<u>Embedded advanced monitoring system for elementary carbon composting</u>

Up to very recent times, the production of compost mainly focused on its usage in gardening and generally for fertilization purposes. Apart from the absence of contaminents like lead, copper, PCBs, PFTs and polychlorinated dibenzo-dioxins (PCDDs) there were no legal requirements for the commercialization of gardening compost. Generally speaking the buyer of compost uses to judge the quality of compost from its outward apperance, e.g. consistency, texture, color and smell.

In a modern and computerized environment, such a mere subjective judgement is not possible any more, particularly when dealing with special compost with the ability to generate elementary carbon. Therefore the entire process, starting with the raw material and ending with the carbonized compost has to be monitored meticulously.

If monitored, composting is normally checked by the periodic insertion of sensors at different place within the composting row, on one hand because of the lack of continous monitoring solutions and on the other hand because of the increased cost. Hence, a solution for continous monitoring at reasonable cost is mandatory, particularly considering a fast growth of the biocarbon composting method.

1. Introduction

The composting process is a technique that allows the transformation of organic waste into compost, generally with the purpose of obtaining a value-added product. Composting is carried out, through microbiological reactions of mineralization and humidification of organic matter, to achieve a biologically stabilized final product, which does not consume oxygen, nor is it capable of generating phytotoxic metabolites [1]. Special composting processes are able to produce stable elementary carbon [2].

Compost can be produced by implementing the closed aerobic method, which is a method that generally requires a closed reactor and constant oxygenation during the process [3]. By the state of temperature three stages are observed in the aerobic composting process, these are: mesophilic (20 to 45° C), thermophilic (45 to 70° C) and cooling (70 to 20° C). It is important that physicochemical factors such as: *(1) temperature*, *(2) humidity*, *(3) particle size, (4) pH, (5) aeration and (6) type of organic residue* are controlled to carry out the composting process.

The composting process is generally not automatically controlled, but rather checked by periodic measurements. This is now changed through an automated intelligent system. According to [4] intelligent systems incorporate sensing, actuation and control functions in order to describe and analyze a situation, and make decisions based on the available data in a predictive or adaptive manner, thus performing intelligent actions. Therefore, the development of an intelligent system that allows the monitoring and control of the variables involved in the composting process, through the implementation of a set of sensors and actuators controlled by a software hosted in the microcontroller, is an efficient and price reduced solution. that allows for installation at large scale.

Resulting from there requirements an embedded software system that has the ability to automate and monitor composting is used. The system hast the ability to maintain the physicochemical conditions to obtain quality compost with high amount of elementary carbon as outlined in [2].

2. Embedded Systems

The term embedded system first appeared in the 1970s, thanks to the appearance of the 4004 chip by a Japanese company called Busicom, being a calculator the first application given for an embedded system. This implementation led to the development of a general purpose electronic circuit that could be implemented in a complete calculator production line [5].

Regarding the transformation process of organic wastes, nowadays, it is possible to find a great variety of systems. Pansari et al. presented a remote monitoring system using temperature, humidity and methane gas sensors (DTH11, MQ) to improve the aerobic process in compost piles; furthermore, they used an Arduino board and measured the variables temperature, humidity, methane gas [6]. Wardhany et al. developed a smart composter that consists of activating a shredder of organic waste collected and deposited in a fermentation box; they incorporate a remote monitoring system for temperature, humidity and height of the shredded organic waste in the fermentation box using LDR, DS18B20, Kalembasan, Ultrasonic sensors and an Arduino MEGA board [7]. In 2019, Pratama et al. proposed a prototype for aerobic composting; the prototype consists of a compost mixing machine with a fuzzy logic based mixing automation system based on the received temperature and moisture values using YL-39 YL-69 Soil Moisture sensors, DS18B20, pH sensor and a RaspBerry board [3]. Finally, Elalami et al. presented the design and fabrication of a rotating electromechanical machine dedicated to aerobic treatment of organic waste and managed by a remote control that allows controlling temperature, pH, humidity and ammonium parameters in real time, however, they do not mention which electronic devices they used [8].

Regarding software development models focused on embedded systems, several models are reported in the literature. In [9] some approaches based on the V-Model are addressed; Browm analyzes some models based on the life cycle reported in the IEC 61508 standard [10]; Douglas introduces the Rapid Object-Oriented Process for Embedded Systems (ROOPES) method which is based on the spiral model [11].

