A Wireless Sensor Network to Study the Impacts of Climate Changes in Agriculture: The Coffee FACE in Brazil

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Abstract—**Climate change is considered one of humankind's greatest challenges in the near future. The climate change is expected to interfere in the scenario of worldwide agriculture. Its economic, social and environmental impacts can be positive, negative or neutral, since these changes can decrease, increase or have no impact on plant diseases, pests or weeds depending on each region or period of time considered. A type of experiment called FACE, Free Air Carbon-dioxide Enrichment, has been conducted in the USA, UK, Germany, Japan, Australia, Italy, Denmark, among other countries, to study particularly the impacts of the CO2 concentration increasing on crops. In Brazil, the first FACE experiment in South America has been installed by a group of scientists of Embrapa (Brazilian Agricultural Research Corporation). Compared to the existing FACE projects, the Brazilian implementation has been innovated with a wireless sensor network approach. In the present article, we describe the design and some operational aspects of that implementation.**

Keywords-Wireless Sensors; Environment Monitoring; Plant Diseases; Climate Change; FACE Facility.

I. INTRODUCTION

The global atmospheric CO_2 concentration is increasing rapidly in the last decades and despite the international efforts for the reduction of CO_2 emission. It will probably continue increasing and a long period will be necessary for it to return to the previous concentration [1]. The effects of high CO_2 atmospheric concentration on crops are often observed in the host plant, resulting in alterations in the host-pathogen relationship. CO_2 enrichment promotes changes in plant metabolism, growth and physiological processes. There is a significant increase in the photosynthetic rate and a decrease in the transpiration rate per unit of leaf area, while total plant transpiration sometimes increases, due to the larger leaf area. Despite the evidence of beneficial effects of CO_2 on the host plant, it is not well known whether these effects will still take place in the presence of pathogens, pests and weeds or other limiting factors, particularly in tropical countries [2]. Few studies have been conducted in controlled conditions. They might not reflect plant responses in the field, where there are variations and interactions among temperature, precipitation, and other factors. The search for more realistic conditions has led to the use of open-top chambers (OTCs) and Free Air Carbon-dioxide Enrichment (FACE) experiments [3].

In Brazil, the first FACE facility has been installed near Jaguariúna city - state of São Paulo, besides the installation of six OTCs experiments throughout the country (Belém, PA; Petrolina, PE; Sete Lagoas, MG; Londrina, PR; Jaguariúna, SP; and Vacaria, RS). The project named "Impacts of climate change on plant diseases, pests and weeds", with the nickname "Climapest", has been supported by Embrapa (Brazilian Agricultural Research Corporation). The severity of diseases and pests, weeds, plant development, interaction with microorganisms, plant nutrition, production and other possible impacts will be evaluated. The Climapest-FACE has been planned to discover the effects of high CO_2 concentration on coffee diseases, pests and weeds, as well as plant characteristics. The studies with forest species, apple, peach, soybean, grape, corn, cotton, castor beans, forage crops, coffee, cassava and banana will be conducted in the OTCs.

There are more than 30 FACE facilities around the world. They consist of a set of circles having pipes around them to perform the CO_2 fumigation. The fumigation can be achieved by direct injection or prediluted injection [4]. In either case the main operational issue is to maintain acceptable fluctuations and gradients of the CO_2 concentration inside the circles, which are affected mostly by the wind. In Brazil it was chosen the direct injection system and an octagonal arrangement of pipes, which is generally utilized in existing installations. Each octagon segment has individual gas valves to compensate the wind direction and a flow control device to compensate the wind speed changes. The OTCs have smaller circles, around 2m in diameter, and a plastic cover with an open top surrounds them. The basic instrumentation for a FACE and OTCs experiments usually consists of an Infra Red Gas Analyzer (IRGA) to measure the CO_2 concentration, an anemometer, a set of proportional or on-off valves and other environmental sensors like air temperature and humidity, solar radiation and precipitation. The improvement that has been accomplished for the Brazilian FACE and OTCs instrumentation is to operate all those devices based on the Wireless Sensor Network technology, already present in the rural area [5] and which is the expertise of the Brazilian FACE implementation group [6]. This approach has simplified the system installation and maintenance and has improved its electromagnetic compatibility, since lightning is a huge issue in Brazil.

