Smart Compost Monitoring System using Open Source Technologies

Vrettos G. [1], **Kazamias G.** [1], **Lekkas D.F.** [2*]

[1]Analysis and Simulation of Environmental Systems Research Group, University of the Aegean
[2] Laboratory of Waste Management, Department of Environment, University of the Aegean

*corresponding author
e-mail: dlekkas@env.aegean.gr

Abstract

This article describes a smart Composting Monitoring System (CMS) developed to monitor assist composting processes. The system comprisesseveral components (monitoring devices, a data base and a web application) that provide multiple functionalities and capabilities. The characteristics of the CMS are discussed and a description of its structure and its components are presented. The sensor system is interactive and versatile and can accommodate several sensors as well as monitor multiple composting units. The article ends with the presentation and discussion of results obtained with the monitoring system..

Keywords

Wireless sensor network, temperature and moisture measurements, methane sensor, Arduino, GPRS

1. Introduction

Composting, which can be defined as a process of biological decomposition and stabilization of wastes under aerobic conditions (Paredes et al., 2002), can transform organic wastes into a stable final product that is not phytotoxic, that is free of pathogens, and that can be used as a substrate and nutrient source for plant growth or as a conditioner to improve soil properties (Huang et al., 2006). Composting represents the most common option to recover material from the organic fraction of municipal solid waste due to the possibility to use compost as a fertilizer (Cesaro et al, 2015). This method appears as the proper procedure to solid waste management which reduces the organic waste effectively. In Europe the use of compost is regarded as a way forward to address both security of nutrients and organic matter supply thus improving soil conditions (European Union, 2012). It has been estimated that 32% of the produced compost originates from biowaste and 9% from mixed waste, whereas the remaining part mainly comes from green waste and sewage sludge. Almost 50% of the whole amount of compost produced in Europe is used in agriculture (Sayen and Eder, 2014).

Composting process is controlled from some parameter such as temperature, moisture and oxygen content. As composting is a microbiological aerobic process, temperature characterizesthe microorganisms' activity in the different stages (mesophilic, thermophilic etc). Monitoring temperature fluctuations during composting period, could allow adequate control of the process in case of diversion from required standards. Moisture content is the factor which makes the nutrients bioavailable when is around 50-60%. Lower content reduces the bioavailability and consequently obstructs the degradation process. Higher content turns the process to anaerobic resulting to methane production. The aerobic condition could be easily controlled whenthe oxygen content is monitored.

The duration of composting process is usually 3-4 months and the above parameters should be monitored in order to maintain the optimal conditions. The standard monitoring method is achieved by sensors with probes in order to take measurements from different points in the pile. Some of them can be wireless and have on-line connection to a server, but the cost is usually too high. In literature, there are only a few studies on network monitoring applications for composting parameters (O'Connor et al., 2015; Lopez et al., 2014; Casas et al., 2014; Shen et al., 2012).

In this paper, a complete monitoring solution for compost piles is presented. The system uses sensors to measure a set of parameters from the field and transmits them to a data server through wireless communication. Unlike the methods suggested by other researchers such as Wi-Fi connection or low radio frequency bands (Lopez et al., 2014, Casas et al., 2014), a GPRS System through the GSM cellular network has been used. Data transfer speed limitation is approximately 85 kbps which is very limited for general applications but more than enough for the system. The GPRS system offers wide coverage without the use of cables or other low range wireless technologies. A web application is used in order to visualize the data that is stored and also to manage the composting piles. The major advantage of this solution is its versatility and cost. Also, using open source software and hardware makes the whole system a low cost still a reliable solution. The web application, offers live data visualization and interaction with the system.

2. The System in parts

This measurement system consists of three main parts:

- **Monitoring Device**
- **Database**

- **Web Application**

Monitoring Device

The monitoring device is the heart of the system and the most important element. The main functionality of the device is to take measurements such as temperature, air humidity, ground moisture and methane. Other researchers used autonomous devices that were placed in the ground in different depth levels in order to have better results (Lopez et al., 2014; Casas et al., 2014). A more "traditional" way of measuring has been selected, using probes that are equipped with the appropriate sensors. The sensors are attached to a probe used to penetrate the compost pile. The probe has a number of sensors attached at different lengths for multi-level-measurements. To collect analog data from the sensors, a microcontroller is used. In order to make it agile, data transmission is done by a GSM module which operates with a SIM card. The module is attached to the microcontroller and transmits the data to a database server using the HTTP protocol.