3. Materials and Method used

Electronic and mechanical materials make up the composter control unit. As for the electronic components, the following are used: a microcontroller, a micro SD memory, and humidity, temperature, oxygen and weight sensors, each of these components were chosen through a previous analysis and comparison of their characteristics. These components are shown in the follwing figures and are described below.

Figure 1, Arduino

Figure 1 shows an Arduino Mega 2560 electronics board based on the ATmega2560 microcontroller, it has 54 digital inputs/outputs of which 14 can be used as PWM (pulse width modulation); it also has 16 analog inputs and a 16 MHz crystal oscillator.

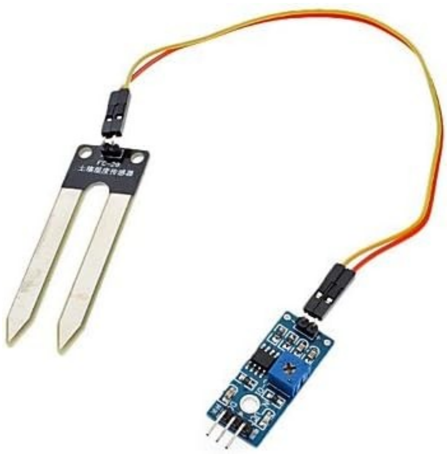


Figure 2, Hygrometer

The FC-28 sensor is made up of two separate plates coated with a conductive material, these plates allow to obtain the soil moisture when a variation in its conductivity is detected. It has a YL-38 module containing an LM393 operational amplifier that transforms the conductivity signal obtained into an analog value. This type of sensor allows to obtain the humidity as an analog value (0-1023) or digital value (High or Low).

Figure 3: Temperature sensor

The temperature sensor used is the DS18B20 which communicates over a bus called 1-Wire and requires only one data line to send the information to the microcontroller.

