Continuous on-site monitoring of water conductivity/temperature with a homemade Open-Source, Arduino-based instrument useful for education and research

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Abstract

As early as 1851, papers [1] were published that studied conductivity as an important parameter for monitoring water bodies such as: drinking water sources, irrigation water, heating water, water for industrial uses, and wastewater.

The measurement of conductivity, together with that of pH, is now a fundamental parameter for the characterization of water bodies.

In 2005 a complete microcontroller board, called Arduino, was born in Italy, in a former Olivetti study and research laboratory. To date it is impossible to enumerate both hobbyist and professional projects based on Arduino.

The one presented here is a working instrument for measuring, spot or continuous, the conductivity of an aqueous solution based on Arduino UNO R3 widely used in laboratory [2] and consisting of 2 printed circuit boards (PCB) containing only passive components, using for the electrodes two 316L stainless steel spirals, inspired by the circuit described by L.G. Smith in 1952 [3].

The instrument is truly Open Source since all the wiring diagrams, PCB construction drawings, wiring, and even the management and calibration software are provided free of charge.

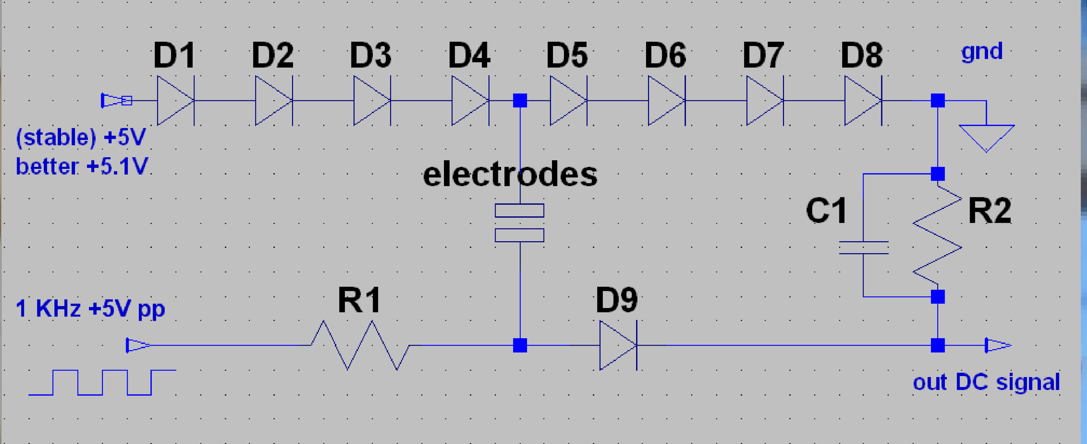

Fig.2, the simplified interface circuit of the PCB shown as c) in fig.1, with D1-D8=1N4448, D9=BAT54A, R1=1KΩ, R2=1MK Ω, C1=10nF

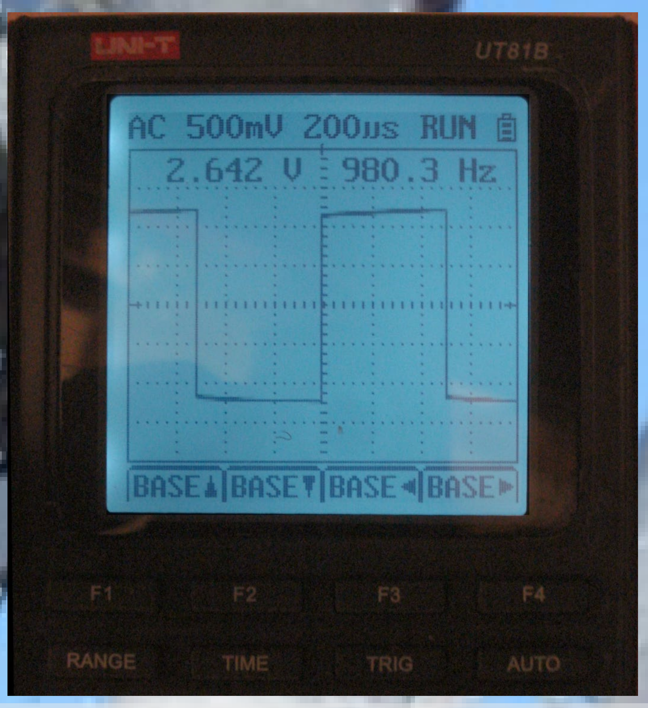

Fig.3, the waveform on the electrodes, in MilliQ water, measure by handyscope UNI-T 81b. The square wave is as expected symmetric over 0 V (using x1 probe with 10Mohm impedance)