As mentioned earlier, open source technologies were used. As a microcontroller, an **Arduino Mega**is used with an **Arduino GSM Shield V1** attached. For the measurements a number of sensors have been integrated; 3 temperature sensors the **DS18B20** model from **Maxim Integrated,** a**Adafruit's DHT11 humidity/temperature sensor** for the humidity of the air measurement as well as a **soil moisture sensor from SparkFun**. Finally for the methane measurement a **Methane CNG Gas Sensor with a MQ-4 head from SparkFun**is used.

The whole monitoring system as well as the transmission system is packed inside a waterproof case which is connected to the probes.

Database

A database has been designed and developed in order to store and use the collected data. The database handles both the data from the sensors as well as data from the web application itself. A set of tables have been created; e.g. "**piles**", "**sensors**", **"users", readings.**

The table "**piles**"collets data about the piles, those are all the descriptive information about the characteristics of every pile or windrow. Another table that serves the web application is named "**sensors**" and it contains functional data about every probe. This table allowsthe implementation of more than one probe in our system. In other words the database can handle several piles in several sites. Therefore an officer can monitor a number of composting unit under a single database. The table "**users**" serves as a place to store the user data for the web application. Finally the most important table, "**readings**" contains all the data captured from the sensors. As mentioned earlier for the current set-up presented in this study, data from 3 different temperatures sensors, one humidity, one moisture and one methane sensor are stored. In order to run this system **mysql** opensource database solution has been used.

Web Application

One of the most important virtues of the presented system is the ability to visualize data and interact in real time. The web application is dynamic and supports a set of actions and functionalities. The user – that is the composting officer – is provided with options of initialization, termination piles, monitoring and interaction while presenting them in a dynamic map. Comparing to other web interfaces presented by other researchers (Lopez et al., 2014), the web application is not only capable of monitoring the conditions of the windrows, but it is also a web platform that provides total control and management of the composting piles. The developed application offers versatility and better visualisation of the compost field as well as opportunities to expand as a platform (including more sensors and sites) comprising a complete solution for management and supervision of composting units.Ascreen shot of the main page is presented in Figure 1. Every different windrow has its own data and this data can be presented in many different ways. As we can see from the image, every pile/windrow is marked with a specific color depending on the progress status. The available statuses/colors are: 1) **Fresh →blue**, 2) **Mesophilic→orange**, 3) **Thermophilic →red**, 4) **Maturation→green**, 5) **Stable → brown**. This representation allows for easier and direct observation of the progress of the piles/windrows.

The web application also has an authentication system and one can register either as a user or administrator (composting officer). The administrator, can create, edit or remove piles, attach or detach sensors to/from specific piles, and also manage the users of the application. The administrator has access to every kind of data presentation and the ability to download specific pile data. On the other hand, the user has only the ability to view data presentations as well as information about the piles and sensors.

