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WIRELESS SENSOR SYSTEM FOR PROCESS MONITORING OF TREE SEED STORAGE

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ABSTRACT Monitoring both temperature and oxygen concentrations over time is necessary in order to provide critical information on whether the conditions that tree seeds experience are optimal for breaking dormancy and securing optimal seed quality. Manual control of conditions in hundreds of drums with seeds is very time consuming and the use of permanent sensors with wires is difficult in the case of rotating and movable drums. Therefore, a novel approach involving wireless monitoring systems was applied to measure property parameters in a tree seed storage or pre-treatment facility by placing wireless sensors network throughout the storage area, where the system will facilitate long-term data collection at scales and resolutions that are better than those obtained using traditional methods. The developed sensor nodes proved capable of precisely measuring the temperature and oxygen content inside two different tree seed treatment storage facilities, with a high communication reliability and a uniform distribution of the sensors in the material inside the drum both at steady conditions as well as when the seeds were being mixed.

Keywords: Biomass survey, biomass storage, process control.

INTRODUCTION The application of wireless sensor networks to monitor storage and pre-treatment parameters inside tree seed storage facility has not been reported in the literature. Cold moist stratification of seeds of many tree species is necessary to break seed dormancy and allow fast and normal germination (Jensen et al., 2004). Novel cold stratification techniques use controlled moisture content in seeds maintained throughout the stratification period and uses drum-pretreatment, that reduces water loss from seeds and allow automated mixing of seeds for maximum homogeneity (Anonymous, 2004; Jensen et al., 2004). Since minor deviation in temperature or moisture content of seeds in the drum may lead to inefficient dormancy breakage, seed damage and reduced germination, it is of high interest to identify methods that allow continuously monitoring of conditions that seeds experience during treatment. Viable, hydrated seeds use oxygen in the respiration process and heat is generated in the seed. Significant changes may occur in a few hours and treatments often last many weeks. Monitoring both temperature and oxygen concentration over time therefore will provide critical information on whether the conditions that seeds experience are optimal for breaking dormancy and securing optimal seed quality. Manual control of conditions in hundreds of drums with seeds is very time consuming and the use of permanent sensors with wires is difficult in the case of rotating and movable drums. As a novel approach, wireless monitoring systems will be applied to measure property parameters in a tree seed storage or pre-treatment facility by placing networked wireless sensors throughout the storage area, where the system will facilitate long-term data collection at scales and resolutions that are better than those obtained using traditional methods.

MATERIALS AND METHODS

Wireless sensor node Various wireless standards for monitoring and automation applications have been established, and in general, a lower frequency allows for a longer transmission range and a stronger capability to penetrate different materials (Wang & Wang, 2006). Furthermore, radio waves with higher frequencies are easier to scatter. To obtain a long effective transmission communication range with high penetration capability, 433 MHz was selected as the communication frequency for this application. To enhance communication reliability, each sensor node actively participated in handshaking communication (Lewis, 2004). Therefore, acknowledgment messages were sent back to the originating node when the sensor messages were received by the gateway. The acknowledgment messages might include information relevant for network re-tasking purposes such as modifications in the network sampling rate.

The applied wireless sensor monitors temperature and oxygen concentration. The sensor is powered by a 3.6 V lithium battery giving an unattended operational time of approximately 6 months, depending on the data sampling rate. The oxygen sensor is an O2 A3 from Alphasense of the galvanic type. The temperature sensor is TMP36 from Analog Devices. For data processing, the sensor has a microcontroller with an embedded radio transmitting and receiving module. The sensor measures the temperature and oxygen level at specific time intervals and transmits the data wirelessly to a receiver station. The sampling time interval was set to 1835 seconds, roughly 30 minute.

Experimental setup Cold stratification of seeds of Abies nordmanniana at controlled moisture content of 34 % (Jensen, 1996;1997) is recommended to last for a minimum of 6 weeks at 3-5°C (Gosling et al., 1999) and measurements here began after 1-2 weeks of cold stratification and finished when stratification was considered to have broken the dormancy fully in seeds.

