CoScienza Ambientale
Misurare la natura è come ammirarla con altri occhi, quelli dei nostri strumenti e della nostra intelligenza nell'interpretarne i dati

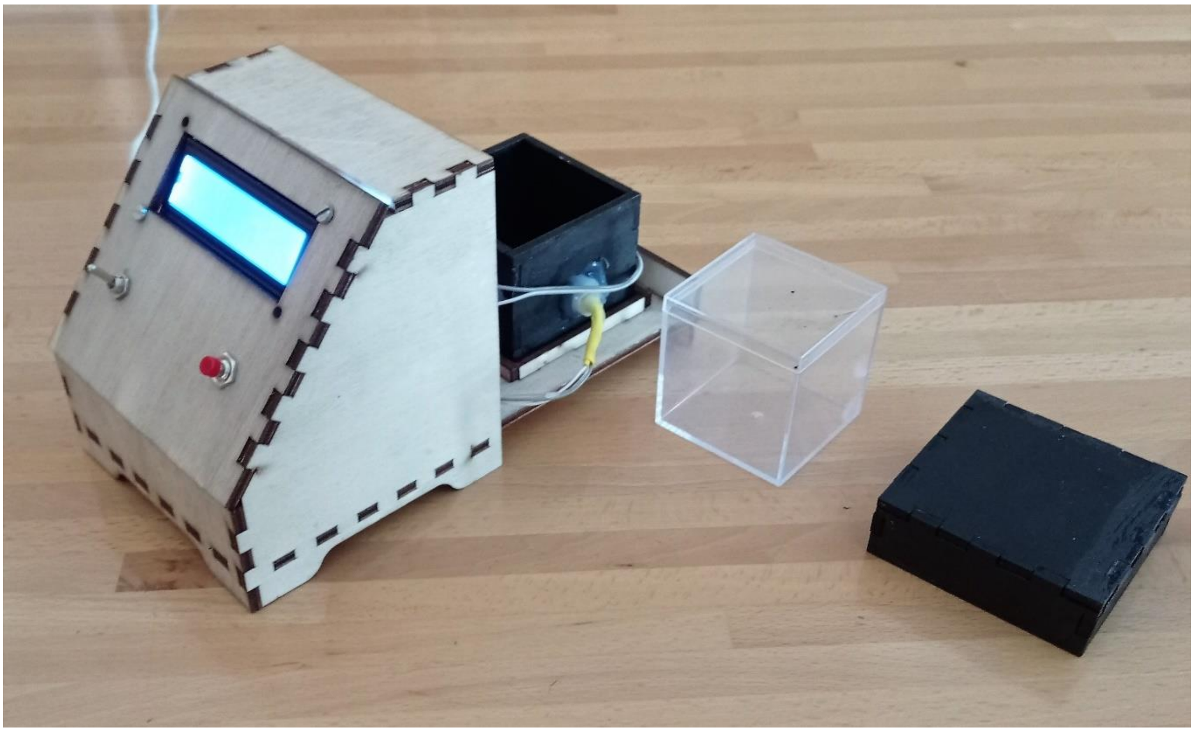
MultiOptics

Optical instrument for water analysis

Turbidity and colorimetry

Version 2 - 11/11/2023

Paolo Bonelli
paolob087@gmail.com
www.coscienzambientale.com



INDEX

Introduction

The MultiOptics instrument, built in "open-source" and "low-cost" mode, is able to analyze the optical response of a water sample with different colors emitted by an RGB LED source. The light transmitted and diffused at 90° through the water sample is measured by two photoresistors and processed by a multiprocessor Arduino like.

The sample is contained in a transparent plastic cell (cuvette), inserted in a closed and dark container; the source and the two photoresistors are mounted on the sides of the container. Figure 1 shows a schematic drawing of the instrument, with the exclusion of the electronic part. The cuvette is larger than the standard ones, this is to have more sensitivity in the light absorption mode.

The instrument, at the time of writing this document, can measure the turbidity and concentration of orthophosphate in a water sample, but could measure other chemical species dissolved in the sample colored with appropriate reagents.

The instrument can be built with easily available and inexpensive components: the wooden parts were made of 4 mm poplar plywood, cut with the “Laser Cut” numerical control machine of the maker space WeMake (wemake.cc) in Milan. The cuvette is a clear plastic cube with a side of 55 mm.

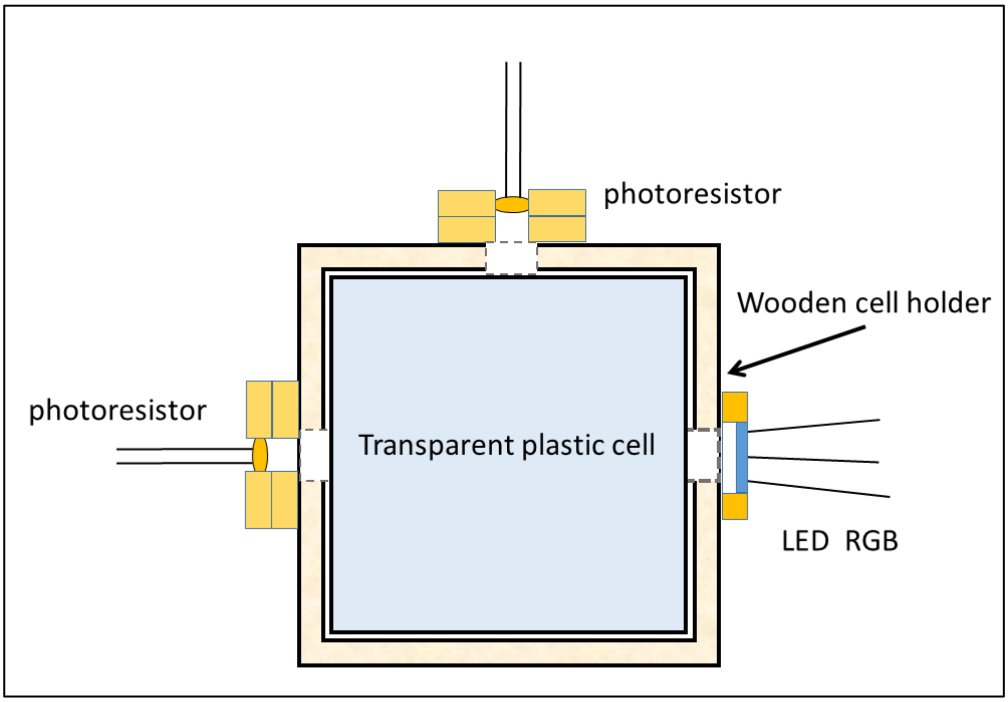


Figure 1 - Transparent cell with cell holder and arrangement of components

The light source consists of a “Neopixel” RGB LED capable of producing light of any color and various intensity, which must be driven by a microcontroller.

