Progress Towards an Intelligent Beehive

Building an Intelligent Environment to promote the Well-being of Honeybees

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***Abstract*— Honeybees are not only important for their production of honey but also, and more fundamentally, they are almost certainly the most effective pollinators of crops. However, there is strong evidence that the honeybee is under threat. Various factors, including parasites, bacterial and fungal infections and pesticides have been suggested as causes of this. In this project, we aim to promote bee well-being by encouraging bees to live more naturally, and propose an "intelligent beehive", equipped with an array of appropriate sensors, to allow the continuous monitoring of conditions in the hive in a non-invasive manner. In this paper, we discuss the issues surrounding bee welfare and decline, present our innovative hive designs and some preliminary results and analysis, concluding with future work we plan to carry out, collecting & analysing data from a range of hives equipped with a much broader range of sensors, including a discussion of our equipment and methodologies.**

Keywords—honeybees; well-being; monitoring; intelligent sensor network; beehive

I. Introduction

The honeybee (*Apis Mellifera*) is vital to ecology and agriculture through its phenomenal ability to pollinate crops and other plants. However, as has recently received widespread publicity in the media, the honeybee has been in serious decline in many countries over recent decades, which has been attributed to a wide variety of factors, including the use of pesticides and parasites such as the Varroa mite. Nevertheless, the practices of conventional beekeeping, involving frequent invasive inspections of hives, interfering with and stressing the bees, and potentially spreading infections and parasites, quite possibly contribute to this decline. In this paper, we propose an alternative approach to beekeeping – using an intelligent monitoring system within the hive to minimize the frequency of inspections and encourage the bees to live as naturally and with little interference from humans as possible.

The remainder of this paper is structured as follows. The next section outlines some of the key issues surrounding honeybee colonies and beekeeping, the modern problems associated with these, and previous work on monitoring various aspects of the environment of a beehive. We then proceed to describe our novel hive design, and propose two possible approaches to monitoring a bee colony inside it. A number of our hives have recently (March 2016) been deployed at various locations in the local area, and data from these is already being collected. We subsequently propose methodologies for analyzing and interpreting the data, and conclude the paper with a summary of what has been achieved so far and suggesting future directions for the work.

II. Honeybee Colonies and Previous Work Monitoring Them

A. Honeybees and Honeybee Colonies – key issues

When it comes to pollination, it would be difficult to devise a more effective control system than that which already exists in the functions of a honeybee colony. Properly understood, bees could also act as a "barometer" to environmental health. The extraordinary cognitive abilities of honeybees have been successfully dominating pollination services through millions of years of change, so it is a natural choice to let them manage their own natural lifecycle and lifestyle as they see fit.

The cognitive abilities of honeybee colonies are most fully expounded by the works of Thomas Seeley, especially in his books "Honeybee Ecology" [1] and "The Wisdom of the Hive" [2]. In short, the colony is constantly integrating information from the environment to make decisions about maximising growth, such as maintaining the hive at a constant temperature of 34°C during hot days and cold nights while the brood is developing, to the amount of brood being laid against the value of resources available to the colony. All this is being done against the constant changes going on in the environment as different flowers come in and out of bloom. Honeybees respond quickly and efficiently to these changes, and their methods for doing so are well understood.

B. Previous Work on Monitoring Honeybee Colonies

Aristotle (c 384 – 322 BC) is credited as first noting that honeybees perform a bizarre song and dance and speculating that it was some form of communication. The first full length book on beekeeping in English was Charles Butler's 1623 work "Feminine Monarchy". However, it was the famous German ethologist Karl Ritter von Frisch (1886 – 1982) who first unravelled the hidden messages encoded in the mysterious "waggle dance" performance [3,4]. The Nobel Prize for Physiology or Medicine 1973 was awarded jointly to Karl von Frisch, Konrad Lorenz and Nikolaas Tinbergen "For their discoveries concerning organization and elicitation of individual and social behaviour patterns (of animals)" (Nobel Prize citation, 1973). Frisch' s work was continued by his student Martin Lindauer, who in turn was a mentor to Thomas

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Seeley, who has written or co-written over 150 scientific publications on honeybees, and to this day continues producing ground-breaking work on bees and their individual and social behavior, including "The Wisdom of the Hive" [2] and "Honeybee democracy" [5]. In "Honeybee democracy", he makes an exciting comparison of the swarm as a cognitive entity, identifying the honeybee to a neural component of swarm intelligence [5].

