A Method to Implement a Monitoring System Based on Low-Cost Sensors for Micro-environmental Conditions Monitoring in Greenhouses

Elio Romano, Massimo Brambilla, Pietro Toscano and Carlo Bisaglia

Abstract The precise monitoring of the inner microclimate of a greenhouse implies an increase of the production costs following the expensive needed sensor arrays. Currently, there is availability of low-cost sensors and cards for data storage and processing, but their application in real scale facilities is still under study. This research aimed to find a solution to manage and implement the outcome of various information (i.e. luminosity as well as air humidity and temperature) on the internal environment of a tunnel greenhouse to point out the most critical dynamics occurring during the growth cycle of basil plants in summer. Placing low-cost sensors inside a tunnel greenhouse made it possible to acquire data with an adequate rate (0.1 min^{-1}) and spatiotemporal distribution throughout the facility. Data storage and processing took place thanks to an on purpose created weather station based on Arduino Yun Rev2 board. The highest variability of air temperature and moisture inside the greenhouse occurred when the solar radiation begins to heat the cover of the greenhouse (between 6.00 and 7.00 AM) and few hours after the maximum peak of solar radiation (843.4 ± 133.3 W/m^2). Low-cost sensors combined with spatial fitting of the data provided insights about the effective microenvironmental conditions occurring on daily basis. This, implemented with IoT technologies, will be the base for the realization of economic monitoring systems.

Keywords Air temperature · Air moisture · Protected crops · Arduino board · Remote control

1 Introduction

Greenhouses, protecting plants against diseases and adverse environmental conditions, represent a feasible solution as they make it possible to control the optimal temperature for crop cultivation (Oliveira et al. 2016). However, changes in climate

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can interact with other greenhouse stressors and affect plant growth, yield and quality of produce (Gruda et al. 2019).

Researchers have shown an increased interest in monitoring greenhouse temperature using different sensor configurations, hardware architectures, and control techniques (Shamshiri et al. 2018) as the non-uniform distributions of microclimate parameters affect the greenhouse environment impairing crops' production and quality. Temperature and irradiation are considered as two major factors relating to microclimatic effects (Ahemd et al. 2016).

Currently, monitoring greenhouse temperature is complex in terms of sensing technology (Postolache et al. 2012). Increasing the number of installed sensors, if on the one hand results in improved monitoring capacity, on the other causes engineering and management costs to increase. Furthermore, the sensors' exposure to environmental factors (e.g. direct sunlight and humidity) may lead them to malfunction or damage with unexpected failures and economic damage for farmers. Environmental modelling and virtual sensing may represent a solution to this (Guzmán et al. 2018) provided that high calculation power is available (Carvajal-Arango et al. 2016). The sensing concept has enabled the production of robust, small, and reliable low-cost sensors that, conveniently connected to any hub (e.g. Arduino and Raspberry boards), make it possible to implement a monitoring network with reduced power consumption, maintenance and complexity (Sowmya and Praveen Sam 2018).

The presented study deals with the set-up of a simple, low cost, Arduino based system to monitor the environmental parameters in a small-scale greenhouse to evaluate the feasibility of the low-cost sensors for the continuous monitoring aimed at achieving optimum plant growth and yield.

2 Materials and Methods

A greenhouse (12 m long, 2.5 m wide and 2 m high), made of a metal structure and with plastic covering, was set up at the CREA-IT facility of Treviglio (45°31′17.18 N; 09°33′50.82 E). Inside it, 24 pots of basil plants, grown in a substrate made of peat and perlite (50% v/v), were placed on a shelf 1 m above the ground high and as long as the greenhouse. It was subdivided into three longitudinal sectors (S1 and S3—lateral; S2—central), so that each sector had 8 identical pots.

The low-cost sensors used to monitor the greenhouse micro-environment were all based on the Arduino board (www.arduino.cc) and made it possible to measure air and soil moisture content and the amount of incident light.

The *YL-69* hygrometer sensor (Fig. 1a) assessed the soil moisture measurements. It measures the soil resistance (Rs), which is directly proportional to the moisture present in the soil (Kolapkar et al. 2016). To verify the difference in humidity of the soil between the sectors and in the same thesis, three humidity sensors have been positioned for each sector compared.