II. MATERIALS AND METHODS

By the time this project started (January 2009), most necessary instruments were not commercially available as wireless devices. Therefore, the decision was to buy conventional sensors and actuators, as well as wireless ZigBee based modules, to develop a general-purpose interface circuit to integrate those parts to achieve the required wireless sensor network devices. In Table 1, it is shown a list of the chosen devices and the features considered for developing the interface circuit. The CO_2 sensor model GMP343 was selected for the FACE experiment and the CO_2 sensor model GMM222 was chosen for the OTCs experiment. The weather devices, i.e., the anemometer, the sensors of air temperature, air humidity, precipitation and barometric pressure are all part of the same instrument, the WXT520 weather station.

The wireless modules were purchased from Telegesis Inc., specifically the ETRX3 series. They incorporate the ZigBee protocol and operate in 2.4 GHz. They are IEEE 802.15.4 compliant and they are expected to operate in the planned range of 100 meters from each other with an on-board antenna. They also have all necessary digital and analog inputs/outputs, besides a serial interface and five counter/ timers. A set of proprietary AT commands facilitates their software development.

The general-purpose interface circuit was designed with the following premises:

- Should be powered by a 12Vdc external source or a 4.2Vdc internal lithium-ion battery;
- Should have serial communication with either EIA or TTL levels;
- Should provide four analog single ended inputs with fixed gain individually adjustable;
- Should have a switchable 12Vdc output capable to supply the power requirements of the selected sensors and actuators devices;
- Should provide I/O pins and power supply lines in a connector for a secondary interface board.

The block diagram of the achieved circuit can be seen in Figure 1. Two light emitter diodes (LEDs) inform the system operation mode. The 3.3Vdc regulator is a low dropout and low quiescent current circuit since the internal battery mode is supposed to be low power giving long battery life operation. This basic circuit was used to interface all devices listed in Table 1 but the latching Solenoid Valves. For those valves it was developed a secondary board with H bridge circuits to provide the direct and reverse pulses for up to four solenoids.

Figure 2 shows the final assembly for the GMM222 CO_2 probe adapted as a wireless sensor. A 12Vdc lead-acid battery associated to a photovoltaic panel was used as power supply due to the relatively high power requirements of the probe itself. The remaining devices had similar construction.

The network coordinator is an USB ZigBee interface, also purchased from Telegesis Inc. This USB stick has been used with the Windows 7 and Ubuntu Linux version 10.4 operating systems through, respectively, the Telegesis Terminal and the minicom terminal, to send the AT command lines directly to the devices. In this way, basic tests have been conducted to: check, list or modify the sensor network, switch the devices power; perform serial communication direct with the devices (through a data mode); acquire analog and digital signals; and switch the valves. Based on the set of the most useful AT commands, a program has been written in the LabView 8.2 graphical development environment to perform data collection and run the control algorithm for the CO_2 injection (Figure 3).

