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b+WSN: Smart beehive with preliminary decision tree analysis for agriculture and honey bee health monitoring ☆

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ABSTRACT

United Nations reports throughout recent years have stressed the growing constraint of food supply for Earth's growing human population. Honey bees are a vital part of the food chain as the most important pollinator for a wide range of crops. It is clear that protecting the population of honey bees worldwide, as well as enabling them to maximise their productivity, is an important concern. In this paper heterogeneous wireless sensor networks are utilised to collect data on a range of parameters from a beehive with the aim of accurately describing the internal conditions and colony activity. The parameters measured were: CO_2, O_2, pollutant gases, temperature, relative humidity, and acceleration. Weather data (sunshine, rain, and temperature) were also collected to provide an additional analysis dimension. Using a data set from a deployment at a field-deployed beehive, a biological analysis was undertaken to classify ten important hive states. This classification led to the development of a decision tree based classification algorithm which could describe the beehive using sensor network data with 95.38% accuracy. Finally, a correlation between meteorological conditions and beehive data was observed. This led to the development of an algorithm for predicting short term rain based on the parameters within the hive. Envisioned applications of this algorithm include agricultural and environmental monitoring for short term local forecasts (95.4% accuracy). Experimental results shows the low computational and energy overhead (5.35% increase in energy consumption) of the classification algorithm when deployed on one network node, which allows the node to be a self-sustainable intelligent device for smart bee hives.

1. Introduction

Humans and honey bees have had an important relationship from the beginning of civilisation, with records of honey bee agriculture (apiculture) dating as far back as 2400 BC (Crane, 2013). In modern times the Western honey bee (*Apis mellifera*) plays a role in a range of human activities, including nutrition, medicine, and agriculture. The most vital activity of the honey bee for humans is pollination. The EU parliament noted in 2008 (resolution T6-0579/2008) that 79% of human food depends on honey bee pollination. As the global human population grows, to secure food supplies, the amount of pollinator dependant crops will increase dramatically. Aizen and Harder (2009) found that the volume of pollination dependant crops has grown 300% in the last 50 years. It is also noted in the same work that wild/feral honey bees are increasingly subsidising the pollination requirements of commercial agriculture. As pests such as Varroa spread, wild native or feral introduced honey colonies have virtually disappeared in several countries. To protect food supply, and agriculture-dependant economies, honey bee populations need to be maintained in an optimal state of health and afforded opportunities to grow. A bee colony costs ~€250 in Ireland and improved monitoring would be significant for beekeepers worldwide. The global value of pollination is estimated at €153 billion (Gallai et al., 2009) and improved pollination by healthy bees, through hive monitoring, could increase the performance of agriculture dependant economies.

Wireless Sensor Networks (WSN) consist of embedded sensing, computing, and communication devices, and are a key technology

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of the Internet of Things (IoT) concept. WSN have found many applications, including healthcare, environmental monitoring and medicine (Boyle et al., 2011; Sardini and Serpelloni, 2011). One of main challenges of WSN is enabling them to perceive and understand the world in a similar way to humans. Perceptive low-power sensor devices should be able to interpret the world around them using intelligent algorithms. Machine learning technologies have been used with great success in many WSN application areas, solving real-world problems in entertainment systems, robotics, health care, and surveillance. Another important feature of WSN is the potential to achieve long life time, or even better self-sustaining operation through energy harvesting (Sardini and Serpelloni, 2011).

Many bee monitoring systems can be found in literature (Odoux et al., 2014). Automated, precision beehive monitoring has been identified by many as an important and feasible goal (Zacepins et al., 2015). It is clear, however, that the interdisciplinary analysis of beehive data is in its infancy. In this paper, data have been analysed from biological, meteorological, and engineering perspectives. The result of this analysis allows the data collected from the in-field hive to be used to provide information on the status of the bee colony and external conditions. The system described can be used to provide feedback and prediction for the agriculture sector (covering an area of up to 170 sq. km – the typical home range of bees in a hive (Beekman and Ratnieks, 2000)), which relies on accurate short term weather prediction.

This would be important to economies such as Ireland where agriculture is primarily grass-based (beef and dairy production) (Central Statistics Office, 2016). Such agricultural activities can be strongly influenced by weather, making accurate forecasting vital. There are strict environmental protection requirements relating to weather and farming practices, including spreading of slurry and fertiliser. Identifying incoming weather is also crucial for farming activities, including optimising silage harvest and preventing spread of diseases such as potato blight.

