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Authors (Partner)	Raul Bardají (CSIC), Jaume Piera (CSIC)			
Responsible Author	Jaume Piera		**Email**	jpiera@icm.csic.es
	Partner	CSIC	**Phone**	+34 932 30 95 00

Abstract	This document provides a review of the state of the art in low-cost smart sensors
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1. Executive summary

In this document we expose the review of crowdsourcing technologies for water transparency measurements. In particular the review is focused on the state-of-the art in low-cost smart sensors, to be used in:

- The prototype of a low-cost buoy
- The extended sensor system for wearable underwater camera

The different modules have been conceived using accessible commercial products that could be acquired and used by participants with little or no technological skills. This feature is particularly important as it allows integrating the final products in educational projects. Introducing the water transparency crowdsourcing technologies in schools may increase enormously the potential number of participants involved in water optical characterisation and opens new possibilities for outreach and sensitization activities.

The final section of this review includes a short list of complementary projects. These projects have been selected as they similar architecture platforms (low cost and open hardware-software) to implement some useful devices. Using similar platforms they could be easily integrated in the CITCLOPS measuring concept.

2. The low cost measurement system for the buoy

The first crowdsourcing technology to estimate water transparency is based on sensor attached to low-cost moorings (Figure 1). Attached to the buoy there are several light sensors at different water depth. The vertical light extinction estimated from the light sensors is the parameter used to estimate the water transparency. The system use wireless personal area network (WPAN) technology to connect the participants to the low cost buoy from which they retrieve or consult data (i.e. light sensor measurements). The same device used to retrieve the data from the buoy will be able to upload the data to the Internet (when the participant decides to do it or automatically).

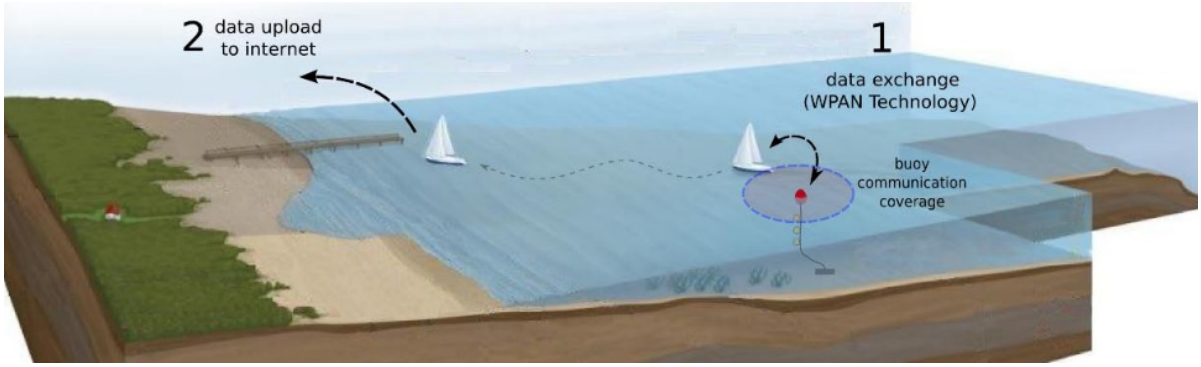

Figure 1: Low-cost moored sensor data system (reception and transmission)

The system integrates different modules: (1) The light sensors; (2) the microprocessor and the communication module, wich is divided in (3) transmission module; (4) antennas and (5) receptor module. This last module has been planned to be implemented using two different approaches: (5a) architecture based on the same electronics used in the buoy and (5b) based on smartphones.

The module structure of the low cost system is shown in the Figure 2. It consists in an easy programmable microprocessor that obtains the information from some sensors. The sensors can measure light properties or other complementary information (temperature, pressure ...). The information can be transmitted to a mobile receptor when is required.

All the sensor and transmission system has been designed to be embedded in a low cost buoy. The cost of all the system (buoy included) is planned to be less than 250 euros.