TABLE 1. LIST OF SENSORS AND ACTUATORS AND THEIR FEATURES

Device	**Operation method**	**Signal interface / Protocol**	**Power requirements**	**Response time**	**Supplier**	**Model / Comments**
CO_2 Sensor 1	IRGA	Serial RS-232/ASCII or analog (0-2.5V)	12 Vdc (11 to 36) / 1 W (max. 3.5 W)	2 s (no filter, no average)	Vaisala	GMP343 / Difusion probe
CO_2 Sensor 2	IRGA	Serial TTL/ASCII or analog (0-2.5V)	12 Vdc (11 to 20) / 2.5 W	20 s	Vaisala	GMM222 / OEM / Difusion probe
Anemometer	Ultrasound	Serial RS-232/ASCII	12 Vdc (5 to 32) / 36mW (with no heating)	0.25 s	Vaisala	WXT 520
Air Temperature	Capacitive			Immediate		
Air Humidity	Capacitive			Immediate		
Rain	Piezoelectric			Immediate		
Barometric Pressure	Capacitive			Immediate		
Solar radiation	Silicon photodiode	Analog (mV)	None	Immediate	Li-cor	LI-90 (Quantum) and LI-200 (Pyranometer)
Flow Controller	Differential precision temperature sensor windings	Serial RS-232/ASCII or analog (0-5V)	12 Vdc / 9.6W	2 s	Aalborg	GFC 17 with optional RS-232
Solenoid Valve	Latching	Direct and reverse pulses	12 Vdc / 24W (100ms pulses)	Immediate	Jefferson	BA222-70

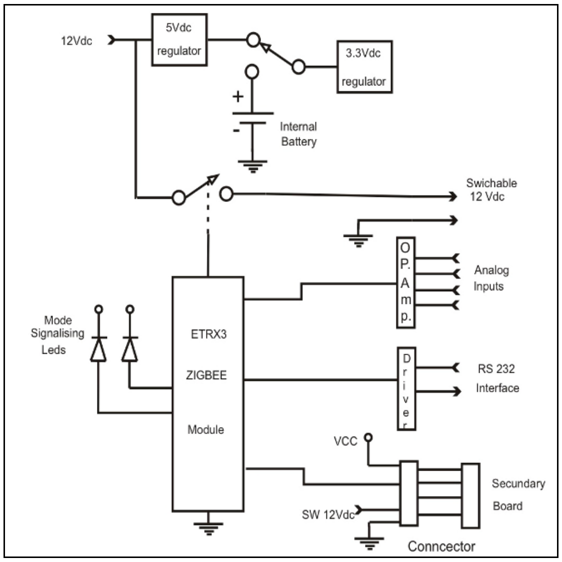

Figure 1. Block diagram for the circuit used to implement the wireless sensor network nodes.

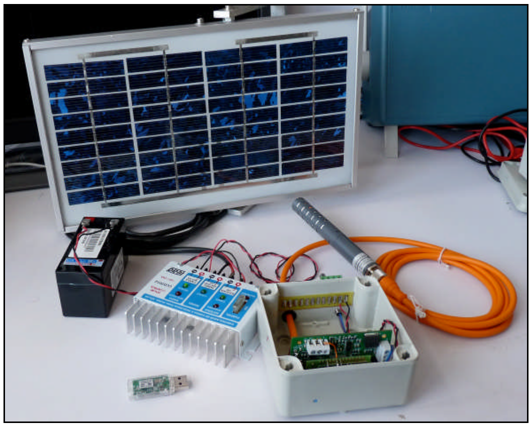

Figure 2. The OTCs CO_2 probe adapted as a ZigBee device powered by a 12Vdc lead-acid battery associated to a photovoltaic panel.

Figure 3. Screen shot from the system program showing the control window, the configuration and data collecting window and the data-plotting window.

III. RESULTS AND DISCUSSION

Six OTCs experiments and one FACE facility have been established with the obtained Wireless Devices. Only the operational aspects restricted to the FACE facility are presented here. The OTCs have similar results from the operational point of view. Figure 4 shows one FACE plot of twelve, with the adapted sensors and valves. The experiment has been running with a constant gas flow of 60 l/min. The injection occurs only from two octagon sections, the ones positioned against to the wind direction. If the wind direction predominates towards just one section, mostly at a right angle to it, then the control algorithm alternates the injection from its left and right neighbors sections in a cycle of 5 seconds each, besides injecting all the time from the central section. In order to save money in the CO_2 consumption it was decided to run the injection only during the day, through the period from 7:00 to 17:00 hours. Therefore, during the night data have been collected only from the plots with injection to make sure there is no gas leak and to have data from the environment concentration. The system has been adjusted to allow injection only for wind speeds in the range from 0.2 to 4.0 m/s. There is yet no variation in the flow to compensate for wind speed. By the time the flow controllers were purchased, the specifications have been mistaken and they have not yet been replaced. Figure 5 shows the graphs of data collected during an arbitrary regular day of operation. It can be observed higher concentrations during the early morning period, due to calm wind conditions, and lower concentrations in the afternoon, due to heavy wind conditions during that period.