In 1997, Halit et al produced a paper [6] in which attempts are made to control queen bee behavior with artificial sounds. This is an interesting departure from previous work which seemed to focus on simply understanding the bee language.

The first person to develop an electronic device for listening to bee sounds was Edward Farrington Woods (1901-1976), who produced the "apiductor" – a sound analysis system specifically designed for bee acoustics [7].

The first scientific study to address the actual monitoring of bees appears to be by Ferrari et al in 2008 [8] and is significant to this report. The principal method used in their work was the use of Power Spectral Density (PSD) and spectrograms, although the temperature was monitored as well. The results of the investigation revealed significant acoustic characteristics in the immanent lead up (1/2 hour prior) to a swarming event. They had in fact identified the buzz running signal, so the signals identified could not be used as a long term prediction of swarming

Work by Bencsik et al [9] again used spectrographic analysis to study the acoustic data, making use of Principal Components Analysis (PCA) and eigenspectra to identify and classify the sounds. One interesting and unusual aspect of their work was the use of accelerometers in place of microphones to gather their acoustic/vibration data.

Other work has been performed on species different to honeybees. Mhatre et al [10] applied similar techniques to sound reception and perception by small insects, as do Reynolds & Riley [11]. Boucher et al studied the interactions between worker and drone honeybees [12], while Pace et al [13] used Hidden Markov Models to analyse the acoustics of the sounds used by humpback whales to communicate between each other.

Our initial work in this area [14, 15] focused on using acoustic signals produced by a honeybee colony in an attempt to identify whether the colony did or did not include a healthy queen bee – the former being called "queenright" and the latter "queenless" states. In those studies, we used spectral analysis and a Self-Organising Map [16] to classify and distinguish between the two states.

III. Novel Beehive Design and Monitoring System

In this section, we describe our approach to addressing the problems. In the next sub-section, we describe our novel hive design, whilst in the subsequent sub-section, we describe the sensor system included for monitoring the hive, its bee colony and the surrounding environment. Twelve of our hives have been deployed around the local area, at nine different locations all within a 10 mile (16 km) radius of the main Kingston University campus. This area of deployment allows use of a variety of suburban and rural situations, whilst keeping environmental factors such as ambient temperature and rainfall reasonably uniform. A further four hives have been deployed at other locations, further away, but still in Southern England, at sites in Surrey, Sussex and Devon.

A. Novel Hive Design

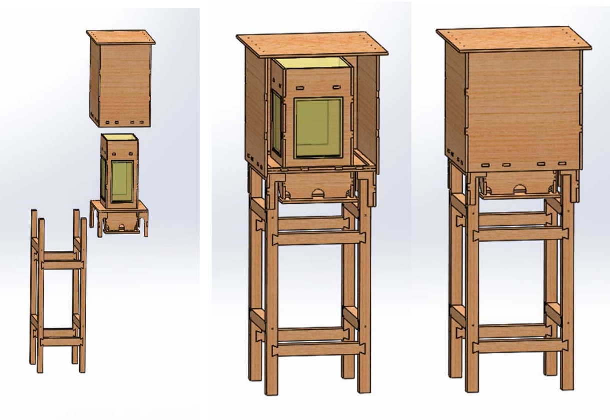
As noted above, traditional beehives are designed so as to be easy for beekeepers to make inspections and remove honeycombs. However, our primary aim is to promote bee well-being rather than make the work of beekeepers easy. We have followed some of the observations made by Seeley [2] concerning what types of "nest sites" or hives tend to be preferred by honeybee swarms seeking a new home – namely that the hive should have a volume of about 40 litres, and that the entrance to the hive should have an area of around 12.5 cm^2 and be South-facing. However, we have compromised on some of Seeley's principles – notably that the hive should be around 5 metres off the ground. Whilst this may be advantageous in deterring predators, honey thieves, etc., it is impractical from the point of view of making the hive accessible for maintenance and inspection. Our design instead hosts the hive around 1.5 metres off the ground – much less than proposed by Seeley, but considerably more than the 30 – 50 cm commonly used by beekeepers, and may be sufficient to deter ground-based predators.