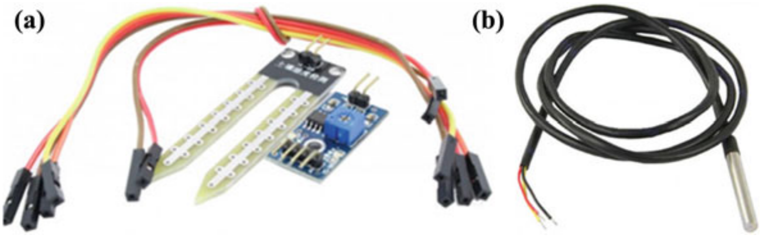

Fig. 1 The modules to measure the soil moisture content (**a**) and the probe to read the soil temperature (**b**)

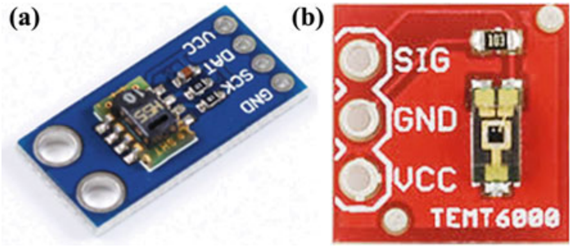

Fig. 2 The CJMCU-SHT10 sensor to read the air moisture and temperature (**a**), the TEMT 6000 sensor for light intensity measurement (**b**)

The *DS18B20* probe (Maxim Integrated Products, Inc., USA—Fig. 1b) measured the temperature of the growing substrate. Its precision is ± 0.5 °C in the range from—10 °C to + 85 °C The probe is made of stainless steel, however since it had to remain immersed in the ground, the surface was previously covered with a layer of Parafilm® (Bemis Company, Inc., USA). To study the homogeneity of the temperature in the ground over the entire observed surface and to detect any differences throughout the length of the greenhouse, three soil temperature sensors were inserted into just as many pots placed in the center of the shelf of the series in each sector.

The sensor *CJMCU-SHT10* (Sensirion AG, CH—Fig. 2a) made it possible recording air moisture and temperature. Both sensors were seamlessly coupled to a 14 bit analog to digital converter and a serial interface circuit. Three tunnel sections of 2 meters in length were chosen: within each section, six air humidity and temperature sensors were placed in three different heights from the shelf surface where pots were placed (30, 60, 90 cm).

The amount of incident light was monitored by a *TEMT6000* sensor (Vishay Semiconductor GmbH, Germany—Fig. 2b). It is based on a phototransistor that produces a voltage output between 0 V and +5 V that is directly proportional to the incident light.

Air temperature and moisture acquisitions occurred at the rate of 6 acquisitions per hour. The recorded data, after preliminary processing with MS Excel spreadsheet, underwent statistical processing using R software (R Core Team 2018) and Minitab 17® (Minitab 2010), to study averages, standard deviations and coefficient of variation (CV%). Analysis of variance followed by Tukey and Duncan post hoc comparisons ($p < 0.05$) were carried out on air and substrate temperature and air humidity. To study the distribution of the microclimate inside the greenhouse, the Surfer® software (Golden Software, LLC) was used for the realization of interpolated graphs through the kriging algorithm (Wackernagel 1995) after data standardization with respect to their average and standard deviation.

3 Results and Discussion

The top part of Fig. 3 shows the hourly average air and soil temperatures together with air relative humidity (RH). In the bottom one there are the hourly CVs of the same variable that allowed choosing the hours to study the occurring dynamics.

Soil moisture data could not be processed as the chosen sensor turned out to be very sensitive to the variations resulting from pot irrigation. As a matter of fact, to grow basil seedlings, fertilizing solutions with hydro soluble mineral elements were used. These might have caused a failure in sensor response causing it to misread soil moisture because of both the effect dissolved ions and solids have on Rs (Cloete et al. 2016; Roberts Alley 2007) and the unavoidable oxidation process that affects resistive sensors performance and lifespan (Yeow Tan et al. 2018).

Substrate temperature records were in the 16.6–36.6 °C range: the position of the pots along the greenhouse significantly affected the maximum average temperatures achieved in each sector (32.3 °C on average for S1 and S3 and 28.0 °C for S2) but it turned out not to be significant minimum averages (18.8–20.1 °C range). However, with reference to the hourly averages, it turned out that at 8.00 AM the high CV results from the difference between S1 and S3 (29.4 ± 3.9 °C and 26.1 ± 5.5) and S2 (23.2 ± 2.1) while at 6.00 PM the lowest CV comes from the substantial homogeneity of temperatures along the greenhouse (25.6 ± 3.8 °C, 25.8 ± 2.6 °C and 25.8 ± 4.0 °C for S1, S2 and S3).