The most important practical observation is that the wireless instrumentation offers no significant time delay for the system control, allowing to follow the changes in wind direction in about a second. That is excellent considering that a lag time of up to 30 seconds has been reported for this application [7]. The experiment has been running for seven months now, what can be considered a middle-term evaluation. As expected, lightning has not been an issue. On the other hand, the network has often hung up. The problem has been identified as some ZigBee modules getting stuck in the data mode. This mode is used for direct serial data communication with most devices, and despite the correct sequence of the Telegesis AT commands supplied to open and close this mode, the transmission has eventually failed. A self-recovery solution has come up by a timeout function implemented in the ZigBee modules to leave itself the data mode. This function is also available among the Telegesis AT commands. This operational evaluation has included the system software, which has been improved a lot since the first day of operation in August 25th, 2011, with monthly updates.

V. CONCLUSION AND FUTURE WORK

In the present article, we have described the design and some operational aspects of the implementation of the FACE project in Brazil. The implementation was innovated with a wireless sensor network approach. It has been shown that the wireless instrumentation poses no significant time delay for the system control

Future works and challenges include: 1) to utilize the correct flow controller to compensate the effects of the wind speed; 2) to improve the injection control algorithm, reducing the operating costs; 3) to make the fumigation as uniform as possible inside the plot and avoiding the contamination of neighbor plots; all that making use of the advantages of wireless sensor network.

Figure 4. Partial view of one FACE plot showing the adapted devices: 1) one CO2 probe and one weather station at the plot center and 2) one flow controller and eight valves, one for each octagon section, positioned at the south border. The general- purpose circuit is inside the small plastic boxes. A 65 Watts photovoltaic panel has been used to supply power for each plot.

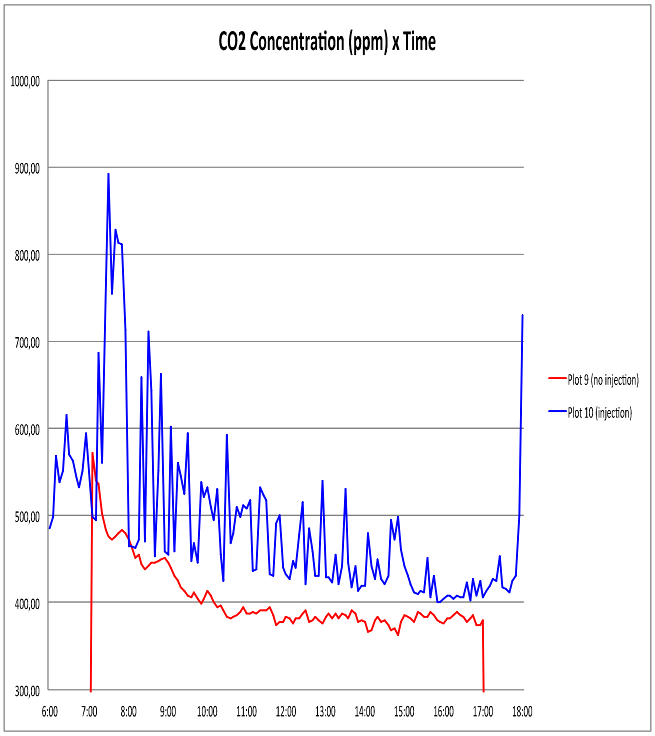

Figure 5. Data collected during one arbitrary day of operation at the center of two adjacent plots, one with and other without CO_2 injection

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