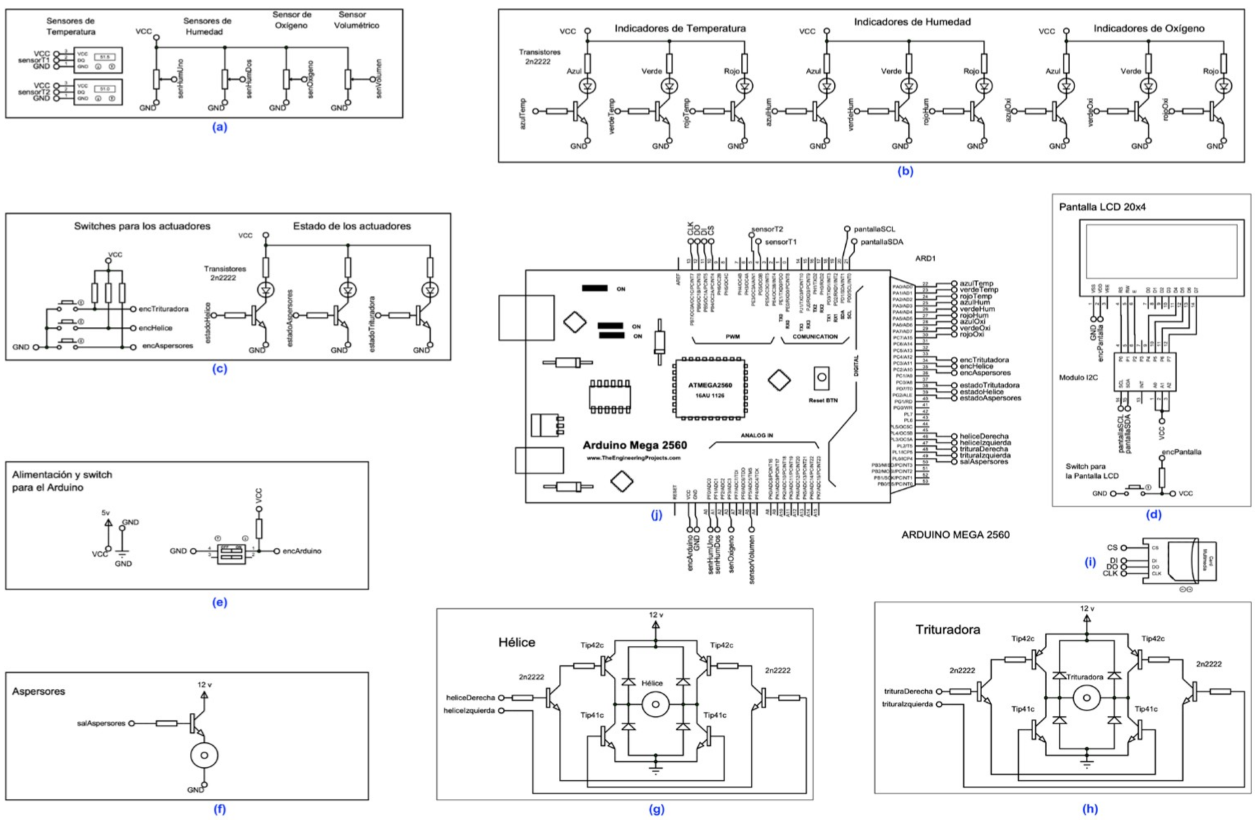
Figure 4: O2-Sensor

The gas-Grove sensor allows to obtain the oxygen concentration in the air, based on the principle of an electrochemical cell. Among the advantages of using this sensor are: (1) high accuracy, (2) high reliability, (3) strong ability to avoid interference, and (4) high sensitivity.

Figure 5: micro SD module

Micro SD, this module allows the Arduino microcontroller to store and extract information from the micro SD memory, it works with 3.3 or 5 V, it requires the SD.h library to establish communication between the Arduino microcontroller and the SD memory. SD memories are the most used for portable devices thanks to their small size and large storage capacity.

4. Hard- and Software Integration



The design of the embedded system components was performed in a specialized software called Proteus. This design allows visualizing the connection between the hardware components and testing the operation. Modules were created for each of the parts of the system, grouping components depending on the function they perform.

The sensors are located inside the monitoring unit, they obtain the values of the physical variables and send them to the electronic board where the embedded software is stored in the FLASH memory of the microcontroller. The electronic board contains the embedded software of the system that is in charge of obtaining the values of the physical variables.

The control unit constantly monitors, temperature, humidity, oxygen and PH-value and and as such controls the transformation of organic solid waste into compost, in order to maintain the system in ideal conditions. Because of this, at the beginning of each of the stages, the variables are read by the sensors.

In stage 1, the mesophilic stage, the temperature should remain in the range of 25 to 45° C, the humidity should be 30%, the amount of oxygen should be less than 0.1 l/min*kg and the composting area should be totally filled. In case of detecting different values from the established ones, actions have been determined that make it possible to preserve the ideal conditions of the composting unit., see Figure 7 (a).
In stage 2, the thermophilic stage, the temperature tends to increase due to microbial activity, so the ideal range for the temperature is between 45 and 70° C. Humidity is maintained at less than 30% and oxygen at 0.1 l/min*kg, and the composting area should remain at a medium to full level.

In stage 3, the cooling stage, the temperature drops below 70°C and the humidity decreases even further. If abnormal values are detected, a high humidity message is stored in the system. Oxygen should be maintained at 0.1 l/min*kg, the composting area should remain at medium to full level.

5. Typical data acquisition

The integrated System is in charge of monitoring all relevant parameters, such as temperature, humidity, oxygen level and pH value. This is necessary in order to ensure that all parameters are within a small range of the desired values.