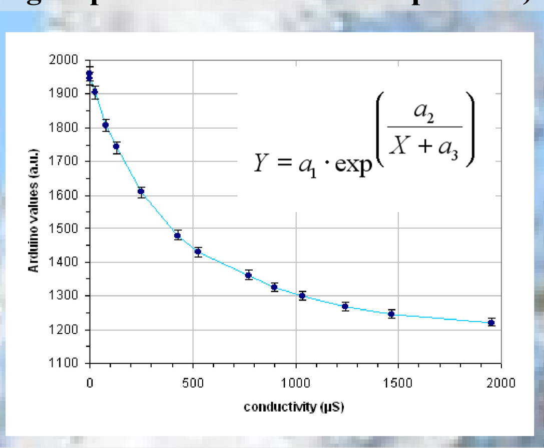

Fig.5, calibration curve and the fitting equation. Similar curve was often obtained as example during calibration of a NTC temperature sensor.

Brand (label)	Value by reference (uS)	Value by Arduino (uS)	Error (%)
Distilled	1.23	1.66	-34.9
Valmora	67.76	67.61	.2
Santa Croce	197.61	194.98	1.3
Tullia	267.01	262.79	1.6
Sorgesana	397.34	386.36	2.8
Nepi	638.65	601.76	5.8
Sveva	1174.44	1113.38	5.2

Tab.1, some data on sample used for the, the error % was evaluate using the leave-one-out method