Figure 1 Main page - selection / creation of piles

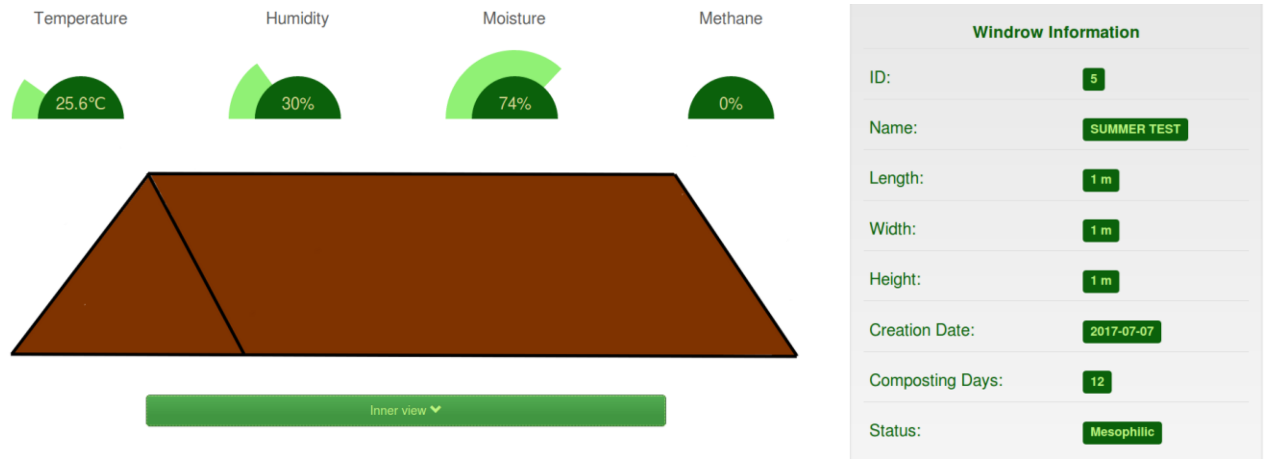

Figure 2. Windrow information

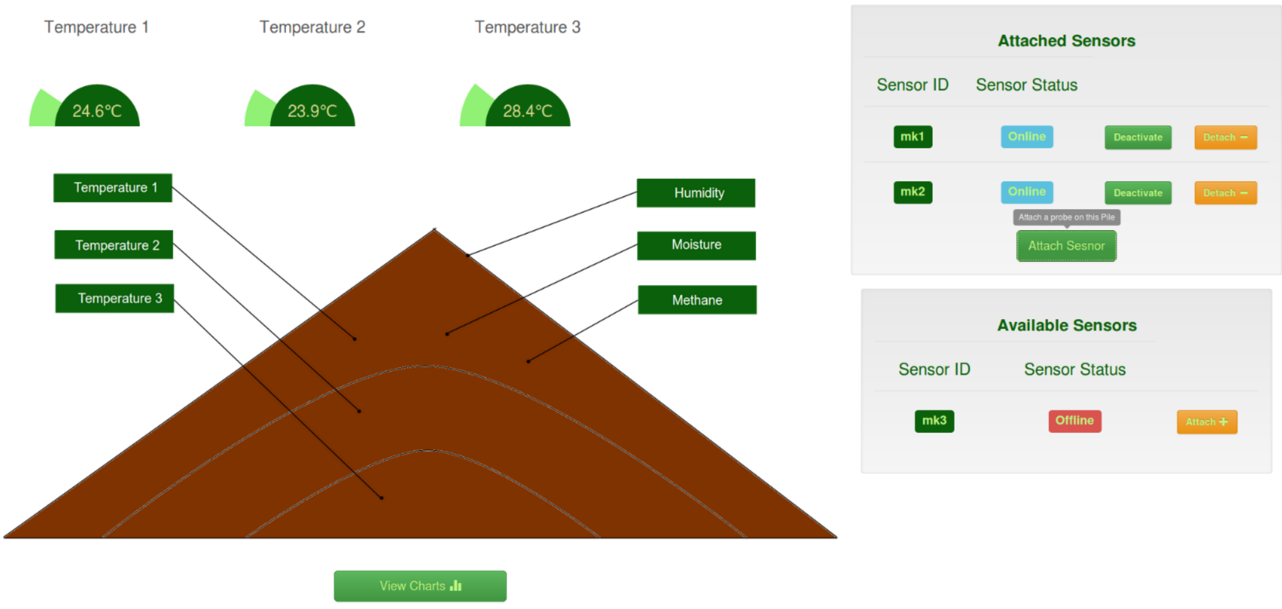

Figure 3. Insight on the sensors attached on the windrow

Figure 4. Different visualizations of the stored data (weekly and daily views)

It is also possible for the user to download pre-defined data from the piles. Selecting a specific pile, makes it possible for the user/admin to view data about the pile as well as the current status of the sensors (see Figure 2).For better insight there is also an "**inner view**" of the windrow (see Figure 3). There is also detailed information about the conditions at different depth levels of the pile.