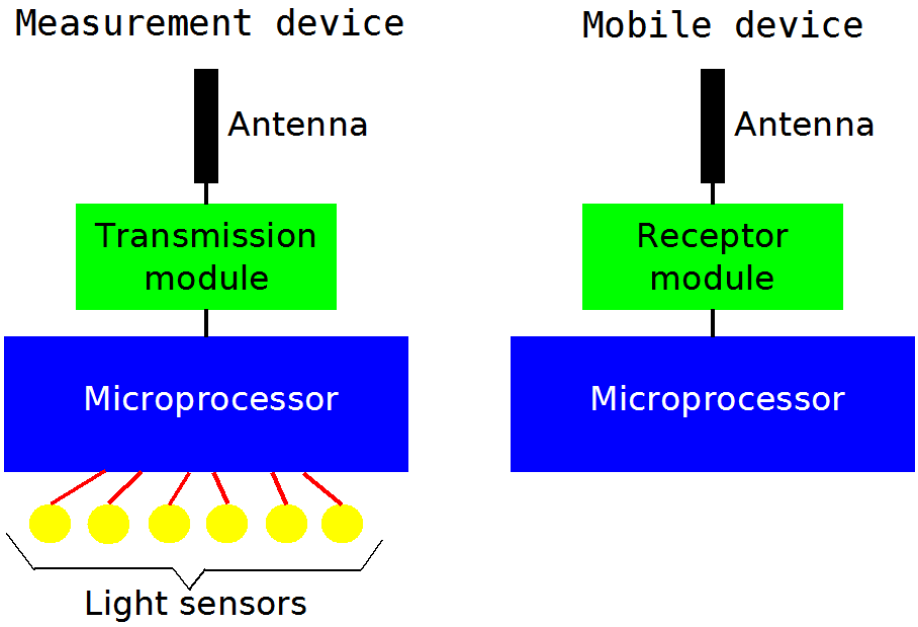

Figure 2: Basic modules of the low cost system

There are not similar products in the market. For this reason in the next sub-sections the different system modules has been conceived using accessible commercial products that could be acquired even for potential participants with little or no technological skills. With these commercial products, citizens can create their own measurement instruments with the idea of "*do it yourself*". This feature is particularly important as it allows offering the final product as educational project. Prices of each component are analysed in comparative tables.

2.1 Commercial components (State of art)

2.1.1 Optical sensors (quasi-digital)

The review of low cost light sensors has been focused on quasi digital-optical sensors. This type of sensors converts light (irradiance) measurements into a frequency signal. With this simple conversion it is possible to estimate directly the light intensity without the need of an analog-to-digital converter devices (usually one of the most expensive parts in a conventional digital sensor system). The use of quasi digital-optical sensors is one of the best options for a low-cost design. There is an additional advantage: the light-frequency conversion allows large time integrated measurements (from several seconds to minutes). This feature is very important in light measurements near the surface, where commonly there are large light fluctuations caused by the effect of sunlight-focusing by surface waves. It is important to eliminate this light variability component to estimate correctly the water transparency. Large time integrations reduce the measurement variability associated to the light fluctuations caused by the surface wave effect.

In the following table there are some quasi-digital optical sensors that can be acquired in the market. The price of these sensors is less than 5 euros.

Name	Datasheet
TSL230ARD	http://www.ams.com/eng/content/download/250243/975877/file/TSL230RD_TSL230ARD_TSL230BRD-P.pdf
TSL230BRD	http://www.ams.com/eng/content/download/250244/975885/file/TSL230RD_TSL230ARD_TSL230BRD-P.pdf
TSL230RD	http://www.ams.com/eng/content/download/250245/975893/file/TSL230RD_TSL230ARD_TSL230BRD-P.pdf
TSL235	http://www.ams.com/eng/content/download/250249/975925/file/TSL235R-E.pdf
TSL237	http://www.ams.com/eng/content/download/250250/975933/file/TSL237-J.pdf
TSL238	http://www.ams.com/eng/content/download/250251/975941/file/TSL238-J.pdf
TSL245	http://www.ams.com/eng/content/download/250252/975949/file/TSL245R-D.pdf
TSL237T	http://www.ams.com/eng/content/download/250253/975957/file/TSL237T-J.pdf
TSL238T	http://www.ams.com/eng/content/download/250254/975965/file/TSL238T-G.pdf
OPT101P-J	http://www.ti.com/litv/sbbs002a
TCS3200D-TR	http://www.mouser.com/ds/2/588/TCS3200-E11-191102.pdf