The experiment was carried out at two locations involving private companies: Abies Seed, Tapsøre, Denmark, from 20th of March to 20th of April – 2009. And Majland A/S, Sdr. Omme, Denmark, from 2nd of May to 19th of May – 2009.

At the first location, the measured medium was tree seeds of the species Abies nordmanniana, harvested in the fall 2007 in the Ambrolauri province, Tlugi, department 14-17 in Georgia. The monitoring was concentrated on the pretreatment (cold stratification treatment), where the seeds initially was imbibed to 30% water content (fresh weight based) on the 24th of February 2009, and adjusted on the 11th of March to 33-34% water content, which is the optimal controlled moisture content for this species. The drums were placed in a rack system inside a 40 ft. refrigerated container and each drum was rotated once a day. All drums have an air intake in the lid to insure the seeds have sufficient oxygen available. When the drums are positioned in the rack, the seeds roughly fill up the drums 60%. This translates into a seed level just underneath the air intakes.

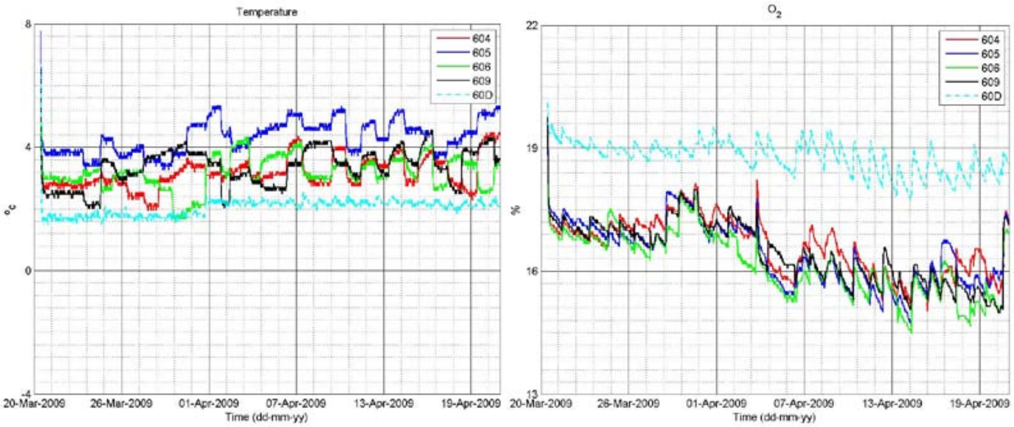
The two drums used during the experiment was labeled 14 and 16 and contain seeds from the previous mentioned lot. They were placed in the rack at the end of the container, in the third row from the bottom, approximately 1,5m above the floor. This is just next to the refrigeration unit but the drums are not affected directly by the air flow. The placement of the drums next to each other will ensure next to identical conditions during the experiment.

10 sensors were divided into two batches with 5 sensors in each, so that no.0 – no.4 were dedicated to drum 14 and no.5 - no.9 dedicated to drum 16. Sensor no.0 was used as a reference for drum 14 and equally, sensor no.9 was the reference for drum 16. Both reference sensors where placed outside the drum on the rack itself. The rest of the sensors, no1-no.4 was placed inside drum 14 and no.5 - no.8 inside drum 16. The placement of sensors inside both drums was done so they were distributed evenly along the length of the drums and in various depths.

At the second location, the measured medium was also tree seeds of Abies nordmanniana, but harvested in the fall of 2008 in the Ambrolauri province. The imbibitions in experimental drums no 218 and no 219 began on the 7th of April, where all water was added at once to reach the same water content of 33-34 %. Each drum was rotated every 4th hour a day. Similar physical setup as 1st location was applied.

RESULTS The results of the experiment is mainly focused on comparing the two locations by analysing the variation in the temperature and oxygen content within the pre-treatment drum, depending on how the pre-treatment procedure were being executed in terms of rotating once per day or every 4th hour, respectively.