The light sensors are two photoresistors (LDR) placed at 180° and 90 ° with respect to the source.

By means of a voltage divider, the resistance variation of the LDRs is transformed into a voltage variation and read from the ADC inputs of an Arduino UNO microcontroller, the same one that controls the RGB LED.

The transparent plastic cell is contained in a sample holder consisting of a black painted wooden box (Figure 2). The LED and of the two LDRs are arranged on three sides of the sample holder (Figure 1). On the fourth side there is the electrical circuit with the connection cables to the Arduino MCU.

The sample holder is removable allowing you to try out various configurations of sensors and light sources.

The fixed part of the instrument includes the MCU, a 16 x 2 character display, a push button, a switch and a rechargeable LiPo battery (Figure 3).

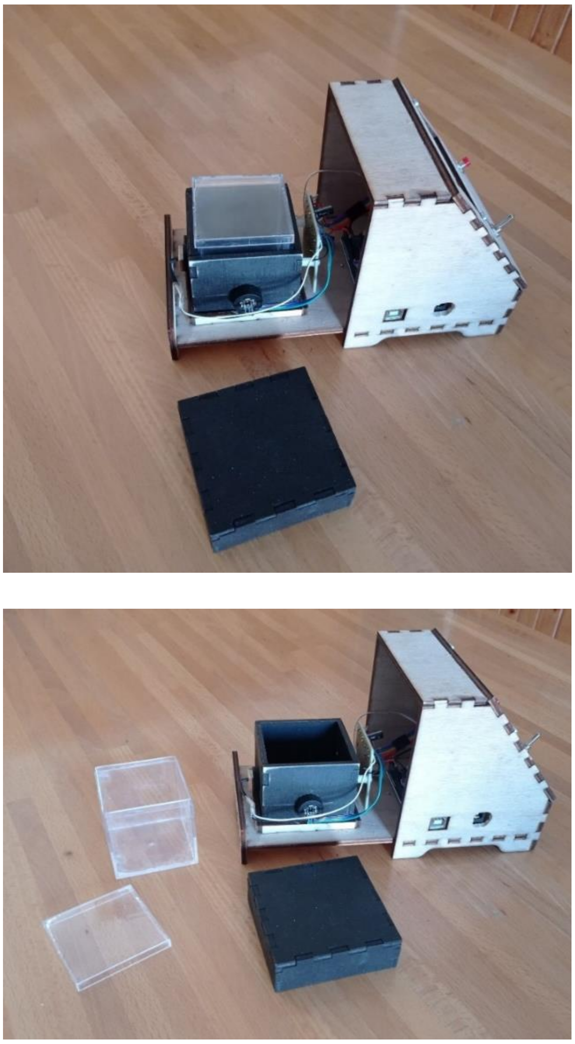


Figure 2 - The photos show the transparent cell inserted in the dark container (sample holder) with its cover. Container and cell are removable. The electronics are contained on the right side.

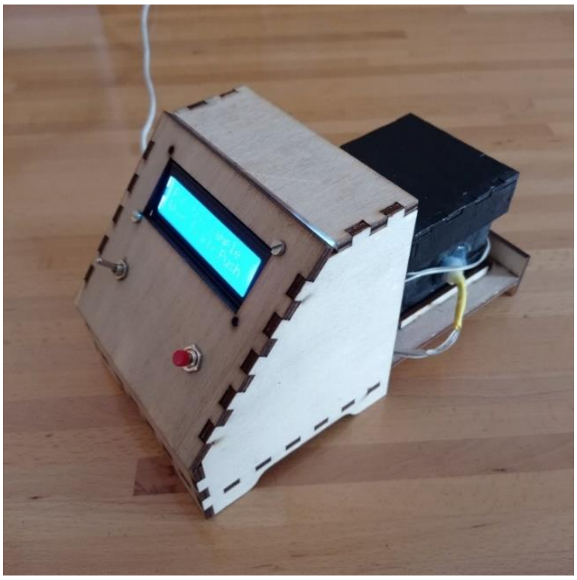


Figure 3 – Front of the instrument where there are the LCD display, the switch and the push button.

Characteristics of photoresistors

The photoresistors used have a different response to the various wavelengths of light, the peak is centered around 570 nm, while it drops to around 20% at the extremes of the visible band (Figure 4). This non-linearity is found in almost all semiconductor visibile light sensors, so at first it was not considered useful to use other types of sensors.

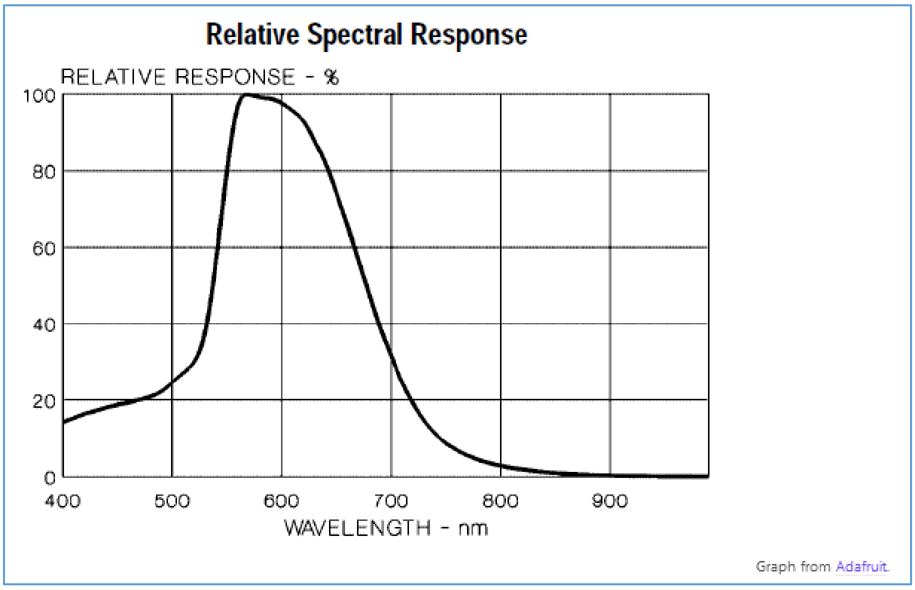


Figure 4

The operation of a photoresistor is simple: its value varies from 0 Ω to its maximum resistance of 10, 50, 100KΩ, according to the type of photoresistor, when it passes from full lighting to dark.

