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Measurement of surface respiration: An IoT approach

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Summary. — This study investigates an approach to measuring surface gas fluxes based on the Internet of Things technology. A wireless self-powered, low-cost, low-power, cloud-connected device is designed to record humidity and carbon dioxide concentrations at multiple points. The manuscript describes the concept and realisation of the device, the hardware chosen and the data communication chain. The manuscript also discusses a preliminary evaluation of the performances of the prototype in a controlled environment, together with major strengths and limitations.

1. – Introduction

In recent years, a novel technology has spread over multiple scenes of human life: the Internet of Things (IoT). The IoT is based on devices (things, nodes) connected to the cloud, to be used both for metering and control, with a novel hardware and data management design [1]. Such a technology, commonly addressed to industrial and consumer applications, may be extremely useful in research fields sensitive to the scale of time and space. Because of a reduced development time, the growing availability of commercial off-the-shelf components and the spreading of networking infrastructure, IoT allows for a continuous increase of points and frequency of observations. In this study, we considered the possibility of using IoT technology to develop a device for the estimate of gas exchange of natural surfaces. Two of the most important gas considered from research in atmospheric and ecological research are water vapour (WV) and carbon dioxide (CO_2). Fluxes of WV and CO_2 are often considered separately —the former is commonly referred to as EvapoTranspiration, and mostly used in the estimate of water budget for crops (for irrigation purposes), while the second is used to estimate carbon fixation from vegetation (primary production) and soil (micro-organism) respiration. In a climate-change scenario, monitoring CO_2 and WV concentrations and flows at the same time is of increasing interest [2]. To date, the estimate of such flows is based on software tools as InVEST [3], relying on data collected by expensive or complex devices (*e.g.*, eddy covariance towers, respiration chamber) that limit the survey to a few points of surface (preventing mapping) or continuous monitoring (satellites) [4]. In the last decade, we saw an explosive increase of availability of Commercial Off-the Shelf (COS) of sensing technologies [5] allowing the development of low-cost devices [6]. A technology particularly interesting is the one of non-dispersive infrared (NDIR) sensors - cheap and reliable sensors are available from several makers [7]. Recently, a rising interest is oriented to wireless low-power technology [8], focused on the development of long-lasting devices. Such a kind of devices is today connected to the internet and a cloud computing system that allows perceiving devices as *things*, becoming part of a growing ecosystem known as the Internet of Things (IoT). In this study, an IoT device has been addressed to the measurement of CO_2 and WV concentrations in a scalable manner. In the following sections, we formerly describe the design criteria, components adopted and the assembly, then we discuss the former performances in a controlled environment, and draw conclusions.

2. – Design and realisation

The device, named ETRometer, has been designed to operate in the open air for a long time, therefore the following requisites have been chosen: internet connectivity, low-cost, low-power, self-powering, easy assembly, open source software, real-time data accessibility and long-time easy data access. Also, the ETRometer should be used to monitor at the same time the concentration of WV and CO_2 in independent contexts, as in the case of respiration chambers, or to estimate fluxes.

About the low-cost and open-source requirement, the Arduino-compliant board family has been analysed, and the choice has fallen on ESP32 [9]. The controller is easily powered (3.3 V, 5 V) and allows for a standby mode (deep-sleep) allowing keeping only the internal RTC alive, to be operated as an alarm clock —it also includes more than 30 programmable I/Os with Digital-to-Ananlog and Analog-to-digital capability, more than 500KB ROM and RAM, and embedded Wi-Fi.

The sensor chosen for the application is the Sensirion SCD30 [10], coupling an NDIR sensor for CO_2, and a combined Temperature and Relative Humidity sensor. The ETRometer has been designed to include 6 of them, which are connected to the controller by a I^2C multiplexer. A MOS-FET component has been used to switch off the peripherals (sensors and other electronics) while the controller is in deep-sleep mode. The power is provided by a Li-Ion battery kept charged by a solar PV cell of $\sim 1\,\mathrm{dm}^2$ (see fig. 1).