At the first location involving Abies Seed, two pre-treatment drums were used during the experiment, drum no 14 and no 16. Figure 3 and 5 shows the temperature variations in the two drums, while Figure 4 and 6 shows the oxygen variations for the same drums, all for the period of the 20th of March to the 20th of April – 2009. It is seen from Figure 3 and 5 that the outside reference temperature measurement is controlled to approximately 2°C, and both drums are located at the same height. In both drums, the temperature is generally above the controlled outside temperature, while the seed are respirating and thereby generating heat. This can also be observed by comparing Figure 3 and 4, where there is a tendency that the temperature increases when the oxygen content is reduced.

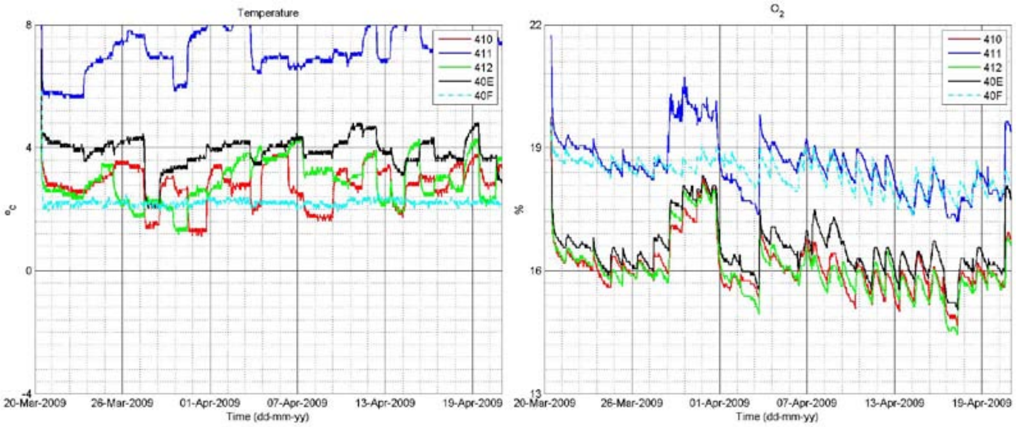


(A) (B)

Figure 3. Temperature and oxygen measurements in drum no 14 and outside reference sensor (60D), for the period 20th of March to 20th of April – 2009. (A): Temperature, (B): Oxygen content

Two specific observations was related to drum no 16, where both a sensor technical problem arose in this drum with sensor no 411 appeared to be out of calibration, and also the temperature dropped below the outside room temperature. Sensor no 411 could have an off-set or calibration error, while in general, the sensor showed 4-5 units higher for both temperature and oxygen content. When conducting the statistical analysis, sensor no 411 was defined an outlier and therefore excluded from the further data analysis.

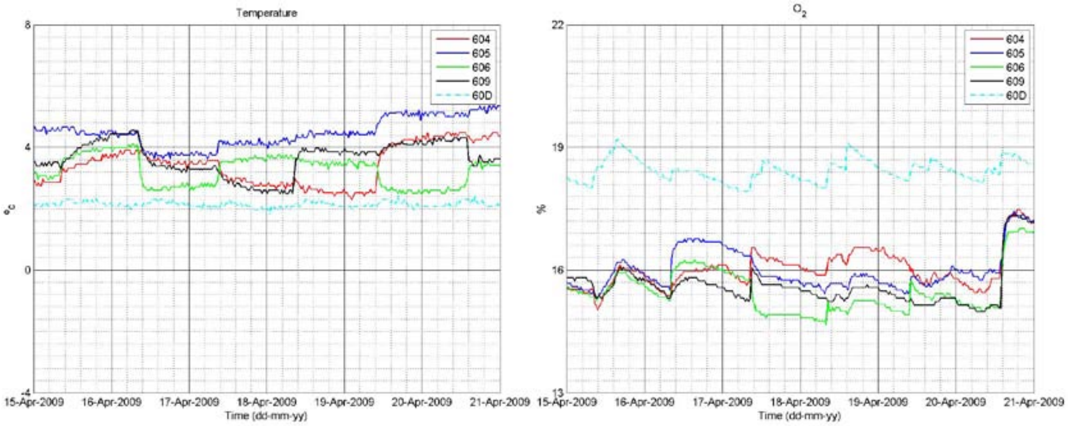
Around the 28th of Marts and to the 1st of April, sensor no 410 and no 412, were positioned somewhere in the seeds, where the temperature got close to only +1°C. At this point, the oxygen content within the drum approached the outside reference oxygen content, which could indicate that the seeds went into a kind of hibernation. When looking at the resulting biological growth test, the seeds in drum 16 had a slightly smaller mean root length compared to the seeds in drum 14.