Some models, such as the LDR 2-20KΩ or the LDR 20-50KΩ, after 10 seconds of darkness reach very high resistance levels, almost a circuit interruption.

The voltage outputs for diffused and direct light are transformed by the MCU into arbitrary units between 0 and 1023, corresponding to the 10 bit analog converter of Arduino.

How MultiOptics works

In the version described here, the instrument is able to measure the turbidity or the concentration of orthophosphate of a water sample; the latter measurement is carried out on the sample suitably treated with the reagents that color it.

Before introducing the sample to be analyzed into the cell, a "white" sample is required, i.e. pure water, which is used to determine the value of light transmitted by the LED without attenuation due to the water to be analyzed.

The Arduino UNO board allows the execution of various programs that:

• drive the RGB LED in the desired modes,

• read the response of the sensors,

• calculate the quantities in their units of measurement according to the calibration parameters.

Currently the program loaded on Arduino is called MultiOptics_Dual, it can be compiled and loaded with the Arduino IDE (www.arduino.cc).

The program turns on the RGB LED in succession: Red, Green, Blue, White, recording the responses of the two LDR sensors. On the basis of these responses, the desired quantities are then calculated.

The program asks the operator for some choices that are presented on the LCD display and to which the operator responds by simply pressing a button (yes) or waiting 5 seconds (no). One of these choices concerns the carrying out of the turbidity or phosphate measurement.

The results of the analysis are shown on the display.

In the developing phase a PC with a USB cable can be connected to the MCU in order to display on the PC more information from the program running on the MCU.

Before carrying out the measurements on the sample to be analyzed, the instrument asks if you want to analyze a sample of pure (white) water. This measurement is essential the first time the instrument is turned on or after a reset of the same.

Interactivity between program and operator

The sequence of program requests, on the display, is shown in figures 5 and 6.

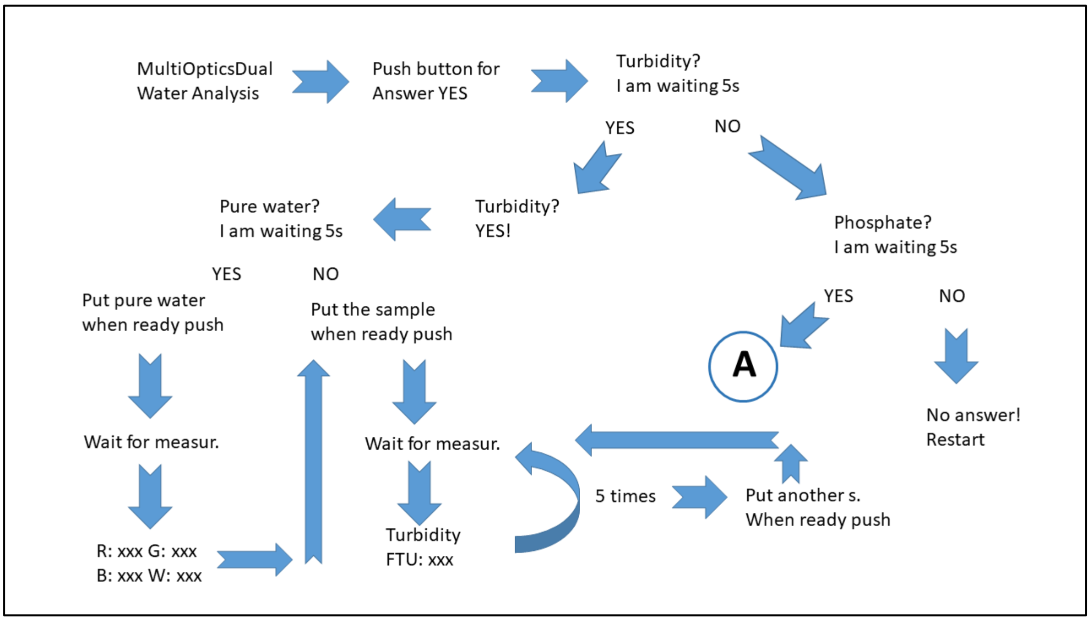


Figure 5

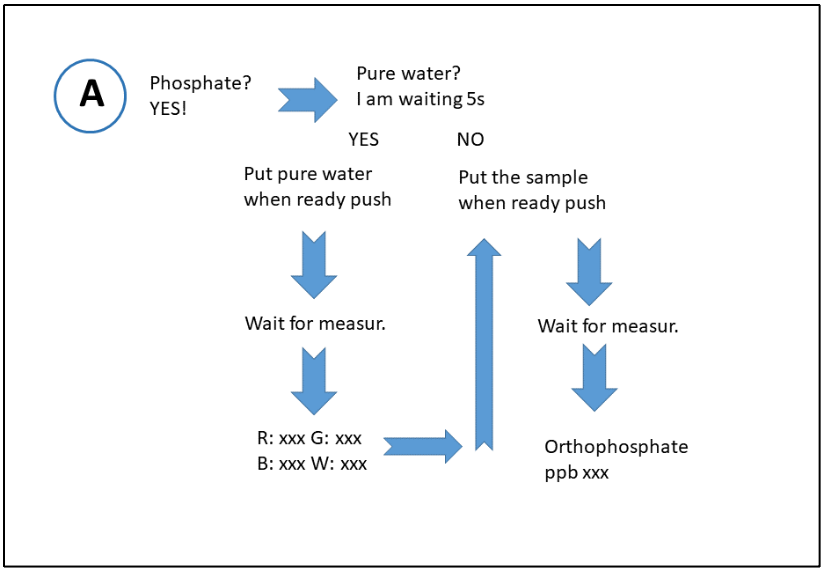


Figure 6

Sample preparation for turbidity measurement

The sample for turbidity measurement does not require reagents. The only precaution to have is to shake the sample well before placing it in the cell. After performing the measurement with pure water, proceed by introducing the sample into the cell and the measurement will appear directly on the display in FTU units (Formazine Turbidity Unit).

Sample preparation for orthophosphate

The preparation of the samples is described in the paragraph, framed below (Figure 7), taken from the manual P-PO4 AM v5 of the Institute for the study of ecosystems of the CNR of Verbania-Pallanza (Italy). The only variant necessary for the MultiOptics instrument is that of the amount of sample must be greater than 50 mL to ensure a liquid level in the cell that exceeds those ones of LED and LDRs.

The right amount of sample together with the reagents is 71 mL. For the proportions to be the same it is found that 2 mL of each reagent can be added to 67 mL of water. In this case: 4 / (67 + 4) = 3 / (50 + 3) c.a

The reagents were prepared in the laboratories of the CNR of Verbania-Pallanza, mentioned above.

