDS consuming 24W at 12V producing *ca*. 2300 lm. Each LED produces light over a 120° arc in air.

Software

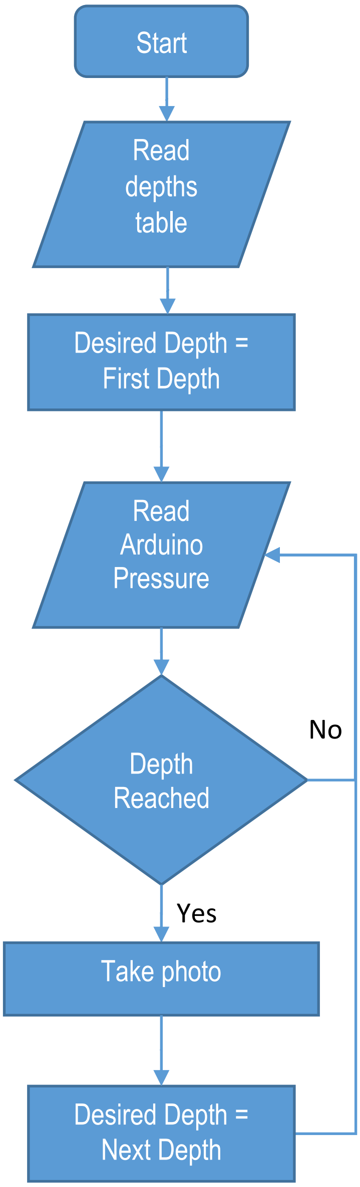
The simplified operation of the software controlling the Arduino and the two Raspberry Pi is schematically depicted in flowcharts 1-3. Flowchart 1 describes the operation of the Arduino microcontroller, which is responsible for reading the pressure sensor, and turns on and off the Raspberry Pi boards, depending on which phase of the dive the system is in. This is decided via two threshold pressure values, one that denotes that the system is on the surface (X in the flowchart), so that the Pi boards are both turned on, for communication, programming or data download, and one that signifies that the system has reached the deepest end of the dive (Y value in the flowchart), so that the Profiler Pi (Pi_1) is turned off, and the Benthic Pi (Pi_2) is turned on. In between these two values the system is in either in descent or ascent mode and the Profiler Pi is turned on, while the benthic Pi is turned off.



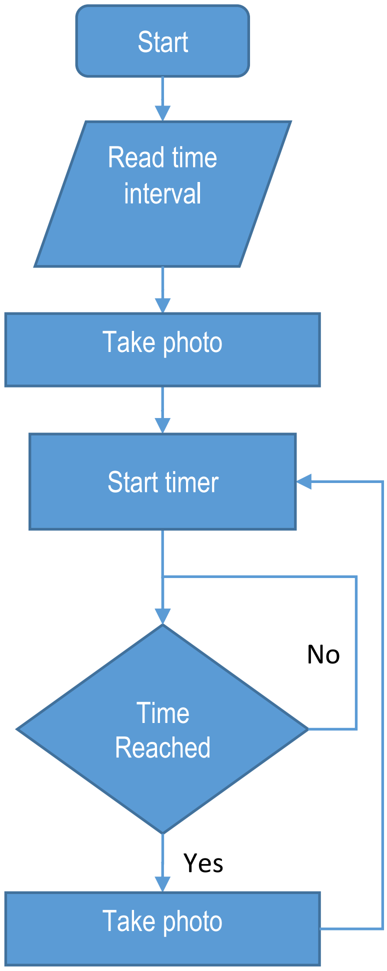
Flowchart 1. The operation of the Arduino controlling the two Raspberry Pi.

The function of the Profiler Raspberry Pi is described in Flowchart 2. It is based on a table of depths, where photos should be taken, which is saved in the memory card and read on boot time. The pressure is read from the Arduino board, and when the desired depth is reached a photo is taken, and the process continues for the next desired depth. Care is taken to read the appropriate ascent or descent depth table, based on the phase of the dive, as determined by the Arduino board (not depicted in the chart).