(A) (B)

Figure 5 – Temperature and oxygen measurements in drum no 16 and outside reference sensor (40F), for the period 20th of March to 20th of April – 2009. (A): Temperature, (B): Oxygen

By studying in more detail the affect of the rotating procedure, Figure 7 and 8 illustrates the temperature and oxygen content variations in drum no 16 for the period 15th of April to 21st of April – 2009. By looking specifically of a 5 day period, it is shown that a temperature variation follows the rotating procedure of the drum. As an example, the sensor being near the surface has a temperature matching the reference outside temperature, and when the same sensor is rotated with the seeds with a resulting new position, potentially at the center of the drum, then the temperature increases due to biological activity. Furthermore, it can be seen that the oxygen content of the room is affected by the rotating procedure of the pretreatment drums.

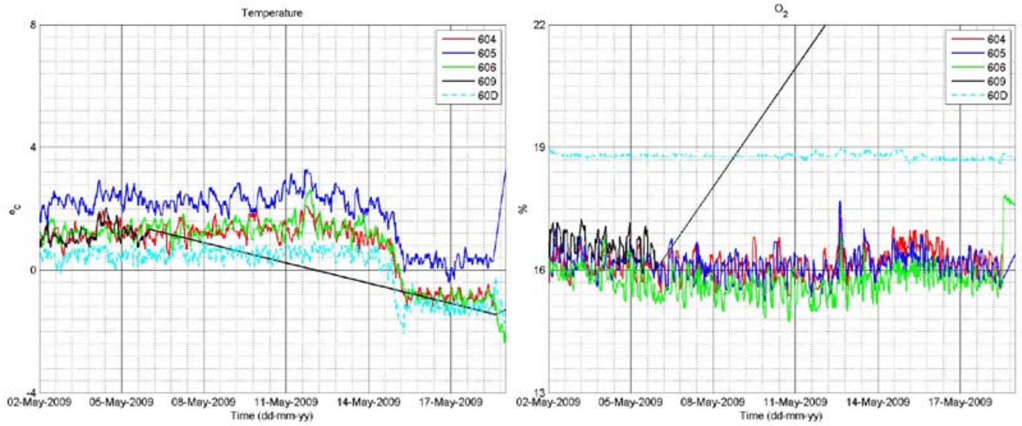


(A) (B)

Figure 7 – Temperature and oxygen content measurements in drum no 16 and outside reference sensor (60D), for the period 15th of April to 21st of April – 2009. (A): Temperature, (B) Oxygen content

At the second location involving Majland, two pre-treatment drums were also used during the experiment, namely drum no 218 and no 219. Figure 9 and 11 shows the temperature variations in the two drums, while Figure 10 and 12 shows the oxygen variations for the same drums, but for this experiment for the period of the 2nd of May to the 19th of May – 2009. In both drums, the temperature was similar to the first location and also generally above the controlled outside temperature.

Comparison of the two locations was performed by comparing the standard deviation within the pre-treatment drum over the two periods of the pretreatment period. Sensor 411 has been excluded. The results shows that when the drum are turned once per 24 hour, then the temperature is more stabile, but the oxygen content varies more within the drum, as compared with the situation when the drum was turned every 4th hour.