The work described in this paper utilised an heterogeneous WSN, deployed unobtrusively in an active field-deployed beehive to gather and subsequently analyse data. The hive parameters measured by two sensor nodes (as shown in Fig. 1) were: CO_2, O_2, contaminant gases (Nitrogen Dioxide (NO_2), Ethanol (CH_3CH_2OH), Ammonia (NH_3), Carbon Monoxide (CO), and Methane (CH_4)), temperature, relative humidity, and acceleration. The analysis of these data provided a unique picture of the beehive conditions at times when traditional beekeeping methods are not possible (night-time, poor weather). Innovative techniques were used to describe the hive status and predict local weather. In this work, WSN technology is applied together with machine learning (decision tree analysis) to monitor the conditions of a beehive, while remaining self-sustainable.

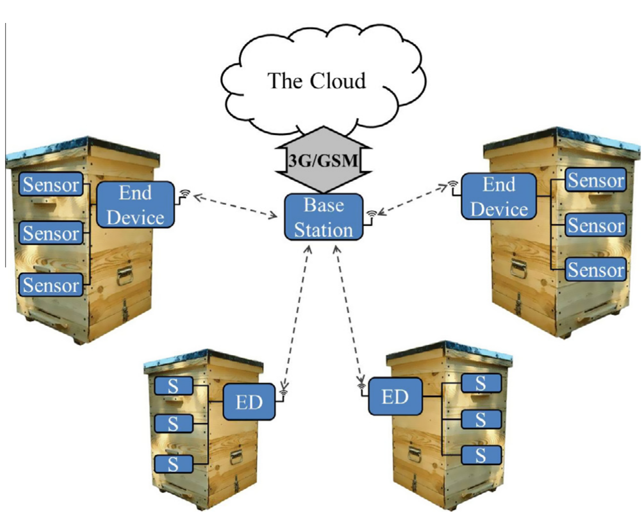

Fig. 1. Network transfers data from the hive to the cloud.

The original contributions of this paper are: synchronised, multi-source, data collection relating to honey bee activity and weather; data collection from an active beehive; interdisciplinary analysis of data; in field evaluation of the developed system; using these analyses and datasets to develop and train decision tree algorithms; presentation of a solution which provides simultaneous feedback on hive health and condition, and information on local weather conditions for agricultural applications; and evaluation of the algorithms in terms of power consumption and accuracy. This paper is organised as follows: Section 2 describes recent work in the area; Section 3 gives a system overview; Section 4 describes the first deployments; Section 5 presents the data analysis; Section 6 outlines the developed signal processing algorithms; Section 7 provides results and analysis of the developed decision tree performance; and Section 8 concludes the paper.

2. Related work and background

Using technology to monitor honey bees has been the subject of extensive previous work, examples include detecting a hive state known as "swarming" by Bencsik et al. (2011) and Ferrari et al. (2008) and counting the number of bees exiting and entering a hive using LEDs by Chen et al. (2012). These systems all use fixed sensors connected to PCs, making them unsuitable for remote, large scale, or widespread deployments. The b+WSN system used low power WSN technology to make these features possible.

Odoux et al. (2014) proposed a method for extended monitoring of honey bee colonies. The approach required sampling twice per month, which provided far fewer data than the system in this paper. They used invasive methods which disturb the colony, causing damage, and occasionally causing the colony to fail. The b+WSN system described in this paper did not require the hive to be opened for readings. A system was described by Phillips et al. (2014) where WSN were used to predict swarming using temperature sensors. The system proposed was only effective in hot climates and the apparatus interfered with the beekeeper's access to the hive. The b+WSN system collected valid data in any weather condition, and did not prevent beekeeper activities which are critical for hive maintenance. Other commercially available systems used individual sensors, were battery powered, and not 3G/GSM enabled for remote deployments (Arnia, 2016; Beewise, 2016). The b+WSN system supported a wide range of sensors as well as energy harvesting for extended operation.

The critical in-hive parameters which may indicate the status of the colony have been identified in the literature as: temperature, humidity, Carbon Dioxide (CO_2) levels, and Oxygen (O_2) levels (Becher, 2010; Heath and Gaze, 1987). These are known to vary in response to one or more of these scenarios: the number of honey bees in the hive, the health of the colony, and the external weather. These observations motivated the choice of sensors.

A system which used threshold-based algorithms in a WSN was described by Gutierrez et al. (2014). The objective was to optimise water use in an agricultural irrigation system. In this paper threshold-based algorithms were utilised to generate interrupts describing the beehive status. For improved performance in the b+WSN system, a machine learning algorithm known as a "decision tree" was utilised as well as threshold-based algorithms, and the results of both methods were compared. An example of a system designed to use decision trees for agricultural decision support was described by Tang et al. (2015). The classification tree developed for the b+WSN system has been deployed in a real system and the performance has been analysed.