The function of the Benthic Pi is very simple, and is based upon a delay loop, taking a photo after a pre-determined time interval (flowchart 3).



Flowchart 2. Function of the cast Pi (Pi_1)



Flowchart 3. Function of the benthic Pi (Pi_2)

Resin embedding.

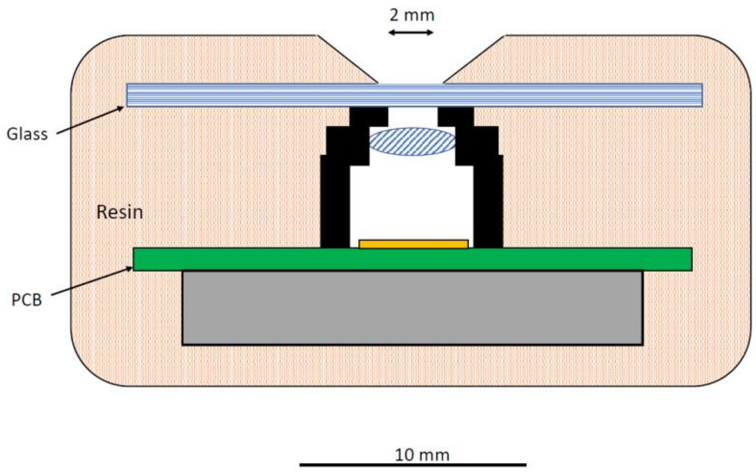


Figure 9. Schematic section of a Raspberry Pi camera module complete with circuit board and cable connector embedded in resin. The air space for the camera optical system is small with a 2 mm diameter window in the glass.

The principle of resin embedding is based on the observation that most solid-state electronic components function satisfactorily at high pressures. Priede & Bagley (2000[xxviii]) showed that if immersed in oil, electronic circuits continue functioning at pressures up to 600 bar (≈6000m depth). The main issue with cameras is that an air space must be maintained for the optical system. In the case of the Sony IMX219 camera the air space is small so that a thin walled housing can resist the surrounding pressure. The window in front of the lens is only 2 mm diameter (Fig. 9) which using 1 mm thick optical slide glass exceeds the 2000 m depth specification for JELAB.

Epoxy resin RX771C/NC with hardener HX771C/NC from Robnor ResinLab Ltd, Swindon UK was used. This resin was chosen for its very low viscosity with good penetration, high mechanical strength and excellent electrical properties. A plug of the required shape was prepared and used to cast a flexible mould of ZA 50 LT bicomponent (base and catalyst) RTV silicon rubber from Zhermack SPA, Rovigo, Italy (Fig. 10).

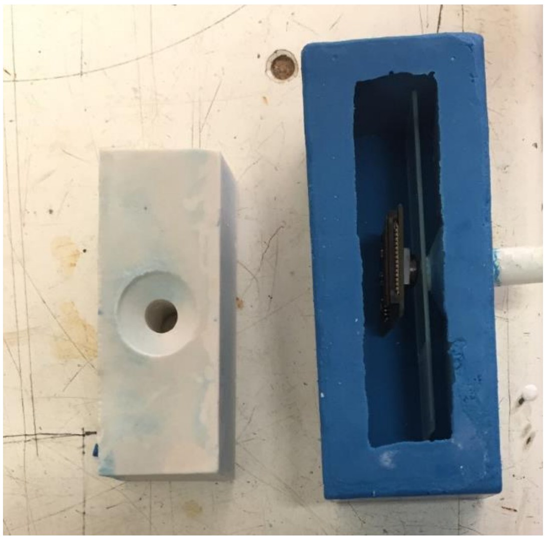


Figure 10. Silicon rubber mould for casting the JELAB2 camera and glass.
Left – Plug made from plaster (replica of the final shape required). **Right** – Silicon rubber mould with the camera and glass inside ready for casting.