(A) (B)

Figure 9 – Temperature and oxygen measurements for drum no 218 and outside reference sensor (60D), for the period 2nd of May to 19th of May – 2009. (A), Temperaure, (B): Oxygen content

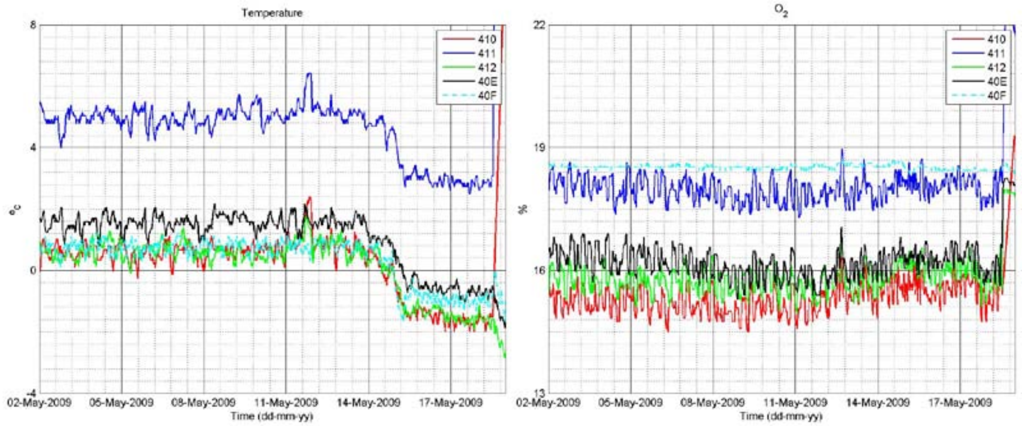


Figure 11 – Temperature and oxygen measurement for drum no 219 and outside reference sensor (40F), for the period 2nd of May to 19th of May – 2009: (A) Temperature, (B): Oxygen content.

DISCUSSION An appropriate frequency rate (433 MHz) for the communication between the sensor nodes and the participation of the sensor network in handshaking communication was selected. Setting the data transmission with the maximum transmission power level to 10 mW gave a satisfactory system performance. Regarding the operational life of the sensor nodes, the experiment carried out in this study showed that the proposed sensor nodes were able to fulfill important requirements related to their future viability under practical conditions. As the objective of this study was to design a novel monitoring system (wireless sensor nodes), the wireless nodes should be able to measure and transmit the measurements during the whole period of the experiment without the necessity of removing them from the storage e.g. to change the batteries. In this experiment, the power supply (battery) lasted during the whole experimental period with only one error occurred for one sensor node, where the soldering of the battery was broken and another error for one sensor where there might be an off-set or calibration error. As wireless sensor systems have not been deployed in full-scale storage facilities, a direct comparison between the results achieved in this study and results from other studies cannot be carried out. From the biological aspect, the measurements revealed that the pre-treatment performed at location 2, where the drums were rotated every 24th hour, resulted in more homogeneous temperature conditions for the seed but with larger variation in the oxygen content. When the drums were rotated every 4th hour, the standard deviation increased for temperature, but became more stabile for the oxygen content within the drum.

CONCLUSION The presented work is an integrated part of the development and the application of information and communication technology, especially sensor and automation technology for grain and seed storage, as important elements in relation to enhanced control measures and increasing documentation demands.

The developed sensor nodes proved capable of precisely measuring the temperature and oxygen content inside two different tree seed treatment storage facilities, with a high communication reliability and a uniform distribution of the sensors in the material inside the drum both at steady conditions as well as when the seeds were being mixed. The temperature measurements revealed that when the drum are turotated once per 24 hour (std. 0,55°C and 0,61°C), then the temperature is more stabile compared with when the drum is turned every 4th hour (std. 0,77°C and 0,98°C). The oxygen content varies more within the drum, when the drum are rotated once per 24 hour (std. 0,74% and 0,66%) as compared with the situation when the drum is rotated every 4th hour (std. 0,51% and 0,44%). The results support the use of a distributed seed monitoring system using wireless sensors in order to obtain and maintain a good vigour and germination quality of the tree seeds.

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