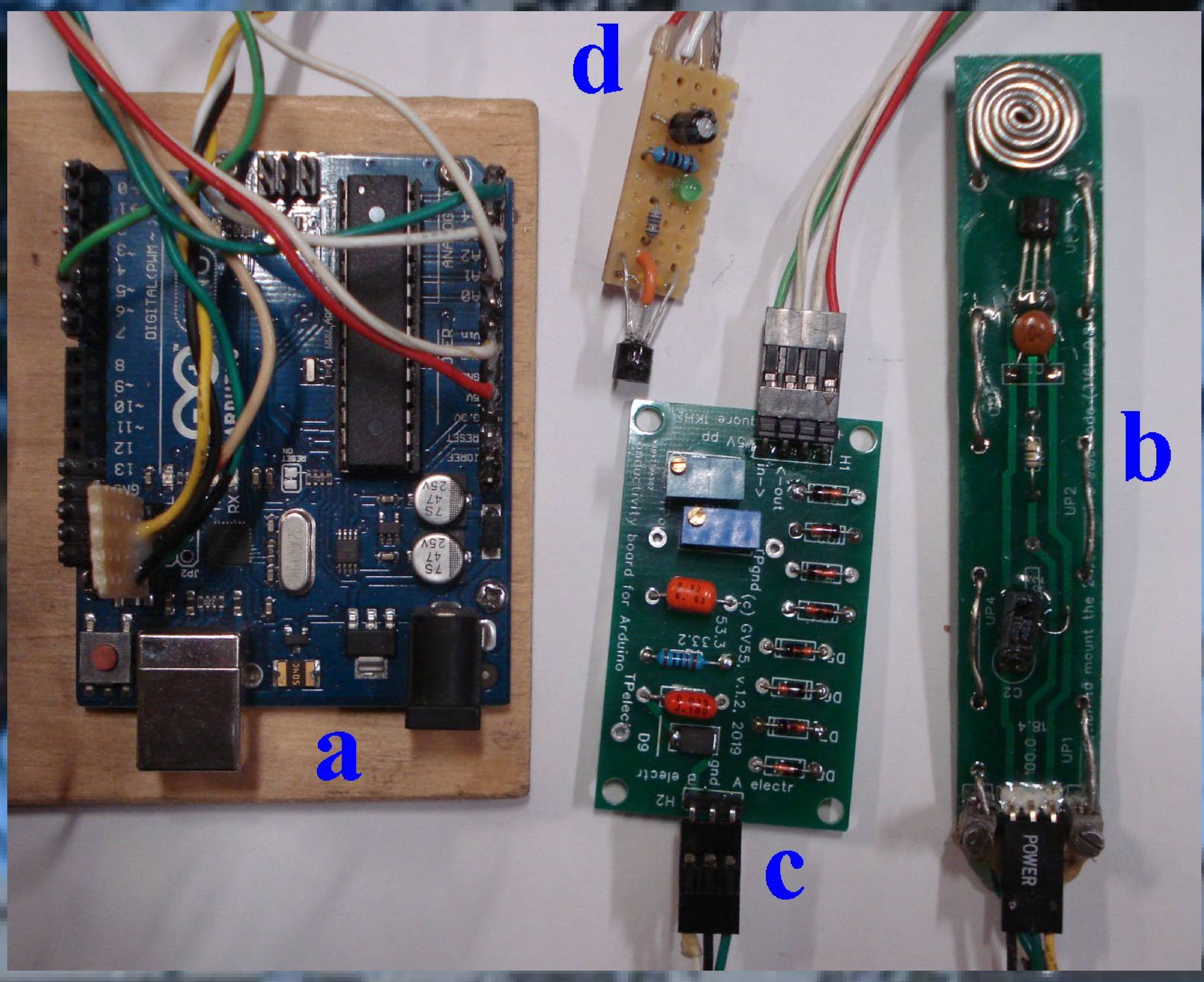

Fig.1 – Photo of the instrument: a) Arduino board with connections, b) electrodes PCB with 361L spiral and temperature sensor, c) electrodes interface PCB, d) air temperature PCB

Introduction

One of the goals of the Arduino teem, fig. 8, was to democratize the use of microcontrollers but, unfortunately, this has produced thousands of projects that are completely wrong in design and implementation.

A web search until June 2022, with the string "arduino conductivity" yields over 700,000 results.

Unfortunately, the first five are also wrong because they both use DC voltage and some wires as electrodes.

The main problem of these 700,000 links is the lack of "chemical correctness" and "accuracy": starting from the inertness to chemical agents of the electrodes, passing through the signal applied to the electrodes and ending with the calibration and accuracy of the measurements; further, no data on the reproducibility and reliability of the measurement / instrument are reported.

Aim of the project

With the aim of filling the gaps highlighted in the introduction, we decided to build an inexpensive conductivity measuring device to be used first in a laboratory exercise for our students and, after a few updates aiming to increase its accuracy and reproducibility, in routine measurements in any type of laboratory or for industrial control.

The original version of the project was submitted for publication [4] and is already functional enough to be used in the monitoring of a water body

An evolution of it is presented here, Fig.1, with the measurement also of air temperature and better shielding of wiring, always as a true Open Source that anyone can reproduce and update to suit their needs.

Strategy

Our idea was inspired by L.G. Smith's article "On Calibrating Conductivity Meters" from 1953 [3]. Fig. 2 shows the simplified circuit which, like Smith's, involves the voltage measure between the electrodes, after transforming the AC voltage into DC voltage, and with R1 used as a current limiter.
A printed circuit, that uses only passive and easy to find and assemble components, has been designed (c) in fig. 1); it acts as a bridge between the Arduino (a) in fig. 1) and a conductivity cell (b) in fig. 1), the last will be further described on.

The Arduino easily produces DC voltages of 5 and 3.3V and pulses from 0 to 5V at intervals of a few milliseconds to minutes; it also produces impulsive signals with modulation (PWM) at a frequency of about 500 and 1000 Hz with duty cycle up to 256 levels. In any case the signal is a square wave between 0 and 5 V but, unfortunately, it is not possible to produce a symmetrical voltage centred on zero (e.g. -1.5, 0, +1.5), necessary to obtain the AC.

Therefore the circuit of Fig. 2 is required to: 1) produce an alternating voltage oscillating on 2 stainless steel electrodes, using a frequency of 1000 Hz as in fig. 3, 2) measure the voltage or current on the electrodes from which conductivity can be obtained by means of an equation.

Material & Methods

As conductivity reference meter the Mettler Toledo S470 Seven Excellence equipped with InLab 731 ISM cell was used, calibrated using 3 standard solutions (Merck, XSinstrument).

The electrodes are made of a spiral-wound 0.8mm 316L stainless steel wire (fig. 4) and mounted on the 100mm long PCB which also houses the MC4701A temperature sensor and some passive components. Between Arduino UNO R3 and the electrodes there is the interface board, c) in fig. 1.

For calibration at least 15 points should be used: a series of mineral waters with different conductivity, 3 standards and some distilled waters.