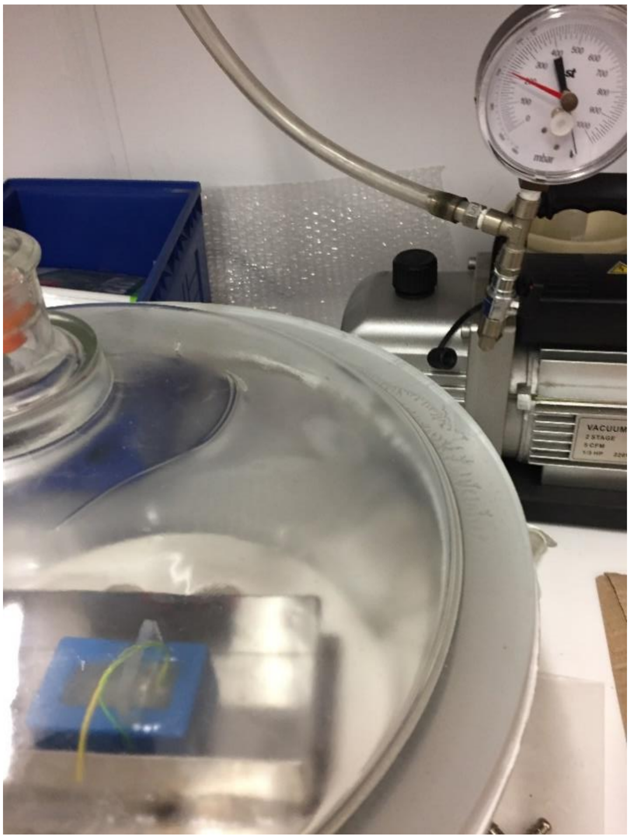


Figure 11. The mould enclosed in the vacuum chamber after pouring of the resin.
Note the pressure gauge in the top right of the image

The components were then placed within the rubber mould ready for casting. After mixing with hardener in the correct ratios the resin was poured into the mould and the entire assembly was enclosed in a vacuum chamber and subjected to reduced pressure of 200 mBar (Fig.11). Vacuum was maintained until all air bubbles (Fig. 12) were expelled and the resin was then allowed to set. This resulted in components set in a clear transparent matrix (Fig 13).

In large volumes of resin, it is difficult to expel all the air and heat produced by the curing chemical reactions can cause bubbling. Excessive heat produced can also break the glass or otherwise damage components. It is not advisable to cast more than 2 cm depth at one pouring. Multiple pours can be done to achieve a large casting but time must be allowed for the previous layer to cure and cool down before the next layer is poured.

JELAB2 was assembled from a number of separately cast components: The power and control module (Fig 14), the LED arrays (Fig. 8) and camera modules.

After individual testing these were then put together into a final overall casting.