Table 1: Quasi-digital optical sensors

2.1.2 Microprocessor module (Arduino)

The microprocessor should be cheap and easy to programme. There are a big community of users that use the Arduino platform [1] in multidisciplinary projects. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software which could be considered a very good alternative to develop citizen science oriented sensors.

Arduino [2] is a single-board microcontroller designed to make the process of adding electronics components (sensors and actuators) very simple. The hardware consists of a simple open source hardware board designed around an 8-bit Atmel AVR microcontroller, though a new model has been designed around a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller.

Arduino boards can be purchased as pre-assembled or do-it-yourself kits. Hardware design information is available for those who would like to assemble an Arduino on their own. There are sixteen officials Arduinos that have been commercially produced to date. Numerous hardware variations of the Arduino are being sold by third parties.

Name	Processor	Frequency	Price (€)	More Information
Arduino Leonardo	Atmega32u4	16MHz	20.88	http://arduino.cc/en/Main/ArduinoBoardLeonardo
Arduino Uno	ATmega328P	16MHz	22.91	http://arduino.cc/en/Main/ArduinoBoardUno
Arduino Due	AT91SAM3X8E	84MHz	43.32	http://arduino.cc/en/Main/ArduinoBoardDue
Arduino Mega2560	ATmega2560[	16MHz	38.09	http://arduino.cc/en/Main/ArduinoBoardDue
Arduino Ethernet	ATmega328	16MHz	41.96	http://arduino.cc/en/Main/ArduinoBoardEthernet
Arduino Fio	ATmega328P	8MHz	13.02	http://arduino.cc/en/Main/ArduinoBoardFio
Arduino Mini	ATmega168	16MHz	14.19	http://arduino.cc/en/Main/ArduinoBoardProMini
Arduino Nano	ATmega328	16MHz	36.83	http://arduino.cc/en/Main/ArduinoBoardNano
LilyPad	ATmega168V ATmega328V	8MHz	20.57	http://arduino.cc/en/Main/ArduinoBoardLilyPadUSB
Arduino Pro	ATmega168V ATmega328V	8MHz (3.3V) 16MHz (5V)	16.70	http://arduino.cc/en/Main/ArduinoBoardPro
ADK	ATmega2560	16 MHz	49	http://arduino.cc/en/Main/ArduinoBoardADK
Micro	ATmega32u4	16MHz	22.73	http://arduino.cc/en/Main/ArduinoBoardMicro
Pro Mini	ATmega168	8MHz (3.3V) 16MHz (5V)	22.73	http://arduino.cc/en/Main/ArduinoBoardProMini

Table 2: Arduino boards

Several companies offer commercial boards similar to Arduino. Those boards can be used too. The next table lists some alternative boards.

Name	Processor	Frequency	Price (€)	More Information
BeagleBone	ARM Cortex-A8	720MHz	89	http://beagleboard.org/bone
Teensy/ Teensy++	AVR	16MHz	20 28	http://www.pjrc.com/teensy/
Pinguino	several	--	35	http://pinguino.cc/
MSP430 Launchpad	MSP430	16MHz	4.3	http://www.ti.com/tool/msp-exp430g2
Seeeduino	ATmega328P	16MHz	22.50	http://www.seeedstudio.com/wiki/Seeeduino_v3.0#Introduction
Waspmote	ATmega1281	8MHz	60	http://www.libelium.com/products/waspmote

Table 3: Alternative microprocessor boards

2.1.3 Transmission modules

Leveraging wireless technology can be challenging without the right combination of expertise and resources. The XBee product family is a series of modular products that make deploying wireless technology easy and cost-effective. Digi [33] has made multiple protocols and RF features available in the popular XBee footprint, giving customers enormous flexibility to choose the best technology for their needs without sourcing from multiple vendors. Whether you need a ZigBee module or a fast multipoint solution, 2.4 GHz or long range 900 MHz—we have an XBee to meet your specific requirements.