Plotting the isocurves of the average t° and RH throughout greenhouse width and height made it possible to evaluate the dynamics of air temperature and RH distribution longitudinally and transversely to the greenhouse volume, (Fig. 4). As expected, the observed temperature and humidity showed two opposite behaviors. When the CV of micro-climatic observations was higher (8.00 AM and 3.00 PM for temperature and RH) the analysis pointed out a high variability of values lower than the related hourly average value. In the hours of minimum CV (6.00 PM and 5.00 AM for temperature and RH), in all the observed sections, the RH had a decrease in the areas most close to the average value, therefore to the zero value. The temperature instead showed the opposite, but with values higher than the average value.

As expected, such variabilities occurred when the solar radiation began to heat the cover of the green-house (between 6.00 and 7.00 AM) and few hours after the maximum peak of solar radiation (843.4 ± 133.3 W m^{-2}). The analysis of the variance carried out on the response values of the temperature and of the recorded humidity showed statistical significance for the effect of the position of the sensors both longitudinally and transversally. The Duncan test, conducted in both the directions of

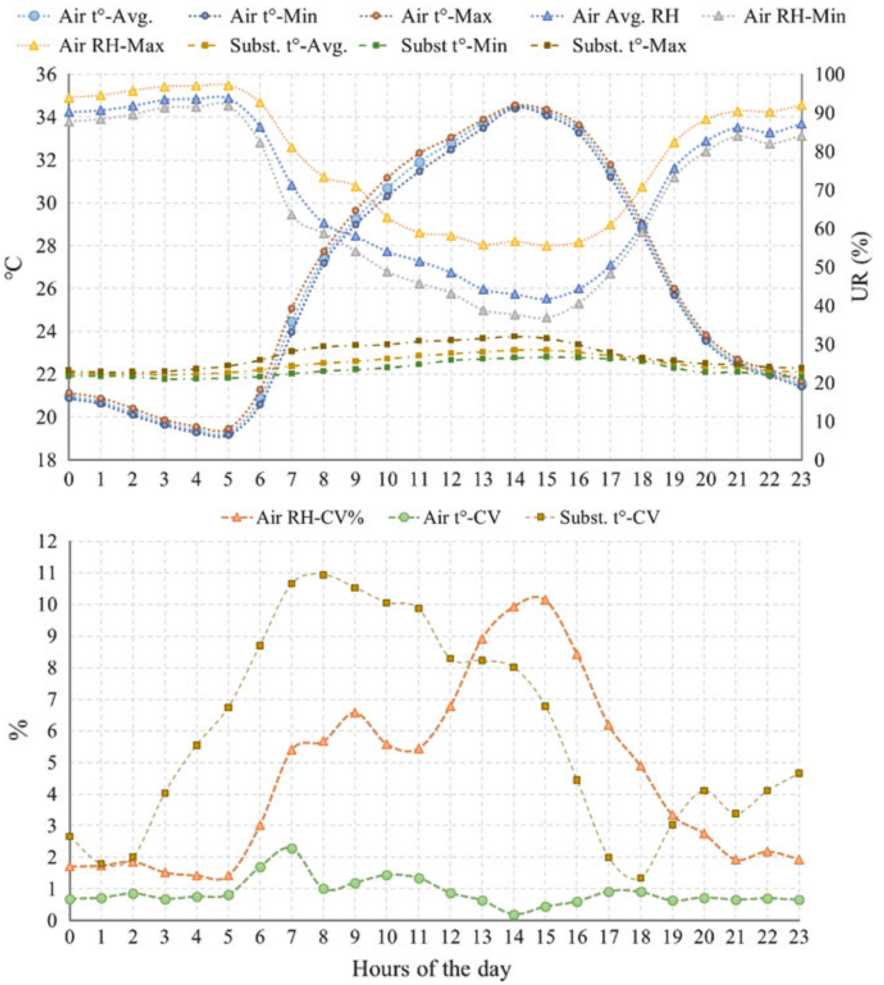

Fig. 3 Trends of average hourly temperatures of air and substrate and relative humidity of air (above) together with the related per cent CV (below) measured during the observation period

sensor's distribution, showed a statistically significant difference between the three sectors of the greenhouse.