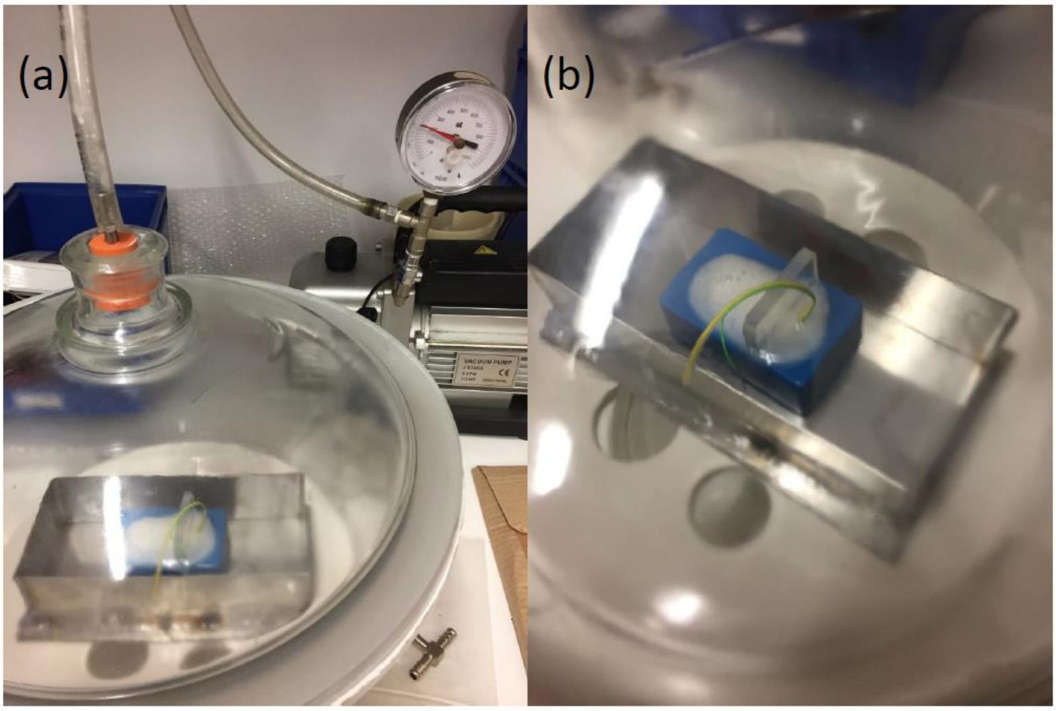


Figure 12. (a) The mould inside a vacuum chamber at 200 mBar.
(b) Foaming of the resin as air bubbles are expelled from the mould under reduced pressure.

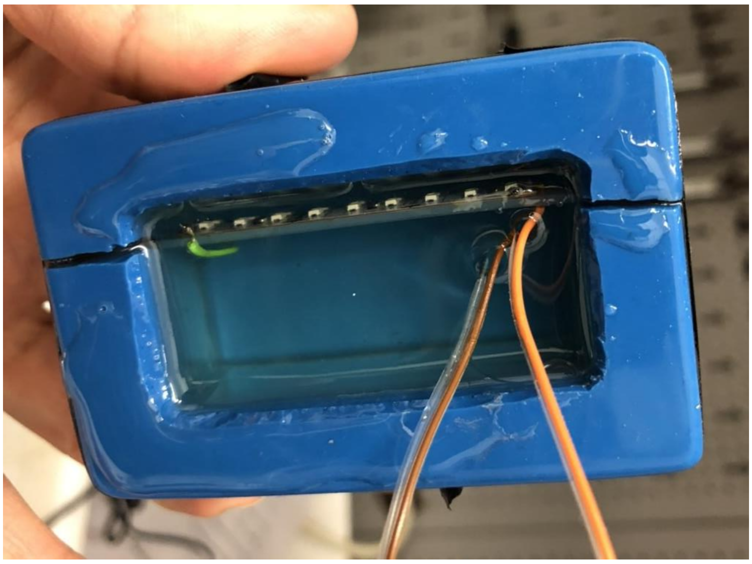
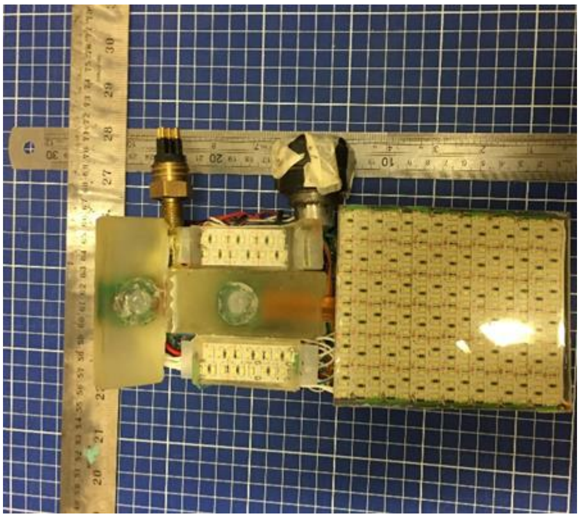
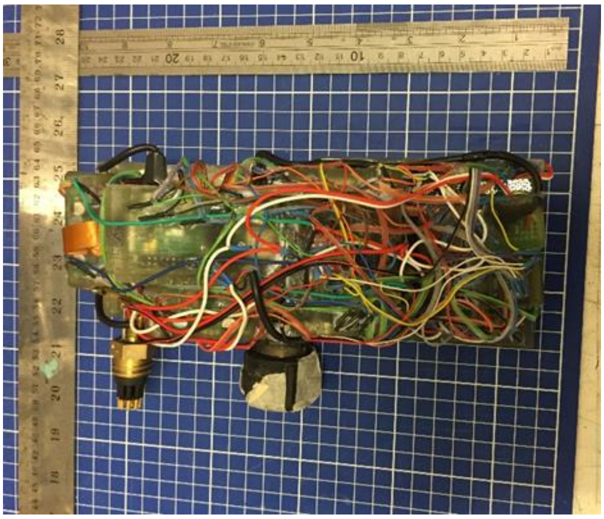