Nest-site properties for which honeybees do or do not show preferences, based on nest-box occupations by swarms.

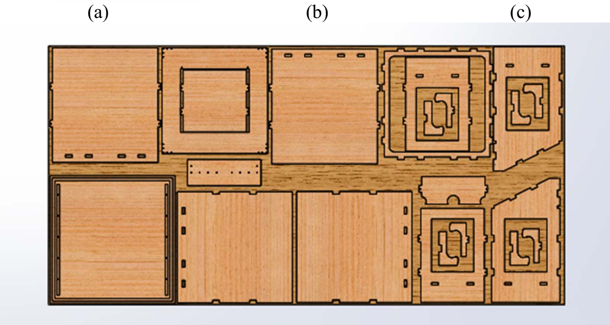
Property	*Preference*	*Function*
Size of entrance	12.5 > 75 cm^2	Colony defense and thermoregulation
Direction of entrance	South > north facing	Colony thermoregulation
Height of entrance	5 > 1 m	Colony defense
Position of entrance	Bottom > top of cavity	Colony thermoregulation
Shape of entrance	Circle = vertical slit	None
Volume of cavity	10 < 40 > 100 liters	Storage space for honey and colony thermoregulation
Combs in cavity	With > without	Economy in nest construction
Shape of cavity	Cubical = tall	None
Dryness of cavity	Wet = dry	Bees can waterproof a leaky cavity
Draftiness of cavity	Drafty = tight	Bees can caulk cracks and holes

A > B, denotes A is preferred to B; A = B denotes no preference between A and B.

Fig. 1 Seeley's findings on honeybee nest site preferences (from [2]).



(a) (b) (c)



(d)

Fig. 2 Design of the physical body of our novel hive : (a) Indivdual components : cover, body and stand; (b) Assembled, but with front cover removed for inspection; (c) Assembled, with full cover fitted; (d) Design of components all on a single sheet of weather-resistant fibreboard, ready for laser cutting.

B. *Sensors for Hive Monitoring*

In the case of the hives already deployed, we are employing a network of sensors designed and implemented by the company, Arnia [17], who have been designing and implementing hive monitoring systems for several years. However, Arnia's systems and services come at a substantial cost, which may be prohibitively high for many beekeepers. Thus, we have also designed our own bespoke sensor network, and we intend to test and evaluate both systems, comparing them for cost, effectiveness (in terms of efficient monitoring of the hives) and value for money. The sensors in our bespoke system will monitor temperatures, mass, sound, relative humidity, gas (pheromone) level, air pressure, and video images. We believe that, in terms of utility for our aforestated aims, the most important sensors, in decreasing order of importance, are weather sensors (external temperature, rain and wind monitoring), which monitor conditions influencing availability of forage, ease of flying, etc.; hive mass monitoring (which can be used to keep track of honey and brood production, and help predict when a swarm night occur); internal temperature and humidity can be very important for making inferences about the activity of the colony and the likely well-being of the brood; and acoustic sensors (microphones) can be used to detect queenlessness, and the likelihood for the bees to swarm; calibration of a gas detector in order to detect and monitor bee pheromones could be useful, but it is not obvious to what extend this would be possible; finally, video monitoring could yield very useful information, but would require very large amounts of data storage, so is not considered a top priority for the time being.

The hives fitted with the Arnia sensors were deployed in mid-March 2016, in good time to anticipate the 2016 swarming season (in the mid-late Spring). However, very little data has been acquired at the time of writing, and nothing warranting detailed analysis so far, but data is now coming in (June 2016) and it is hoped we will have enough to perform meaningful investigation and pattern recognition soon.