One of the most interesting features of Arduino-compliant controllers is easy firmware development and upload by the Arduino platform (based on C language and plenty of libraries for working with different boards). The code embedded in ETRometer starts warming-up of $SCD30$s, reads sensor values, connects to the $WLAN$, reads the current

Fig. 1. – ETRometer with the 2 bars hosting the 3 SCD30s each.

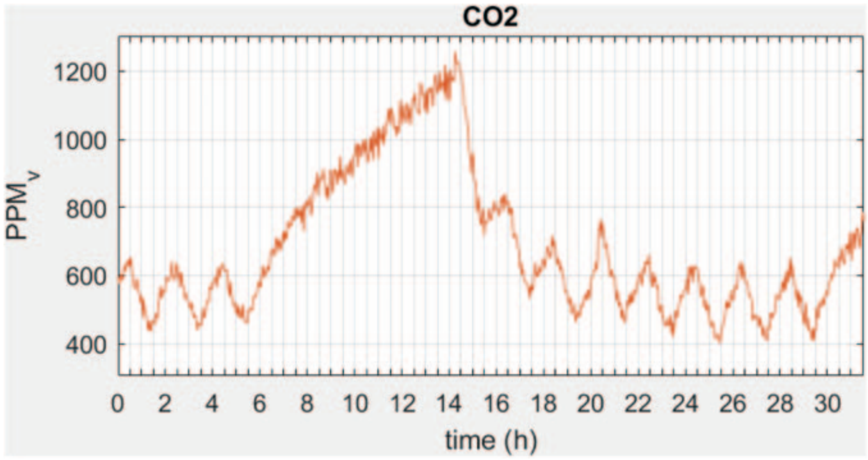

Fig. 2. – Trend of CO_2 in a plant populated growth chamber subject to a cycling light.

date&time from a NTP server, assembles an $MQTT$ message, connects to the $MQTT$ broker and sends messaging, then disconnects from the network, switch off every peripheral (sensors and support electronics) and puts the system in deep-sleep mode.

The $MQTT$ protocol has been chosen because it is one of the more diffused broker-based services in the IoT landscape. The $MQTT$ service manages messages by topics and broadcasts them from/to authenticated clients. Recent message standards as FIWARE, beside suggesting using Json-coded messages, encourages the use of Smart Data Models [11], which are also useful in composition frameworks [12]. As $MQTT$ does not manage data persistency, a $MQTT$ client has been developed to capture the messages sent from ETRometer and append them to a local file for further analysis. A dashboard (web app) has been finally developed (HTML/CSS/JS) to monitor the device online and display the trend of recorded values.

3. – Testing performances

The device has been tested in open-air environment to test the capability of keeping the battery in charge under several duty cycle measurements and variable cloud conditions. A duty cycle of 1/20 (one reading lasting 1 min each 20 min) may be easily kept with one Li-Ion battery during the summer, while a larger PV cell and more batteries should be required in cloudy periods. The ETRometer performances have been further evaluated in closed chambers.

In fig. 2, it is possible to see the trend of CO_2 in a grow chamber hosting vegetation, with a grow lamp cycling with hourly frequency and a dark period (central zone), showing the corresponding Fluctuations of CO_2 partly due to the sensitivity to temperature of SCD30s (due to lamp radiation) and to photosynthesis.

4. – Conclusion

In a few years, IoT promises to transform our lives, as well as the way of doing research, allowing us to reduce costs, and increase spatial coverage and frequency, to develop new observation networks and enrich the existing ones.

IoT is going to introduce the concept of "measurement" (embedded in physics) outside the world of research. IoT is offering plenty of recipes, ready to be used in STEM, whose interest is growing in schools of several levels.

The ETRometer appeared to be a device easy to be assembled and used, and reliable despite the low costs of its components.

Though the current version of ETR could suffer the limited availability of WLANs, few changes may allow rely on growing Narrow Band infrastructures (*e.g.*, Sigfox).

SCD30 sensor appeared robust enough but it still misses a valid automated calibration procedure allowing obtaining reliable values for experimental scientific experiments.

Comparison with other experimental techniques and devices by standardized experimental trials is considered for future development.

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