After carrying out the measurement with pure water, proceed by introducing the sample added with the reagents. The MultiOptics instrument will provide the orthophosphate concentration measurement directly on the display in ppb units.

PROCEDIMENTO

Prima di iniziare a prelevare dai campioni l'aliquota da analizzare, preparare tre prove in bianco (acqua ultrapura più i reattivi) come verifica della seguente procedura analitica.
Il volume di campione analizzato può essere di 50 o 25 mL a seconda del volume totale di campione disponibile, l'aliquota di 50 mL è quella consigliata; in seguito tra parentesi vengono riportati i valori relativi all'analisi dell'aliquota di 25 mL.
Con un cilindro graduato da 50 mL ud una pipetta automatica prelevare 50 mL (25 mL) di campione stabilizzato alla temperatura ambiente di 20÷25 °C e versarli in una beuta da 100 mL (50 mL), aggiungere 1,5 mL (0,75 mL) di miscela di reagenti (I), agitare, e dopo circa 2 minuti aggiungere 1,5 mL (0,75 mL) di soluzione riducente (II) ed agitare nuovamente; dopo 15 minuti ed entro 1 ora dall'aggiunta dei reattivi, si esegue la lettura spettrofotometrica alla lunghezza d'onda di 890 nm utilizzando una cuvetta da 5 cm di passo ottico, azzerando lo strumento con acqua deionizzata.

Figure 7 – see text

Instrument calibration

Turbidity calibration with calcium oxalate

To calibrate the instrument as a turbidimeter, using a substance that is easily available and to prepare, the calcium oxalate method was tested.

Calcium oxalate CaC_2O_4 is insoluble in water and can be obtained by mixing solutions of calcium chloride $CaCl_2$ and oxalic acid $H_2C_2O_4$, obtaining a white cloudy solution that is stable enough for a time sufficient for the measurements and easily dilutable in the desired concentrations.

The reaction is as follows:

$$CaCl_2 + C_2H_2O_4 \rightarrow C_2CaO_4 + 2HCl$$

Both oxalic acid and calcium chloride are readily available on the market, because they are used in different activities and have low costs.

To obtain solutions of known concentration of these two substances, which are sold in the solid but not anhydrous state, therefore with different unknown contents of water of crystallization inside them, saturated solutions are prepared. That is, the substance is dissolved in water until a small amount remains on the bottom. This process must be carried out at a known temperature, typically 20 ° C.

The concentration of these two substances in a saturated solution is given by their solubility, which for Calcium Chloride and Oxalic Acid is respectively 740 and 102 g / L.

https://it.wikipedia.org/wiki/Acido_ossalico

https://it.wikipedia.org/wiki/Cloruro_di_calcio

https://it.wikipedia.org/wiki/Ossalato_di_calcio

To find out how many grams of calcium oxalate are produced by mixing two saturated solutions of calcium chloride and oxalic acid, one can proceed with a stoichiometric calculation:

1 liter of saturated oxalic acid solution, which contains 102 g, + 126 g of calcium chloride, gives 145 g of oxalate in equilibrium.

https://www.chemicalaid.com/tools/reactionstoichiometry.php?equation=CaCl2+%2B+C2H2O4+%3D+C2CaO4+%2B+HCl

The 126 g of calcium chloride are obtained from a volume of saturated solution, which contains 740 g / L, i.e. 126/740 = 0.17 L

Therefore the ratio is 1 L of acid with 0.17 L of chloride, or 100 cc of oxalic acid with 17 cc of chloride, which gives 14.5 g of oxalate diluted in what results from the mixture.

It must be borne in mind that a minimal and negligible part of oxalate is soluble (7.04 mg / L). So if the mixture has a volume of 117 cc (approximate), the precipitated oxalate is 14.5 - 0.0008 = 14.5 g c.a. (0.117 * 7.04 / 1000)

The TSS (Total Suspended Solid) due to suspended calcium oxalate is therefore 14.5 * 1000/117 = 124 g / L

From this mixture, other more dilute mixtures can be prepared to calibrate the instrument.

You could also proceed by diluting the starting compounds first and re-calculating the oxalate concentration.

In order to obtain an empirical relationship between oxalate turbidity and standard FTU units, FTU measurements were made with a professional instrument at the CNR-IRSA laboratory in Pallanza (Italy). The result is the graph in Figure 7. As you can see, the relationship between the two quantities is not linear except for the low turbidity.

The curve in Figure 8 can be used to calibrate other instruments similar to the one shown here. In other words, the oxalate method can be seen as a secondary standard.

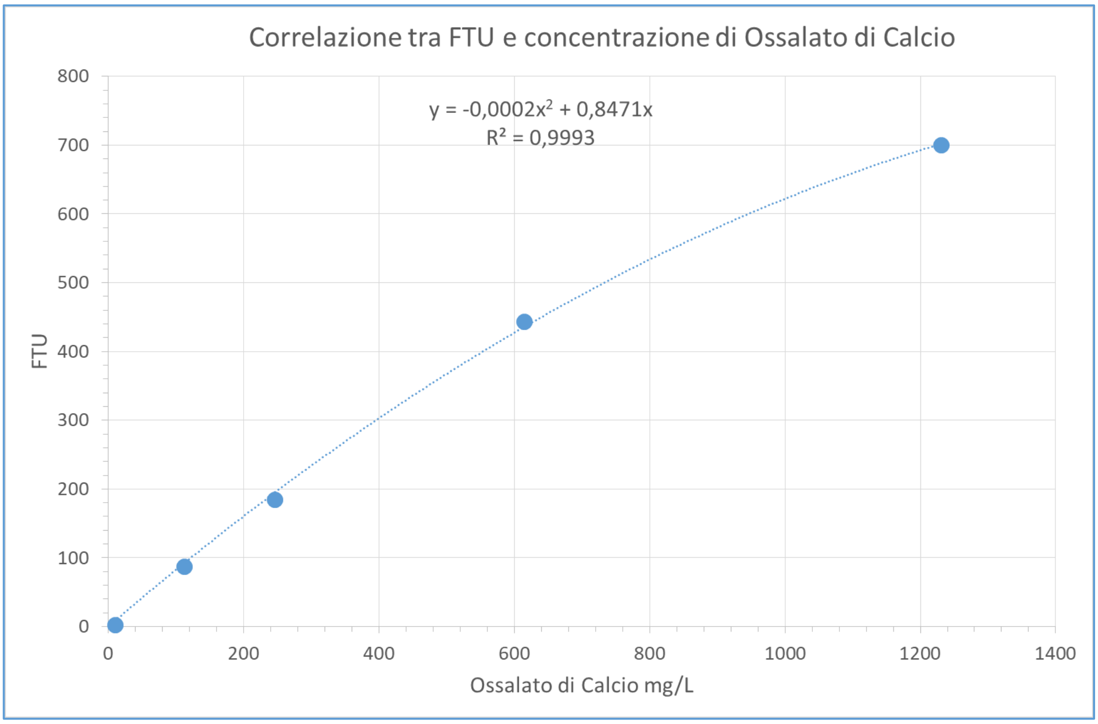


Figura 8 – Correlation between FTU and various concentrations of calcium oxalate

Intercalibration at the CNR-IRSA Laboratory of Pallanza (Italy).