By selecting a specific sensor the user can navigate to charts and graphs that provide different types of information. The user is able to view daily data from the selected pile for a specific measurement. There is also the ability to view 24 hour data for a specific date. From the technology point of view, open source technologies were also used for the development as well as the setup of the web application. The application is hosted in a remote web server. Specifically the web server uses Apache and PHP for the web services. For the front end of the application, HTML5 and JavaScript were used. For the back end PHP is responsible for serving the data requested.

A detailed description of the System

A deeper look of the system is necessary in order understandits functionalities. In the following flow chart (Figure 5), the functionality of the monitoring devices as well as scheme in which the developed system handles the data at the first levelare presented. Analyzing the flowchart, the system routine starts when the device is plugged in. Powering up the device triggers a) the start of the second Arduino, b) the collection of data and c) the attempt to connect to the GPRS System. After a successful connection to GPRS, the device attempts a connection to our web server. If the connection succeeds, data from the sensors as well as a unique device id is being sent to the web server. If the system fails to establish a connection, it repeats the connection routine. After the data transfer, the system goes offline for 60 minutes until the next scheduled power up (controlled by the first arduino). By doing so, the second Arduino with the GSM shield attached only for data transfer is used once every one hour, making the device more energy efficient and stable.

Next, the web server handles the data accordingly. First, a device id check is performed from the database server. If the device exists in the database, the system performs another check to find out in which pile/windrow is the device connected. Subsequently, the sensor data is being saved to the correct pile/windrow in the database. If the device can't be found in the database, the system registers the device automatically and the the new device must be attached (manually) to a specific pile/windrow.