Figure 13. Casting ready to be removed from the mould.
Note the clear bubble-free transparent matrix.

Figure 14. The JELAB2 Power and control system embedded in resin.
This includes the Arduino processor, FTDI Basic break out board,power supplies and LED switching circuits.





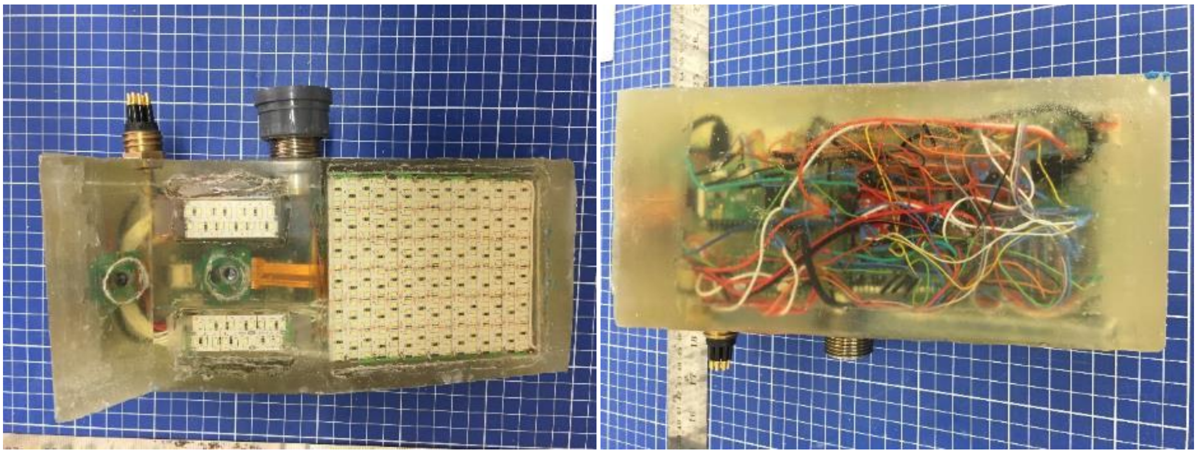


Figure 15. The JELAB2 (right panel: front view, left panel: back view) submodules assembled before and after the final resin encapsulation.

The final JELAB2 package weighed 2.1 kg in the air and 0.375 kg in water.

Underwater trials.

The first underwater trials of the JELAB2 were performed in HCMR's Thalassocosmos facilities in Crete. The system was deployed in a four-meter depth aquacultures tank and in the small harbour next to the HCMR Aquarium (Fig 16,17 & 18). The objective was to test the camera and the LED settings under the influence of different lighting conditions before the deployment in the field.

Figure 16. The JELAB2 test configuration with battery pack and ballast module.

Figure 17. The JELAB2 Benthic camera "raw" pictures taken during night in the Thalassocosmos harbour.