On 26/05/2022 a series of measurements were carried out at the Hydrobiology Laboratory of the CNR-IRSA in Pallanza, in the presence of Gabriele Tartari, researcher at the same Laboratory, aimed at comparing the response of the MultiOptics instrument with standard solutions of turbidity in FTU units and with solutions of known concentration of orthophosphate with reactive ammonium molybdate.

The aim was to have an instrument response calibrated in FTU units for turbidity and in ppb for orthophosphate concentration.

Turbitidy

Different Formazin solutions of 0.8, 8, 10, 20, 40, 60, 100 FTU were prepared starting from a 400 FTU stock solution.

The measurement with the MultiOptics instrument was carried out according to the following steps:

• Put cuvette with pure deionized water and relief of the response of the two LDRs (scattered, direct) with red, green, blue and white light;

• Put cuvette with the solution at known FTU and relief of the LDR response at 90° (scattered) with red, green, blue and white light;

• Calculation of the variable:

$$R = 10\frac{I_s}{I_{d0}}$$

Where:

I_s is the intensity of light measured by the LDR at 90 ° (Scattered);

I_{d0} is the intensity of light measured by the LDR at 180 ° with pure water (Direct);

Figure 9 shows the graph of R versus FTU for the different colours.

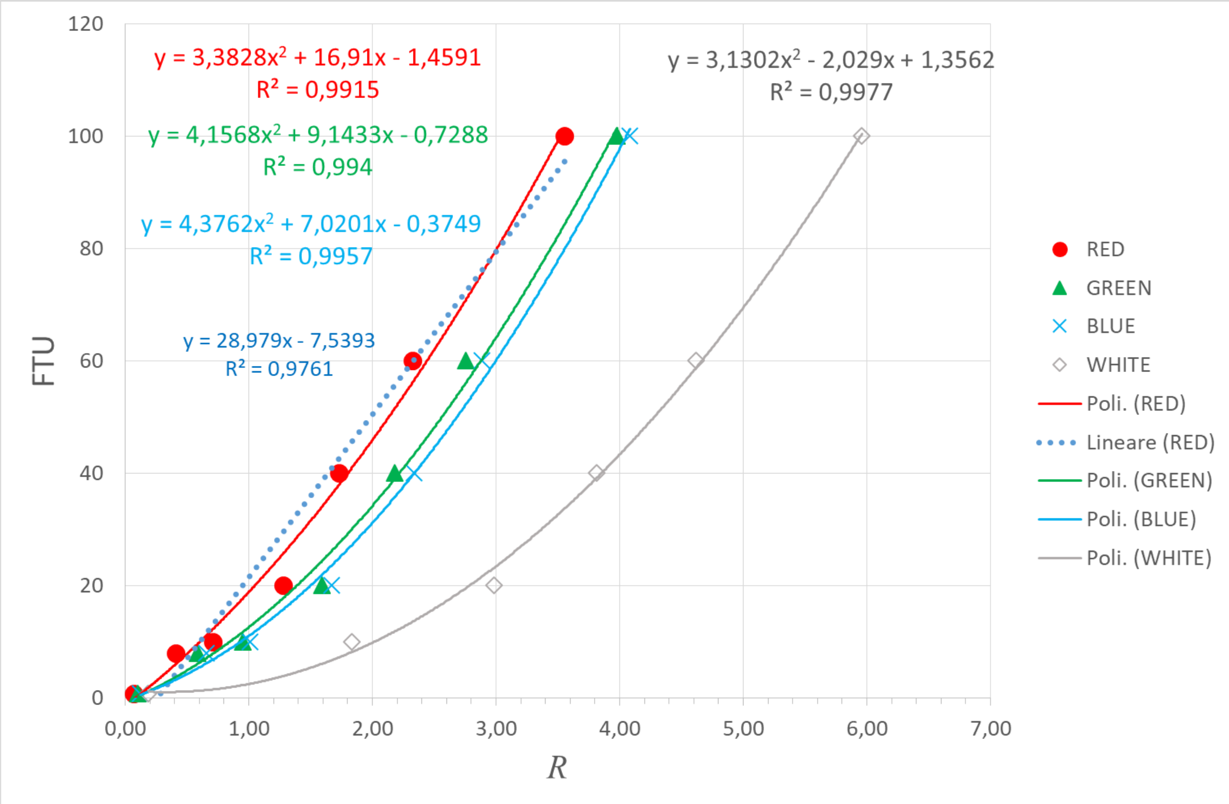


Figura 9

The interpolating curves, all second degree polynomials, were calculated without introducing the point 0,0.

It is evident from the graph that the greatest sensitivity occurs with white light, so this calibration curve has been adopted in the software of MultiOptics.

The non-linear trend of the interpolating curves could be caused by the combined effect of scattering and absorption. In fact, the greater the turbidity, the greater the absorption of scattered light as it travels through the cuvette. This phenomenon is negligible for low turbidity, but becomes important for high ones. The quite large dimensions of the cuvette compared to the standard ones of commercial instruments amplifies the effect of absorption.

Orthophosphate

For this measurement, two reagents are used which, mixed with the water sample to be analyzed, give a blue color of varying intensity with the concentration of orthophosphate (reactive phosphate).

For the calibration of the instrument, solutions of 30, 100 and 200 µg / L (ppb) were prepared with the addition of ammonium molybdate reagent.

The measurement procedure in MultiOptics consists in calculating the logarithmic absorbance of direct light in the various colors. The absorbance quantity follows the formula:

$$A = -log_{10} \frac{I_d}{I_{d0}}$$

Where:

I_d is the intensity of light measured by the LDR at 180 ° (direct light);

I_{d0} is the intensity of light measured by the LDR at 180 ° with pure water.