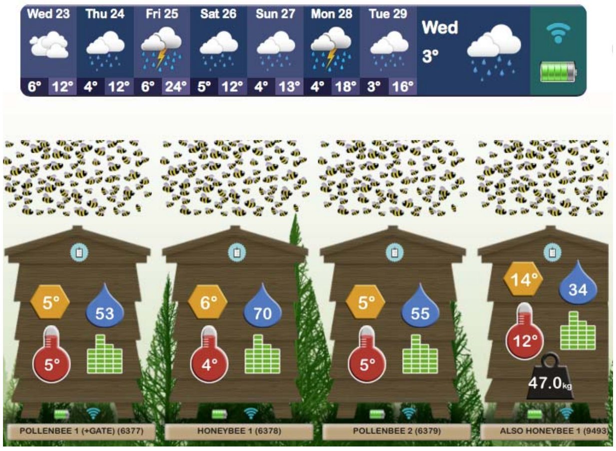


Fig. 3. View of GUI display for monitoring four of our hives deployed in the field, using Arnia sensor technology. The numbers in the yellow hexagon indicates the temperature in the hive's "brood box", and in the red "thermometer" the ambient temperature in the hive. The number in the blue drop shape is the relative humidity (as a percentage) and the green "towers" indicate the levels of sound. The black "weight" symbol indicates the current mass or weight of the hive realtive to when it is empty (only the rightmost hive contained any bees at that time). The "bee" pattern indicates the level of hive activity, and other symbols show the recent and current weather conditions at that site, the wireless connection signal strength and the system's battery level.

IV. Proposed Methodologies for Analysis

Although it is difficult to be precise about the methodologies which will be most appropriate for the analysis of the data until a substantial quantity of it has been acquired, in this section we describe methods likely to be suitable for analyzing the data expected to be obtained in this study.

The data will be intrinsically somewhat heterogeneous – including temperatures, mass, sound, relative humidity, gas (pheromone) level, air pressure, and video images. However, the data are in the form of times series, even if different quantities are sampled at different frequencies. These different sampling rates will mean that comparison between the various series will have to be carried out in terms of the real time which has elapsed since some reference point, rather than simply the number of samples. It is expected that each of the signals will include periodic components – for example, there will almost certainly be a daily component (with period 24 hours) to the ambient temperature – so methods such as autocorrelation, Fourier and cepstral analysis will be appropriate for identifying these. Furthermore, it is expected that there will be relationship between the different series – for example, there may be a relation between the temperature and the sound level in the hive. However, these signals may not rise and fall at exactly the same times – there may be a time lag between a change in one and the corresponding change in the other. This will require cross-correlation analysis, allowing for the inclusion of a time lag between the signals.

Once one aim of this project is to predict notable events in the bee colony's years, such as when the colony is about to swarm, intelligent pattern recognition algorithms will be required. In our previous paper on this topic [15], we employed a self-organising map [16] to explore patterns in the sounds produced by the colony over time. However, this approach had various limitations, and a wider range of machine learning pattern recognition methods [18] should be explored. Analogies could be made with the types of approach used to identify temporal patterns associated with the "Activities of Daily Living" (ADL) of people [19] – for example, Hidden Markov Models [20, 21] have been extensively used to recognize patterns, both in human speech and in other "state based" systems (e.g. [22]).

V. Summary and Future Work

The aim of this project is to present and implement an original and valid solution to a real world problem, namely honeybee colony decline, which is being taken seriously by government bodies in many countries. We have designed, built and deployed several "smart hive", with both a novel physical design and an intelligent sensor network, to allow non-invasive continuous monitoring of honeybee colonies to try to ensure their well-being and provide early warning of events such as swarming or problems such as infestation by parasites.

However, at the time of writing, these "smart hives" had only recently been deployed in the field, so to date very little data has been acquired. The analysis and interpretation of the data therefore remains work for the future. We also recognise that the philosophy of our proposed approach – to promote a more natural lifestyle for honeybees, focusing on their role as pollinators rather than on honey production – may meet some resistance from established conventional beekeepers. Nevertheless, there may be room for compromise using a hybrid approach – perhaps making use of innovations such as the "flow hive" technology [23] recently developed by beekeepers in New Zealand, which allows harvesting of honey from hives in a controlled and non-invasive way, causing much less stress and disruption to the bee colony than do conventional honey extraction methods.

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