The tests carried out with the *TEMT6000* sensor aimed to verify its capability in measuring the amounts of incident light. It resulted that: if, on the one hand, it could react very well to small light changes at sunrise and sunset, on the other, it was found not to be able to produce accurate during the daytime despite the reported successful application in agriculture (Ray 2018). In our case, in line with the findings of Gao et al. (2019), the reduced sensitivity range of the sensor, 0–250 lx (Kumar 2014) caused it to give rise to unacceptable illuminance deviation under direct sunlight when its response compares with the agrometeorological data from ARPA Lombardia (www.arpalombardia.it). However, with scattered sunlight, the algorithm the sensor

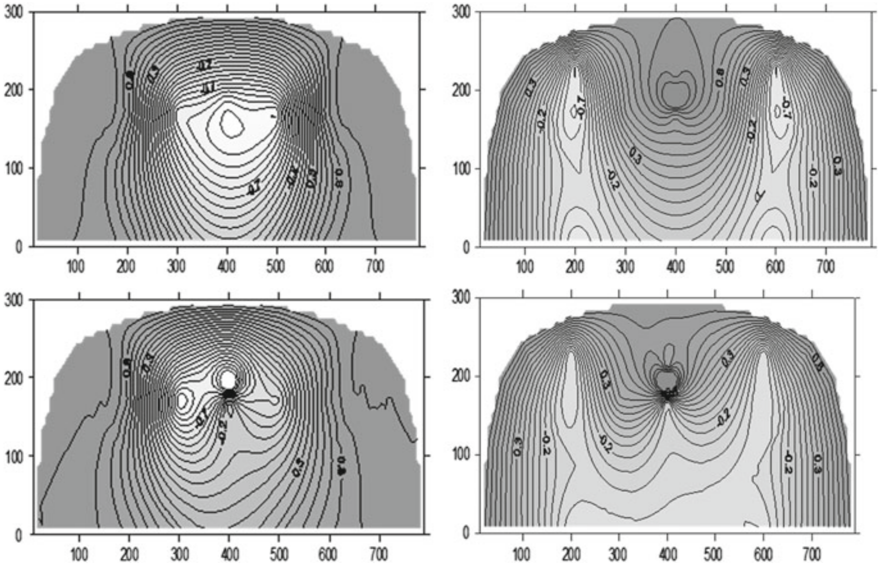

Fig. 4 Example of the distributions of air temperature (on the left) and humidity (on the right) throughout the central sector (S2) when the CV of the acquisitions was highest (above) and lowest (below). Horizontal and vertical axes report the width and the height (cm) of the inner greenhouse space

manufacturer proposes, followed quite well the illuminance trend even without cosine correction and this led us deepening the sensor responsivity in terms of mv lx^{-1} comparing the output of the sensor (mV) with the illuminance (lx) derived from the official data. The ANOVA pointed out that sensor responsitivity significantly changes during the day (Table 1) so that it can be possible setting up a specific calibration process for this sensor.

Table 1 The TEMT6000 average hourly responsivity (mV lx^{-1}). Means that do not share a letter are significantly different ($p < 0.05$)

Hour	mV lx^{-1}		Hour	mV lx^{-1}	
5	0.49 ± 0.25	a	14	0.014 ± 0.02	d
6	0.15 ± 0.06	b, c	15	0.023 ± 0.05	d
7	0.074 ± 0.03	c, d	16	0.021 ± 0.03	d
8	0.032 ± 0.02	c, d	17	0.032 ± 0.04	c, d
9	0.020 ± 0.01	d	18	0.054 ± 0.08	c, d
10	0.016 ± 0.02	d	19	0.086 ± 0.07	c, d
11	0.015 ± 0.02	d	20	0.214 ± 0.24	b
12	0.011 ± 0.02	d	21	0.37 ± 0.16	a
13	0.010 ± 0.01	d			

4 Conclusions

In this study the use of a low-cost Arduino based suite of sensors for greenhouse microclimate monitoring is presented. Based on the results, the system was able to detect the different conditions existing in each greenhouse sector during the day and to catch the dynamics of air humidity and air and substrate temperatures so that it provided insights about the effective microenvironmental conditions occurring on daily basis. However, further improvements of the system architecture need to be set up in particular with reference to data storage and processing that could be improved thanks to wireless connection and on line processing software whose results could support the farm management with IoT technologies. Further studies on sensor calibration are however required to better point out the reliability and the efficacy of this kind of sensors.

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