The graph in Figure 10 shows the Absorbance trend for light in the various colors and for the three concentrations of orthophosphate. In this case the red light curve has the greatest output variation with the same concentration variation. This curve has been adopted in the MultiOptics software.

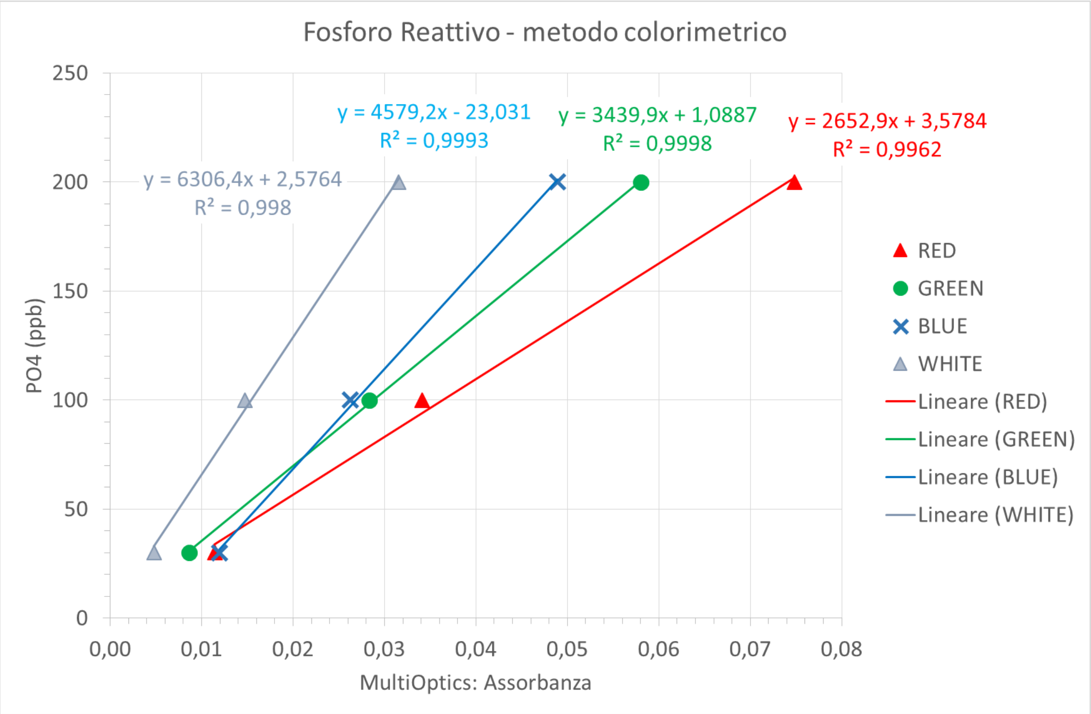


Figure 10

Assembly

MultiOptics is easily built with a Laser-cut machine, a soldering iron and wiring equipment. The case consists of:

• a console containing Arduino, the display, the switches, the battery (see previous figures);

• a cell holder, painted black, which is positioned on the back of the console, containing the photoresistors and the RGB LED arranged as in figures 11 and 12;

• the breadboard-like base with the electronic components of the diagram in figure 14 soldered, fixed to the cell holder by means of shims and screws in order to leave the necessary space for the cover (Figure 13).

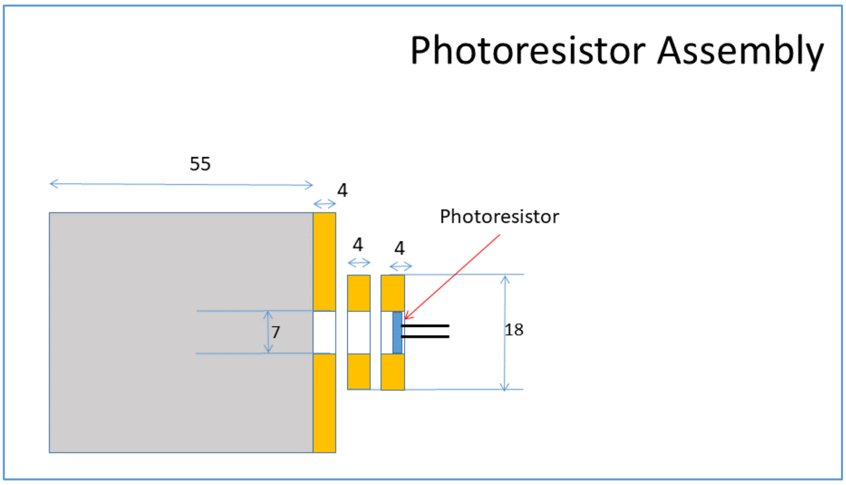


Figure 11 – Arrangement of the photoresistors on both sides of the cell holder.

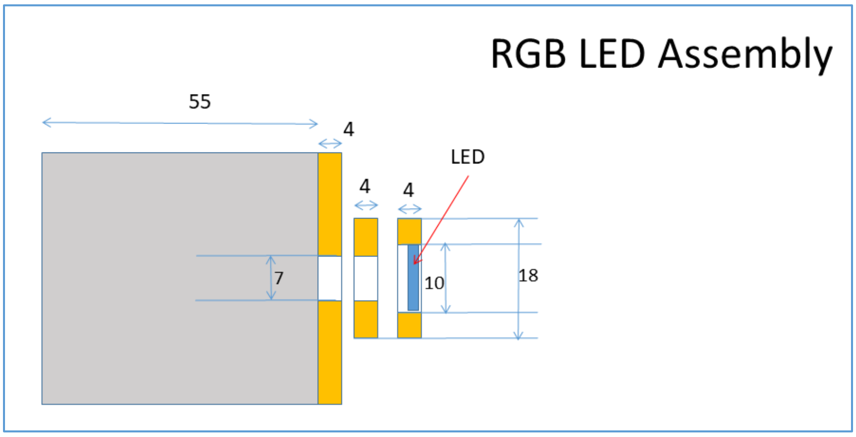


Figure 12 – Arrangement of the RGB LED on one side of the cell holder

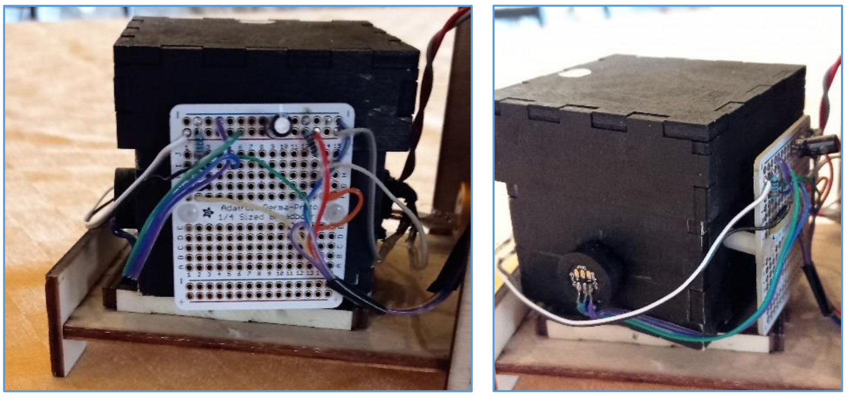


Figure 13

The other electronic components are connected according to the scheme in Figure 15.