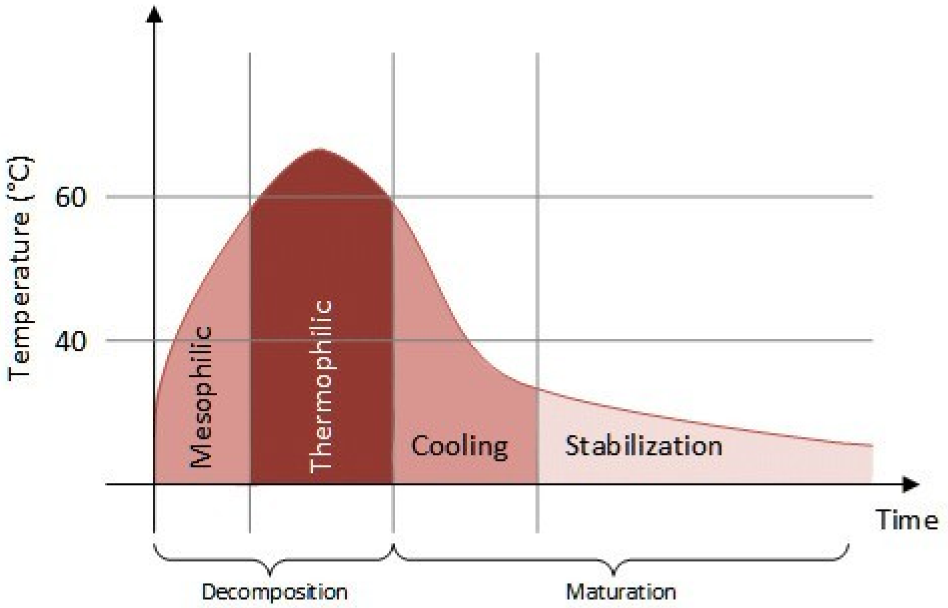


Figure 10: Typical temperature curve of carbonized composting

It has to be ensured, that temperatures do not rise above the threshold temperature of 65 degrees celsius in order to avoid the oxidation of carbon, that is meant to be stored.

Comparing different types of compost temperature checking solutions brings up an obvious advantage to the automated readings provided by the proposed system. A simple calculation shows that labor costs over any period of time, result in extremely high expenditures for off-grid manual control and reading of parameters

While temperature readings seem simple, it still takes a lot of time for a worker to go around the compost area and stuff the temperature probes into compost piles. Because the temperature changes during the day, I presumed it takes about half a person to do that constantly (having the other half for other activities).

IoT sensors provide automatic readings, but there are other costs that have to be taken into account. The probes themselves are more expensive, there has to be some kind of software or middleware installed in the base computer to provide the readings. Then there is also battery life.

[1] Cesaro, A., Belgiorno, V., & Guida, M. (2015). Compost from organic solid waste: quality assessment and European regulations for its sustainable use. Resources, Conservation and Recycling, 94, 72-79. https://doi.org/10.1016/j.resconrec.2014.11.003.

[2] Witte, Biocarbon composting, Book (2017)

[3] Pratama, Y. F., Ariyanto, E., & Karimah, S. A. (2019). Prototype of Automation of Organic Fertilizer Manufacturing Systems Based on Internet of Things. 2019 7th International Conference on Information and Communication Technology (ICoICT), 1-6. https://doi.org/10.1109/ICoICT.2019.8835299. https://doi.org/10.1109/ICoICT.2019.8835299

[4] Sassone, A., Grosso, M., Poncino, M., & Macii, E. (2016). Smart Electronic Systems: An Overview. In Smart Systems Integration and Simulation (pp. 5-21). https://doi.org/10.1007/978-3-319-27392-1_2

[5] Barr, M., & Massa, A. (2006). Programming Embedded Systems (2nd ed.). Sebastopol, CA: O'Reilly.

[6] Pansari, N. B., Deosarkar, S. B., & Nandgaonkar, A. B. (2019). Smart Compost System. Proceedings of the 2nd International Conference on Intelligent Computing and Control Systems, 597-600. https://doi.org/10.1109/ICCONS.2018.8663206

[7] Wardhany, V. A., Hidayat, A., A., M. D. S., Subono, Afandi, A., Muhammad Doni Sururin, A., & Afandi, A. (2019). Smart Chopper and Monitoring System for Composting Garbage. 2019 2nd International Conference of Computer and Informatics Engineering (IC2IE), 74-78. https://doi.org/10.1109/IC2IE47452.2019.8940812. https://doi.org/10.1109/IC2IE47452.2019.8940812

[8] Elalami, M., Baskoun, Y., Zahra Beraich, F., Arouch, M., Taouzari, M., & Qanadli, S. D. (2019). Design and Test of the Smart Composter Controlled by Sensors. 2019 7th International Renewable and Sustainable Energy Conference (IRSEC), (4), 1-6. https://doi.org/10.1109/IRSEC48032.2019.9078197. https://doi.org/10.1109/IRSEC48032.2019.9078197

[9] Boehm, B. W. (1984). Verifying and Validating Software Requirements and Design Specifications. IEEE Software, 1(1), 75-88. https://doi.org/10.1109/ MS.1984.233702

[10] Brown, S. (2000). Overview of IEC 61508. Design of electrical/electronic/programmable electronic safety-related systems. Computing & Control Engineering Journal, 11(1), 6-12. https://doi.org/10.1049/cce:20000101

[11] Douglass, B. P. (2004). Real Time UML: Advances in the UML for Real-Time Systems. Addison-Wesley.