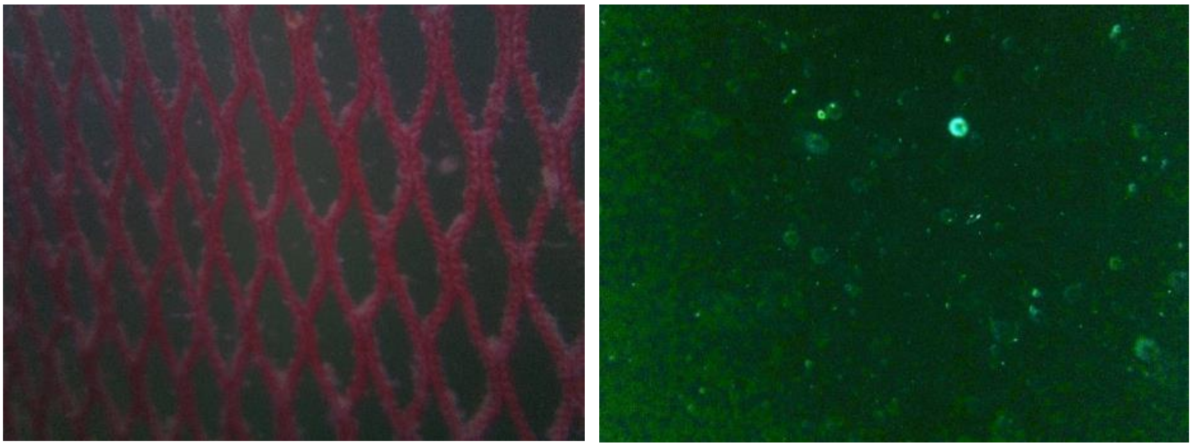


Figure 18. The JELAB2 Profiler camera "pictures taken during the tests in the Thalassocosmos aquacultures tank. **The left panel** picture is an unprocessed picture targeting the nets inside the tank. **The right panel** picture is processed (increased brightness 80%).

Sea trials.

Due to R/V vessels unavailability the only sea trials performed for the JELAB2 system took place in the Heraklion gulf onboard the HCMR rib *"IOLKOS"* using a small manual winch able to lower the system to 100 meters below the surface. This depth limitation did not now allow the Benthic camera to operate effectively during the test because the Benthic LED panel is emitting too much light so the pictures taken in the euphotic zone were over-saturated. The Profiler camera can effectively operate in the euphotic zone and some results are demonstrated in the figures below (Fig 19). The JELAB2 system logs metadata on each image taken using the format demonstrated in the table below:

Relative time (sec)	Depth (m)	Pressure (bar)	Temp (*C)	Picture Number	Battery Voltage
2.0789999999999997	11.76	1.1816	22.94	1	11.54
4.6480000000000015	14.58	1.4648	22.73	2	11.53

Figure 19. The JELAB2 Profiler camera pictures taken during the sea trials in the Heraklion Gulf. **The left panel** picture is a processed picture (increased contrast 60%) captured in 33 meters of water depth as recorder by the system pressure sensor. **The right panel** picture is processed (increased brightness 80%) captured in 55 meters.

4. Conclusions

An autonomous programmable dual camera system with LED lighting panels rated to 2000 m depth has been developed to meet the JELAB specification for a light-weight module capable of being carried on board an ARGO profiler float. The final prototype weights 0.375 kg when immersed in sea water and is comparable to the scientific payload and sensors (eg Wetlabs Fluorometers, SUNA Nitrate sensor) that has been successfully integrated in the Argo floats. The JELAB2 system is based on low cost commercial hardware (Arduino and Raspberry boards) and modules and can be expanded with the addition of more components and sensors. The software controlling the system, based on C/C++ and Python can be modified too in order to meet the demands of different user or scientific missions.
The future steps of the JELAB2 system will include further development and testing in the field aiming to improve the system operational capabilities. In parallel the data analysis will be continued to figure out the optimum sampling scheme (camera settings) for different deployment scenarios. Before the integration in a float the JELAB2 will be exposed to greater water depths for a longer period in order to verify the requirements of the Argo systems. Although the main limitation of the system is the large size of the collected data (pictures) that can not be transmitted using satellite connections, and the float or other host needs to be recovered, the metadata can be integrated in the Argo transmissions. Apart from the Argo floats JELAB2 can be used on a wide variety of platforms like:

- Profiling CTD
- Benthic Landers
- Fixed point mooring lines
- Surface buoys
- Gliders

5. Annexes and references

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