MultiOptics console and cell holder are made of 4 mm thick plywood. The console, once assembled, must be painted with a waxy impregnating paint, while the cell holder with black paint.

The vector files for the wooden structure can be downloaded from:

https://github.com/paolometeo/MultiOptics

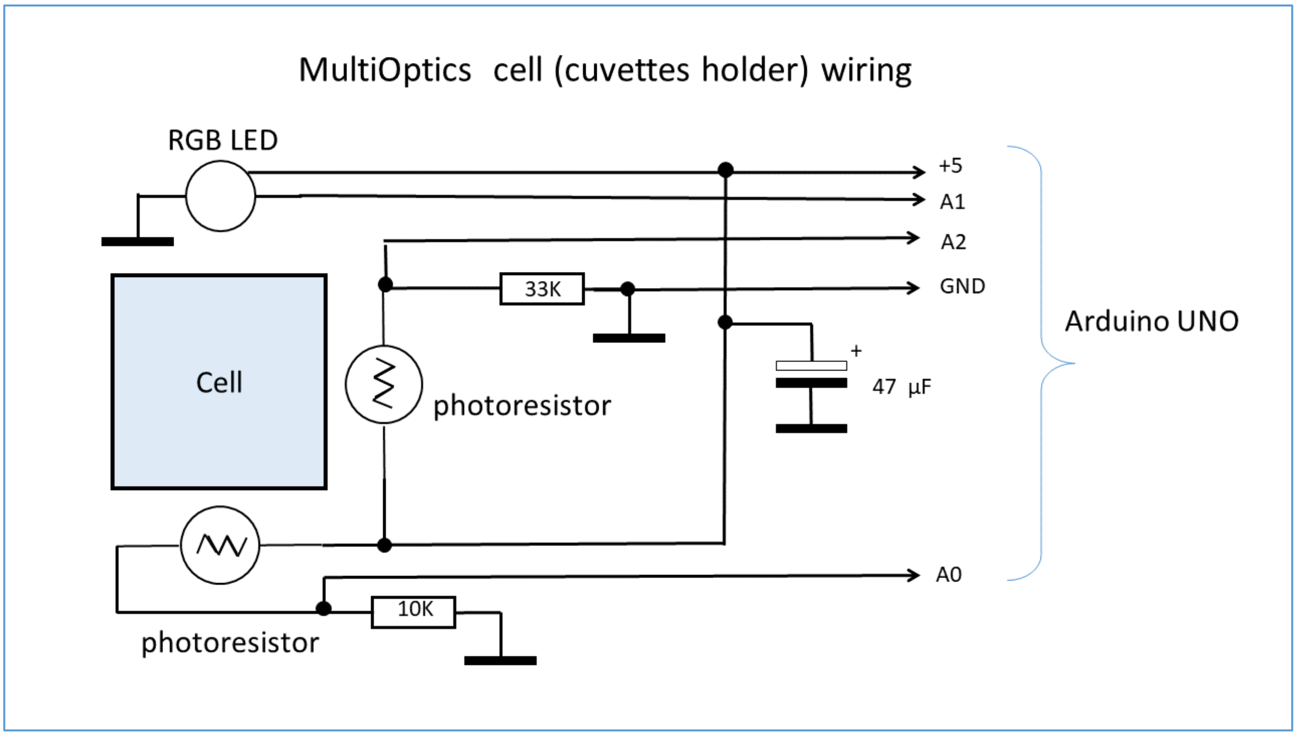


Figure 14

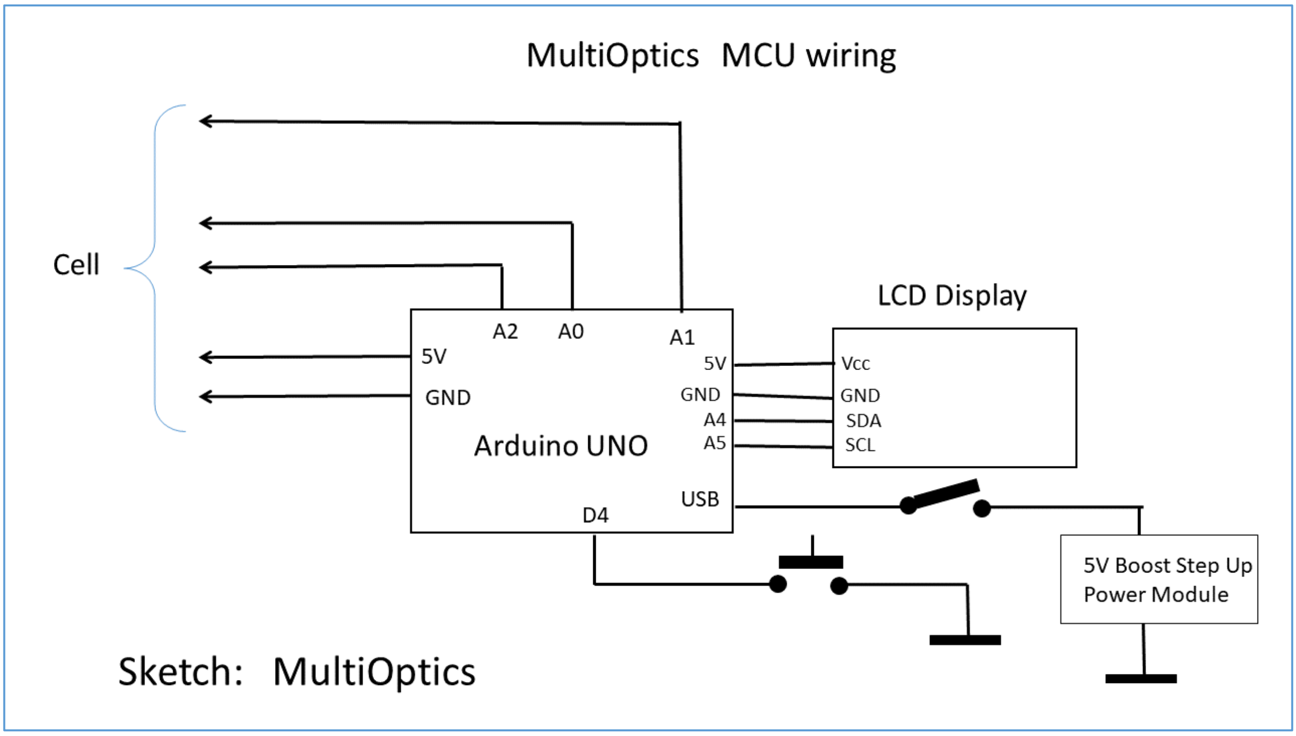


Figure 15

In order to make the connections between the ARDUINO UNO board and the other components easy, a shield was mounted on the Arduino with a row of 15 "female headers" as in figure 16.