All calibration measure were carried out by immersing the cell in the water samples, maintained at 20.0 ± 0.2 °C using a Julabo UC-5B/5 thermostatic bath. Each water should be measured either with the Mettler conductivity meter and with Arduino obtaining a calibration curve similar to that in fig.5.

The continuos on-site monitoring was carried out by partially submerging the PCB with the electrodes in a beaker in which cooling water from a distiller flowed continuously, distiller turned on and off during the experiment.

For "in situ" measures, the temperature must be accurately recorder to permit the correction of the conductivity value through apposite conversion tables [6].

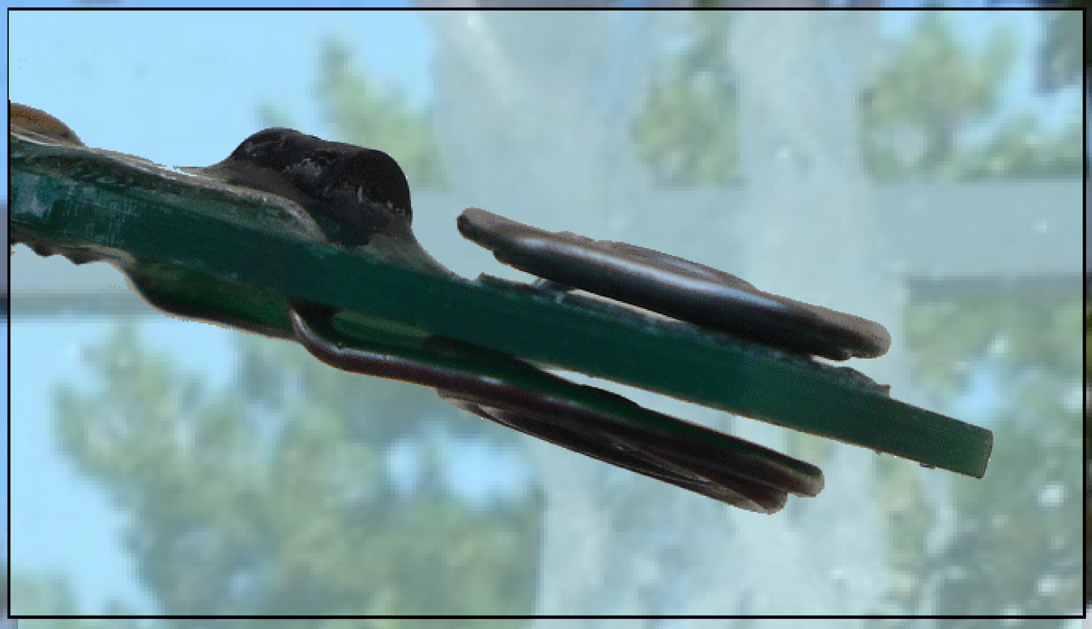

Fig.4, The macro photo of the 2 inox spirals fixed on the two sides of the PCB, the black component is the temperature sensor. To isolate from water all the PCB, excluding the spirals, was immersed 2 times in Araldite resin.