Product	Frequency	Power Output	Maximum Range	RF Data Rate	Protocol	Multipoint	Mesh
XBee ZB	2.4 GHz	1.25/2 mW	120 m	250 Kbps	ZigBee		√
XBee-PRO ZB	2.4 GHz	63 mW*	3.2 km	250 Kbps	ZigBee		√
XBee ZB SMT	2.4 GHz	3.1/6.3 mW	1200 m	250 Kbps	ZigBee		√
XBee-PRO ZB SMT	2.4 GHz	63 mW	3.2 km	250 Kbps	ZigBee		√
XBee 802.15.4	2.4 GHz	1 mW	90 m	250 Kbps	802.15.4	√	
XBee-PRO 802.15.4	2.4 GHz	63 mW*	1.6 km	250 Kbps	802.15.4	√	
XBee-PRO 900HP	900 MHz	250 mW	45 km	200 Kbps	Proprietary (Multipoint and DigiMesh)	√	√
XBee-PRO XSC	900 MHz	100 mW	24 km	9.6 Kbps	Proprietary	√	
XBee-PRO 900	900 MHz	50 mW	10 km	156 Kbps	Proprietary	√	
XBee-PRO DigiMesh 900	900 MHz	50 mW	10 km	156 Kbps	DigiMesh		√
XBee DigiMesh 2.4	2.4 GHz	1 mW	90 m	250 Kbps	DigiMesh		√
XBee-PRO DigiMesh 2.4	2.4 GHz	63 mW	1.6 km	250 Kbps	DigiMesh		√
XBee-PRO 868	868 MHz	350 mW	80 km	24 Kbps	Proprietary	√	
XBee Wi-Fi	2.4 GHz	16 dBm	300 m	65 Mbps	802.11bgn	√	
XBee 865LP	865 MHz	12dBm	4 km	80 kbps	Proprietary (Multipoint and DigiMesh)	√	√
XBee 868LP	868 MHz	12dBm	4 km	80 kbps	Proprietary (Multipoint and DigiMesh)	√	√

Table 4: Xbee modules

2.1.4 Antennas

There are a lot of different antennas in the market. The costs are very different too. We can choose the gain of the antenna, the directivity, the efficient, etc.

Figure 3: Antenna

The following table provides a list of some of the low cost antenna available in the market

Product	Frequency (GHz)	Gain	Price (€)	More Information
ANT-24G-905-SMA	2.4-2.5 Ghz	+5dB	7.56	http://docs-europe.electrocomponents.com/webdocs/0e0b/0900766b80e0bbd5.pdf
ANT-24G-HL90-SMA	2.4-2.5 Ghz	+0dB	7.41	http://docs-europe.electrocomponents.com/webdocs/0ba3/0900766b80ba38b8.pdf
ANT-24G-WHJ-SMA	2.4-2.5 Ghz	+0dB	8.34	http://docs-europe.electrocomponents.com/webdocs/0ba3/0900766b80ba38b8.pdf
ANT-24G-DPL-FP	2.4-2.5 GHz	+2.1dB	11.49	http://docs-europe.electrocomponents.com/webdocs/0ba3/0900766b80ba38b8.pdf
ANT-SS2.4G	2.4 GHz	+0dB	4.35	http://docs-europe.electrocomponents.com/webdocs/0df8/0900766b80df8ad9.pdf
FBKR35068-SM-KR	2.4 GHz	+2dBi	8.93	http://docs-europe.electrocomponents.com/webdocs/0ba1/0900766b80ba126a.pdf
ANT-2.4G	2.4 GHz	+10dBi	14.89	http://docs-europe.electrocomponents.com/webdocs/0793/0900766b80793024.pdf

Table 5: Antenna modules

2.1.5 Receivers based on Arduino platform

The first alternative analysed in CITCLOPS project was the development of a receiver based on the same Arduino platform that was used by the buoy.