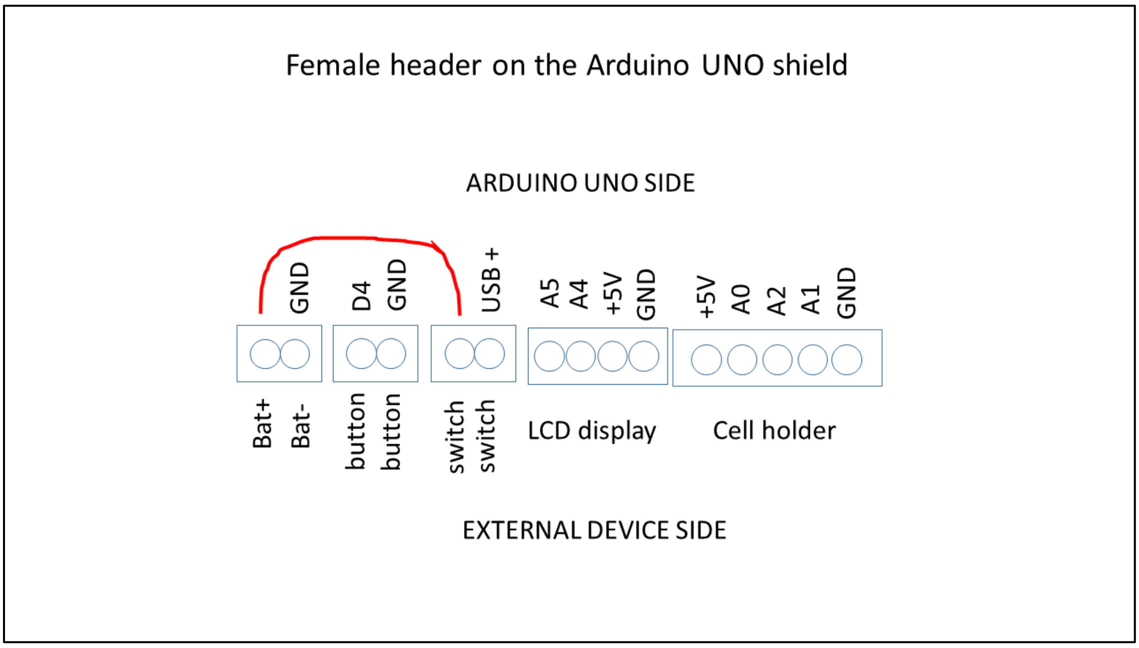
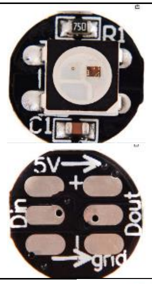
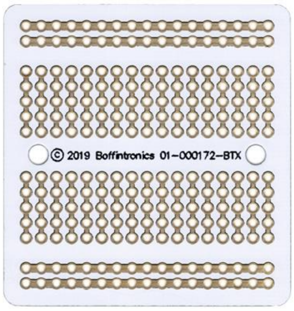


Figure 16

Component list

n	component	Image	Where to buy (just a suggestion)	notes
1	Plywood 4 mm			the dimensions depend on the laser cut
2	Square Transparent Plastic Small Box Crystal Candy Food Packaging Box Wedding Candy Box for Kitchen Tea Sugar		www.aliexpress.com/	5.5 cm
1	Arduino UNO board		everywhere	

1	LCD I2C display 16 x 2		https://italian.alibaba.com/product-detail/LCD1602-with-I2C-LCD-display-1602-62428411429.html	
1	Push button switch		www.aliexpress.com	Normally off
1	One way switch		Farnell.com	
2	photoresistor		https://www.aliexpress.com	
1	BTF-LIGHTING WS2812B ECO RGB Lega 5050SMD Chip LED		https://it.aliexpress.com/	
1	LiPo battery 3.7 – 4.2 V 16850		https://www.aliexpress.com	

1	5PCS 5V Boost Step Up Power Module Lithium LiPo Battery Charging		https://www.aliexpress.com	
1	10K resistor ¼ W			
1	33K resistor ¼ W			
1	47 µF electrolytic capacitor 16V			
1	Solder breadboard 170 plates		https://www.addicore.com/Boffintronics-Solder-Breadboard-170PR-p/ad512.htm	
	LiPo battery 16850 holder		https://www.digikey.it	

Conclusions

MultiOptics is a low-cost instrument but with a lot of technology inside and demonstrates how it is possible today to design and build analytical tools using open source electronics.

Certainly an important topic is the calibration of this type of instrument, which can be faced with inter-comparisons with professional instruments, or by calibrating methods that use secondary standards that are easy to find and inexpensive, as described above for turbidity.

Therefore, the collaboration between makers and research centers independent of market logic is essential to pursue the goal of disseminating measurement tools to citizens to be used in Citizen Science projects.

MultiOptics can be used in measurement campaigns directly on site to discover anomalous pollution events of surface or ground water, such as rivers, lakes, wells and springs.

Citizen Science in the environmental field is an opportunity for the cultural growth of citizens, of any age, who, by learning and practicing analysis techniques, are thus able to better understand the many data and information circulating in this field.

The data collected from citizens, properly validated, can usefully supplement those of the competent institutions responsible for environmental control.

The groups of makers and FabLab networks constitute an important starting point for the development of tools such as MultiOptics, thanks to the enormous amount of knowledge and software available today for free.

References

https://www.appropedia.org/Open-source_mobile_water_quality_testing_platform

https://makeabilitylab.github.io/physcomp/sensors/photoresistors.html

https://www.mauroalfieri.it/elettronica/fotoresistenze-e-arduino.html

https://www.idrolab.irsa.cnr.it/wp-content/uploads/2015/04/p_po4_v3.pdf

https://github.com/paolometeo/MultiOptics