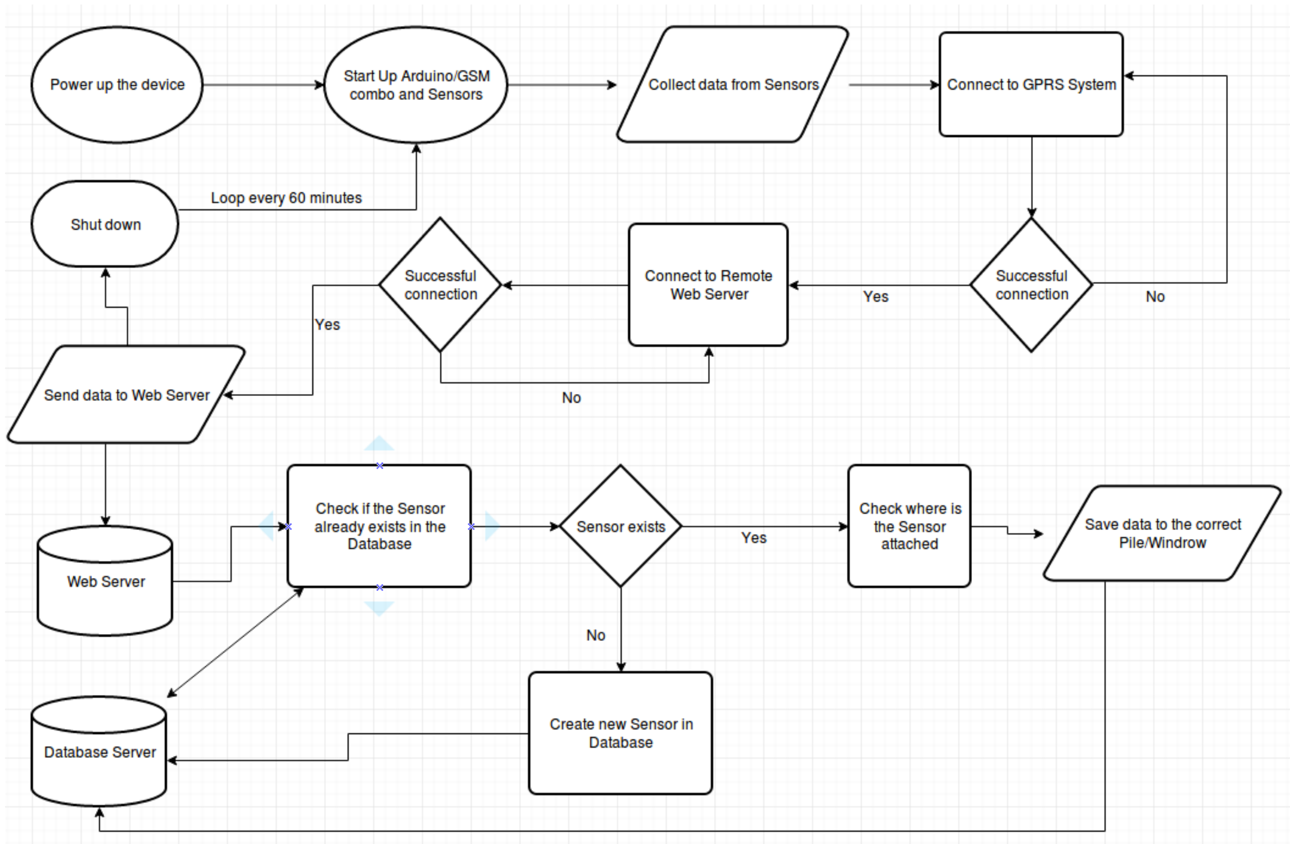

Figure 5 Detailed description of the System

3. Experiments, methodology and results

For this kind of applications a major issue is consistency. In order to make the system robust some consistency testing was necessary. Power consumption is also an issue when dealing with remote monitoring devices. Due to complex issues with GSM module, it wasn't possible to activate/deactivate the module in timed intervals. To deal with the problem, a second microcontroller was used to power up the GSM module when necessary. With this approach we achieved great consistency but sacrificed a bit in power consumption and compactness.

The measurements are taken automatically every one hour. This is a time interval also used by other researchers and is considered sufficient for monitoring composting processes.

Several consistency tests have been performed running the system and then powered it down at different timeframes and specific points. The tests were performed in a controlled indoor environment as well as outdoors. The accuracy of the sensors has also been tested by using certified lab measuring equipment. When problems have been located the sensors have been replaced or adjusted.

Future improvements can be made to the power supply segment which hinders our device from being completely autonomous. A popular and energy efficient solution is the use of solar panels combined with Li-Po or Li-Ion batteries. A second generation of the composting monitoring system is being developed that will use a central station, similar to the "Pile-hub" (Lopez et al., 2014; Casas et al., 2014) buy using both Wi-Fi and the GSM technologies.

4. References

Huang, G.F., Wu, Q.T., Wong, J.W.C., Nagar, B.B., 2006. Transformation of organic matter during co-composting of pig manure with sawdust. Bioresour. Technol. 97, 1834–1842.

Paredes C, Bernal MP, Cegarra J, Roig A. Bio-degradation of olive mill wastewater sludge by its co-composting with agricultural wastes. Bioresour Technol 2002;85:1–8.

A. Cesaro, V. Belgiorno, M. Guida. Compost from organic solid waste: Quality assessment and European regulations for its sustainable use. Resources, Conservation and Recycling 94 (2015) 72–79

Sayen H, Eder P. End-of-waste criteria for biodegradable waste subjected to biolog-ical treatment (compost & digestate): technical proposals. Brussels; 2014.

European Union. Report on the implementation of the soil thematic strategy andongoing activities. Bruxelles: European Union; 2012.

Y. Shen, T. Chen, D. Gao, G. Zheng, H. Liu, Q. Yang. Online monitoring of volatile organic compound production and emission during sewage sludge composting.Bioresource Technology 123 (2012) 463–470

O. Casas, M. Lσpez, M. Quvlez, X. Martinez-Farr, G. Hornero, C. Rovira, M. R. Pinilla, P. M. Ramos, B. Borges, H. Marques, P. Silva Girγo. Wireless sensor network for smart composting monitoring and control. Measurement 47 (2014) 483–495

M. Lσpez, X. Martinez-Farre, O. Casas, M. Quilez, J. Polo, O. Lopez, G. Hornero, M. R. Pinilla, Ca. Rovira, P. M. Ramos, B. Borges, H. Marques, P. Silva Girγo. Intelligent composting assisted by a wireless sensing network. Waste Management 34 (2014) 738–746

D. J. O'Connor, S. M. Daly, J. R. Sodeau. On-line monitoring of airborne bioaerosols released from a composting/green waste site. Waste Management 42 (2015) 23–30