Figure 4: Receiver based on an Arduino platform

The prototype shown in Figure 4 has already been developed and tested. The concept

system (bouy and receiver) were presented [4] to the bio-optical community in the 3rd EOS Topical Meeting (BluePhotonics 3) meeting held in Texel on March 2013 (http://www.myeos.org/events/bluephotonics3). It is planned also to be presented [5] to the Marine Technology community in the IEEE Oceans Conference next June 2013

2.1.6 Receivers based on waterproof Mobile Phones

The waterproof mobile phones could be used as receivers as well. The main advantage of this solution is that many citizens' could obtain the data from the buoys. At present there are not many waterproof mobile phones. The waterproof mobiles are now more expensive than the average but it is expected that this type of product will be offered in larger quantities and models in the next years with cheaper options in the market.

The following table provides information about the waterproof mobile models available now (source www.thephonetrader.co.uk)

Name	Company	More information
Xperia Go	Sony	http://www.sonymobile.com/es/products/phones/xperia-go/
Xperia acro S	Sony	http://www.sonymobile.com/global-es/products/phones/xperia-acro-s/
Defy XT	Motorola	http://www.motorola.com/us/consumers/MOTOROLA-DEFY-XT/m-DEFYXT,en_US,pd.html
Defy Mini	Motorola	http://latam.motorola.com/consumers/Motorola-DEFY-MINI/111004,es,pd.html
Defy Plus	Motorola	http://www.motorola.com/Consumers/XA-ES/Consumer-Products-and-Services/Mobile-Phones/ci.MOTOROLA-DEFY1-XA-ES.alt
Xperia Active	Sony	http://www.sonymobile.com/es/products/phones/xperia-active/
Eluga	Panasonic	http://www.panasonic.es/html/es_ES/Productos/Gamas+de+productos/8903808/index.html

Table 6: Waterproof mobile phones

There are also some mobile phone waterproof covers like there one shown Figure 5:

- http://www.splashpack.com/shop.html
- https://www.liquipel.com/
- http://www.swimmingwaterproofcases.com

Figure 5: Iphone waterproof cover

3. Extended sensor system for wearable underwater camera

Adding sensors to wearable underwater cameras could provide also not only information about water transparency but also additional information to be incorporated in the measurement contextualization (position, water temperature …).

Taking into account the wide range of available low cost sensors for Arduino there are three main approaches to integrate them in wearable underwater cameras: using the USB port of the cameras, using the camera audio channel, integrating imaging capabilities to underwater devices designed with Arduino (see Diveduino project below).

3.1 Arduino sensors

The following table contains a list of low cost sensors that available for an Arduino platform.

