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Intelligent composting assisted by a wireless sensing network

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ABSTRACT

Monitoring of the moisture and temperature of composting process is a key factor to obtain a quality product beyond the quality of raw materials. Current methodologies for monitoring these two parameters are time consuming for workers, sometimes not sufficiently reliable to help decision-making and thus are ignored in some cases. This article describes an advance on monitoring of composting process through a Wireless Sensor Network (WSN) that allows measurement of temperature and moisture in real time in multiple points of the composting material, the Compo-ball system. To implement such measurement capabilities on-line, a WSN composed of multiple sensor nodes was designed and implemented to provide the staff with an efficient monitoring composting management tool. After framing the problem, the objectives and characteristics of the WSN are briefly discussed and a short description of the hardware and software of the network's components are presented. Presentation and discussion of practical issues and results obtained with the WSN during a demonstration stage that took place in several composting sites concludes the paper.

1. Introduction

Composting is an adequate process to treat organic waste, to stabilise it, and to obtain a valuable organic soil useful for agricultural purposes. The uses that can be given to the compost produced will be according to the quality of the raw materials and the management along the process. Quality of raw materials will help comply with legal requirements for soil use while control along the process will also contribute to a good quality product and to better optimise the resources used during the process, namely water and energy.

The composting process requires not only good previous planning (selection of raw materials, mixtures) but also of an adequate monitoring of the control parameters. Since it is an aerobic, bio-oxidative and thermophilic process, the main parameters that enable interpreting of what is happening are the temperature and the moisture evolution. If the initial mixture is adequate (i.e., correct moisture, oxygen concentration and porosity) the composting material heats up as a result of the degradative activity of the microorganisms. As a thermophilic process it is mandatory to maintain a minimum temperature, to sanitise the material, and it is also necessary to maintain a maximum temperature level so as not to affect the decomposing microorganisms. Also, keeping water within adequate limits is essential to sustain microorganisms (too high or too low values reduce composting efficiency (Luo et al., 2008; Tiquia et al., 1996). On one hand, excessive water content will promote the development of anaerobic conditions and cause generation of methane and other molecules responsible for bad odours. On the other hand, reduced water content will stop the process. Therefore, controlling temperature and moisture through time is a key factor to obtain good composting results. In order to ensure optimal conditions for this process, the composting temperature, moisture, and air circulation must be controlled. As long as the process develops, materials added to the mixture brake down into smaller particles, increasing the surface area that microorganisms can grow on. However, if the waste is too small, air will not be able to circulate in the mixture, stopping bacterial growth. Similarly, the moisture level of the material will profoundly affect the compost's degradation.

Composting material must be moistened and mixed regularly to ensure optimum microorganism growth. If the microorganisms that have colonized in the composting material are thriving, the temperature will self-regulate and may become very high. If waste

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remains too cold, it will simply rot and the resulting compost will be of poor quality. If oxygen is present and moisture kept within an adequate threshold, the evolution of temperature will clearly reflect the theoretical thermophilic and mesophilic phases along the process.

Regulations related to composting process in the European Union refer mainly to quality of the final product, but not to conditions to develop the process. In this line, composting is considered as an adequate technology to reduce volume, weight and degradability of organic waste. Degradability is related to generation of environmental inconveniences such as odours, leachates and greenhouse gases. Biological treatments reduce these problems and, according to European hierarchy on waste treatment, composting is recommended.

Actually, some regulations, such as Directive 2008/98/EC (EC 19/11/2008), Council Directive 1999/31/EC (EC 26/04/1999), and Regulation (EC) 1069/2009 (EC 21/10/2009), include some aspects of compost and composting. Directive 2008/98/EC expresses that recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes) are considered as a recovery operation. Nevertheless, European Union has not yet produced a relevant and updated document in relation to composting process, even though some attempts have been underway, such as the Working document on biological treatment of Biowaste, whose 2nd draft can be considered as the most important (DG ENV.A.2/LM/biowaste/2nd draft, 2001). This document defines different aspects such as composting process and conditions related to sanitization and stabilisation of the compost as well as other process requirements. As long as composting is carried out in a thermophilic temperature range it is recommended to keep conditions as listed in Table 1.

The entire composting material must be mixed and exposed to temperature conditions presented in Table 1 to ensure sanitization. Moreover, from this draft, in relation to sanitization, these parameters have to be controlled daily during the sanitization phase.