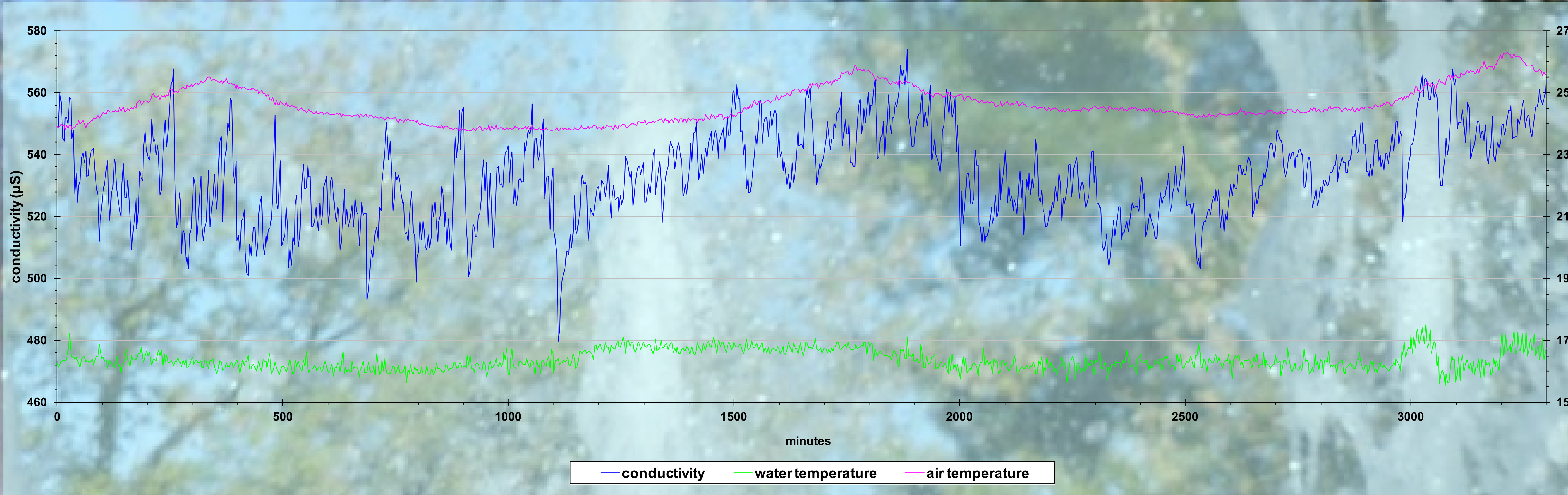

Fig. 6, runplot of the three parameters measured during a 3-day monitoring of the tap water contained in a distiller chamber. The water flow in a 5L container with immersed the b) PCB of fig.1. At about 1200 min the distiller is switched on and consequently the conductivity rises, at 1800 the distiller is switched off. Close to 3000 min. we can see a quick on and off switch. The purple curve is the air temperature not affected by heating.

Results

The use of a PCB for the electrode makes it possible to construct a reproducible cell in which it is also possible to vary the number of turns according to the conductivity to be measured.

However, it needs a calibration and the classic one mentioned in the p.28, 2.39 of BIPM [5] cannot be used, the procedure of p. 48, 5.5 note 2 [5] know as "secondary measurement standard" must be followed which requires a good number of known samples.

Fig.5 shows the calibration curve obtained using the cell shown in Fig.4. Given the calibration, the percentage error can be estimated by randomly choosing a few samples as unknown, results in Tab.1.

Monitoring a stream of water for 3 days yields the graph in fig.6 in which we see that the sensitivity and the response speed of the instrument allow to "read" the faint changes in conductivity due to the temperature changes.

Conclusions

With a few euro, 20 in our simulation, anyone can construct a robust cell and a small passive circuit that coupled with an Arduino UNO, let to perform conductivity/temperature measures from few up to 2000 µS in water.

Since the prototype respects both the concept of the law on which the measure bases and the analytical rules, its construction and use can be considered a first approach to electrochemistry and electronics if used in didactic lab exercises (and C programming).

The proposed instrument use one of the more accurate but inexpensive temperature sensor for air and water that is an important parameter influencing conductivity.

For far away monitoring the external circuit can be upgraded to obtain a more robust noise rejection but without compromise the oversampling.

Also the software, free, can be upgrade to modify some functions and adapt it to different monitoring, or produce a self-containing instrument (with battery, SD card, Bluetooth …)

Fig.7, QR code to obtain .ZIP file with sketch software to be upload on Arduino board and some photo

Fig.8, All of makers and electronics users, also teachers must thank to the Team that developed the Arduino board widely used in didactics.

References

1) Bakewell, F. C., "On the conduction of electricity through water", *Journal of the Franklin Institute* 52(4), 1851, 283
2) J.P. Grinias, J.T. Whitfield2, E.D. Guetschow, R.T. Kennedy, An Inexpensive, Open-Source USB Arduino Data Acquisition Device for Chemical Instrumentation, *J. Chem. Educ.*, 93(7), 2016, 1316-1319
3) Smith, L. G., "On the Calibration of Conductivity Meters", *Review of Scientific Instruments* 24, 1953, 998
4) M. P. Sammartino, M. Tomassetti, E. Dell'Aglio, L. U. Fontanella, G. Visco, Conductivity Measurements using an Open-Source, Low-Cost Apparatus, based on Arduino and coupled to a Handmade Cell, useful for both research and didactic, MAPAN Journal, submitted 2022
5) BIPM, Vocabulaire international de métrologie – Concepts fondamentaux et généraux et termes associés (VIM), JCGM/WG 2 Ed., 2008
6) ISO 7888:1985, Methods of Sampling and Test (Physical and Chemical) for Water and Waste Water, Part 14 Specific Conductance (Wheatstone Bridge, Conductance Cell), Second Revision, IS 3025 (Part 14):2013

Acknowledgment

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