Name	Price (€)	More information
Humidity sensor	20	http://www.cooking-hacks.com/skin/frontend/default/cooking/pdf/Humedad-808H5V5.pdf
Grove - Infrared temperature sensor	8.90	http://www.cooking-hacks.com/index.php/shop/sensors/temperature/grove-infrared-temperature-sensor.html
Grove - Temperature sensor	2.40	http://www.seeedstudio.com/wiki/index.php?title=GROVE_-_Starter_Bundle_V1.0b#Temperature_Sensor_Twig
Digital temperature sensor breakout - tmp102	5	http://www.sparkfun.com/datasheets/Sensors/Temperature/tmp102.pdf http://www.sparkfun.com/datasheets/Sensors/Temperature/tmp102.pdf http://www.sparkfun.com/datasheets/Sensors/Temperature/TMP102_Breakout-v11.pdf
Electronic brick – water sensor	2.50	http://www.seeedstudio.com/depot/datasheet/Electronic%20brick%20-%20water%20sensor.pdf
Temperature sensor - waterproof (ds18b20)	8.75	http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Temp/DS18B20.pdf http://mbed.org/users/snatch59/notebook/onewirecrc/ http://bildr.org/2011/07/ds18b20-arduino/ http://www.cooking-hacks.com/index.php/shop/sensors/temperature/temperature-sensor-waterproof-ds18b20.html
Triple axis accelerometer breakout - mma8452q	7.75	http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Accelerometers/MMA8452Q-Breakout-v11.pdf http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Accelerometers/MMA8452Q.pdf http://www.cooking-hacks.com/index.php/shop/sensors/motion/triple-axis-accelerometer-breakout-mma8452q.html
Gyro breakout board - lpy530al dual 300?/s	18	http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Gyros/2-Axis/ST-DualGyro-PY-Breakout-v11.pdf http://www.sparkfun.com/datasheets/Sensors/IMU/lpy530al.pdf
Digital vibration sensor	5	http://www.cooking-hacks.com/index.php/shop/sensors/motion/digital-vibration-sensor.html
Linksprite jpeg color camera ttl interface	47	http://www.sparkfun.com/datasheets/Sensors/Imaging/1274419957.pdf http://www.linksprite.com/product/showproduct.php?id=15&lang=en http://www.sparkfun.com/datasheets/Sensors/Imaging/JPEG_UART_camera_tutorial.pdf
Tilt sensor – 4-	2.55	http://www.sparkfun.com/datasheets/Sensors/rpi-1031.pdf

Name	Price (€)	More information
way		
G1/2 water flow sensor	9.50	http://www.seeedstudio.com/depot/datasheet/water%20flow%20sensor%20datasheet.pdf http://www.seeedstudio.com/forum/viewtopic.php?f=4&t=989&p=3632#p3632
Flow switch--mr-w1-p	10.50	http://www.cooking-hacks.com/index.php/shop/sensors/flow/flow-switch-mr-w1-p.html
Infrared emitters and detectors	1.50	http://www.sparkfun.com/datasheets/Components/LTE-302.pdf http://www.sparkfun.com/datasheets/Components/LTR-301.pdf http://www.reconnsworld.com/ir_ultrasonic_basicirdetectemit.html

Table 7: Other sensors

4. Complementary projects

There are a lot of open source initiatives that could provide complementary observational platforms and sensoring systems to CITCLOPS. A short review of the most relevant are listed below.

4.1 Spectruino

Spectruino [7] is an Arduino Spectrometer sensor to measure light intensity in a wide range of wavelengths. Internally, this is achieved through a combination of diffraction grating with linear CCD camera and custom firmware.

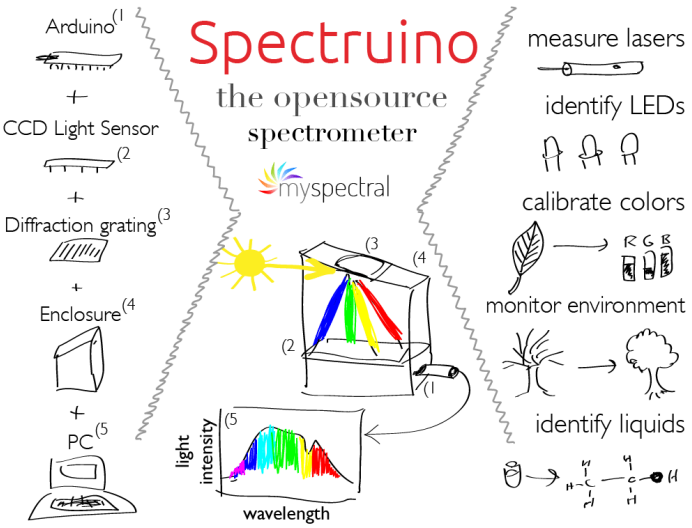

Figure 6: Spectruino

There are several commercial systems similar to Spectruino (most of them with better sensor performance). The most interesting aspect of Spectruino is its price: around 200-250 €.