Referring to sewage sludge treatment, the Working document on sludge (3rd draft) (EC ENV.E.3 2000) considers the thermophilic aerobic stabilisation either as an advanced treatment (hygienisation) or as conventional treatment. For the first, a temperature of at least 55 °C for 20 h has to be maintained, without adding or removing any material during the treatment. For the second one, a temperature of at least 55 °C with a mean retention period of 20 days has to be kept.

The Green Paper on the Management of Biowaste in the European Union (EC 3/12/2008) expresses that "the choice of treatment options needs to be explained and justified in national or regional Waste Management Plans and Prevention Programmes" leaving the final considerations to each country. Standards on the use and quality of compost exist in most Member States, but differ substantially, partly due to differences in soil policies. While there is no comprehensive EU legislation, certain rules regulate specific aspects of bio-waste treatment, biogas production, and compost use.

EC Regulation no 1069/2009 (EC 21/10/2009) regulates health rules for composting and biogas plants which treat animal by-products not intended for human consumption. This document classifies the materials into three categories according to risk to public and animal health. Only materials from categories 2 and 3 can be treated by composting or for biogas production. The Commission Regulation (EU) 142/2011 (EU 25/02/2011) establishes in its annex V, the requirements applicable to biogas and composting plants. In the case of biogas plants, it is compulsory to have a previous treatment in a pasteurisation/hygienisation unit with a maximum particle size of 12 mm, and remain at least at 70 °C for 1 h; in composting, the treatment area must be closed and the temperature must be continuously monitored along the process.

Table 1
Composting temperature conditions according to 2nd draft on biowaste (annex II).

	Temperature (°C)	Treatment time (week)	Turnings
Windrow composting	55	2	5
Windrow composting	65	1	2
In-vessel composting	60	1	–

The work described in this paper was developed with funding of the European Union under FP7 with industry and academic research teams and multiple small and medium enterprises (SMEs) and SME associations in the compost field. The first step in the project was to carry out a two-month long anonymous online, by invitation only survey of composting companies to assess their facilities, conditions of operation and their requirements in terms of measurement of the compost process. The survey results correspond to companies mostly with few employees (58% with less than 5 employees and more than 90% with less than 30). Most composters (73%) serve the agriculture market, 62% in gardening and 47% in horticultures or orchards. Land reclamation composters account to 23% (note that in this field, multiple answers were possible). As far as facilities is concerned, 60% are in an open environment, and half the plants actively aerate the material with blowers while the other half resorts to turning. With regards to measurement conditions, 90% measure the compost temperature but almost half of them do it manually. Measurements are done in one position of the pile and at most at three different depths. For 70% of the respondents, a temperature measurement frequency of 1 per hour or less is sufficient. Those who do measure more frequently, do so because they already have automated temperature measuring systems. Only 43% of plants perform regular moisture measurements and the frequency of measurement is typically between once per day up to once per week. When asked how they would improve temperature and moisture measurements, the responses were focused on improving automated, on-site measurements, in multiple pile locations and measurement frequency increase. More than 80% of composters hope to improve the quality of their products through better monitoring of the temperature and moisture (mostly to optimize when to aerate/turn and to certify the final product). A large majority of the survey respondents showed interest in the project proposed system and indicated that they would be willing and eager to invest in the next five years at least 10 k€ in upgrading their facilities (42% actually indicated an expected investment in excess of 100 k€ in the same period). These conclusions obtained by the survey, validate the initial project objectives which was to develop a new monitoring system with little or no manual intervention required during the lengthy normal compost procedure and capable of automated measurement of temperature and moisture in multiple pile locations. It is in this context that the Compo-ball WSN compost monitoring tool herein described, was developed.

In general, the monitoring and control of the composting process are based on the measurement of the temperature, moisture and oxygen level at several points inside the material. This can be performed manually in the case of windrow composting, but for in-vessel composting, it is necessary to have automated systems. Some examples of automated measuring systems applied in compost monitoring can be found in (Fratticcioli et al., 2004; Kulco and Yaldiz, 2004; Green et al., 2009 and Puyuelo et al., 2010). Homogeneisation of the composting material sometimes is not achieved, and compacity, free air space, water content, etc, can be very different in near points, which can affect reliability of temperature, moisture and oxygen measures. On the other hand, the frequency of measurements can be low, mainly regarding the type of facility in relation to cost, complexity and staff availability.