4.2 Diveduino

Diveduino [8] is a project based on Arduino platform that is not designed to replace a dive computer, but it can log depth and temperature during a dive. Data can be saved to a MicroSd Card in a TEXT file format. At present the project developer has implemented the code to export the data to a commercial data sheet, enabling the users to create dive profile graphics. The prototype has a display that allows also visualizing the dive profile. This elemental software could be expanded easily and adapted to crowdsourcing requirements.

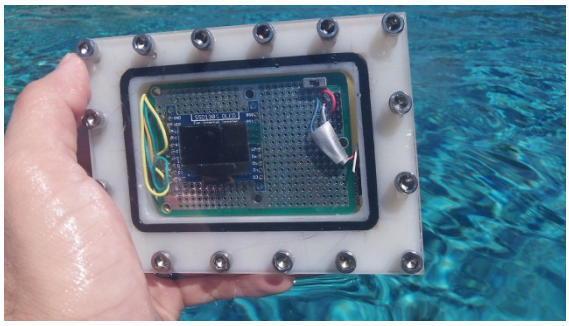

Figure 7: Diveduino

4.3 OpenRov

OpenROV [9] is a *Do It Yourself* telerobotics community centered around underwater exploration and education. They have developed a low-cost telerobotic submarine that can be built with mostly off-the-shelf parts. The goal of OpenROV is to democratize exploration by allowing anyone to explore and study underwater environments.

Figure 8: OpenRov

4.4 Coconut Pi

A group of students from the University of Singapore has created Coconut Pi [10].

An underwater robot using Raspberry Pi for functions related to memory management and Arduino to vehicle controls. The most curious part is that the case is made with a tupperware.

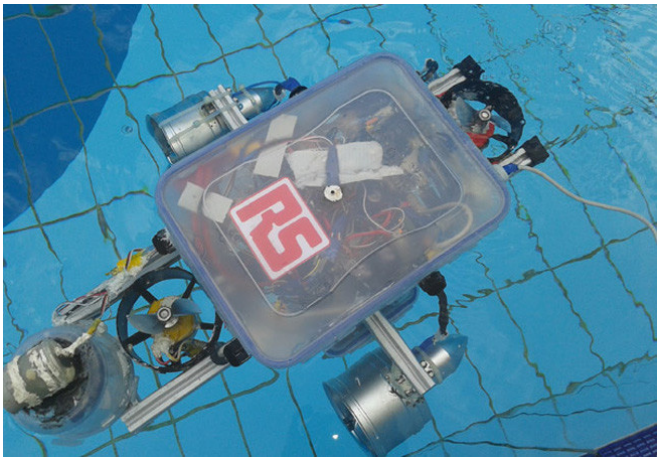

Figure 9: Coconut Pi

5. References

1. http://www.arduino.cc/

2. Arduino Cookbook. Michael Margolis. O'Reilly Media. 2011

3. http://www.digi.com/xbee/

4. Bardaji, R and Piera J. (2013). Monitoring marine environments with crowdsourcing methods: Water transparency estimation using low cost technologies. 3rd EOS Topical Meeting on Blue Photonics. Optics in the Sea (Blue Photonics 3). Texel, Netherlands. 18 March 2013 - 20 March 2013.

5. Bardaji, R and Piera J. (2013). Low-cost moored instrumentation for citizens' education and participation in environmental stewardship. OCEANS'13 MTS/IEEE Conference to be held in Bergen, Norway, from 10-13 June 2013.

6. http://www.circuitsathome.com/camera-control/digital-camera-control-using-arduino-usb-host-shield-part-1-basics

7. http://myspectral.com/

8. http://www.diveduino.com/

9. http://openrov.com/

10. http://coconutpi.wordpress.com/

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