# Big Brother for Bees (3B) – Energy Neutral Platform for Remote Monitoring of Beehive Imagery and Sound

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***Abstract*— Honey bees have played a major role in the history and development of humankind, in particular for nutrition and agriculture. The most important role of the western honey bee (*Apis mellifera*) is that of pollination. A large amount of crops consumed throughout the world today are pollinated by the activity of the honey bee. It is estimated that the total value of these crops stands at 155 billion euro annually. The goal of the work outlined in this paper was to use wireless sensor network technology to monitor a colony within the beehive with the aim of collecting image and audio data. These data allows the beekeeper to obtain a much more comprehensive view of the in-hive conditions, an indication of flight direction, as well as monitoring the hive outside of the traditional beekeeping times, i.e. during the night, poor weather, and winter months. This paper outlines the design of a fully autonomous beehive monitoring system which provided image and sound monitoring of the internal chambers of the hive, as well as a warning system for emergency events such as possible piping, dramatically increased hive activity, or physical damage to the hive. The final design included three wireless nodes: a digital infrared camera with processing capabilities for collecting imagery of the hive interior; an external thermal imaging camera node for monitoring the colony status and activity, and an accelerometer and a microphone connected to an off the shelf microcontroller node for processing. The system allows complex analysis and sensor fusion. Some scenarios based on sound processing, image collection, and accelerometers are presented. Power management was implemented which allowed the system to achieve energy neutrality in an outdoor deployment with a 525 x 345 mm solar panel.**

***Keywords—Wireless Sensor Networks; Beekeeping; Low Power; Intelligent Environments; Environmental Monitoring; Internet of Things***

## I. INTRODUCTION

The need for improved bee keeping has been discussed repeatedly in recent years. It is clear that the global stock of honey bees is growing at a much slower rate than agricultural demand for pollination . Although the population of managed honey-bee hives has increased by approximately 45% in the last 50 years, the fraction of agriculture that depends on pollination has increased by over 300% [1]. From an ecological perspective, honey bees provide a source of both direct and indirect food to a whole host of organisms, including humans. Over time different environments experience pests, new diseases etc. Genetic diversity within plant populations (for which pollination is essential) allows them to adapt to and overcome these changes over time [2]. For these reasons, as well as many others, finding new methods of protecting the honey bee population has become a key focus within academia, as well as industry.

Visual inspection of the bee colony is an important tool for the beekeeper to determine the condition of the hive. The aim of the work described was to implement a visual monitoring system into the hive interior, which would have minimal impact on the bees. Honey bees cannot perceive light in the infrared (IR) spectrum, therefore an infrared camera together with an array of IR LED's were used to collect images from inside the hive. Visual inspection of the hive exterior is also important, as well as observing the activity of the bees exiting the hive. Thermal imaging of the hive exterior can be used to assess the beehive population in a non-invasive manner. [3] To facilitate the most complete possible overview of the hive activity and conditions a system including an internal thermal imaging sensor, and two external cameras (CMOS and FLiR long wave infrared sensor) is proposed. These sensors are utilised in a WSN with significant computational capabilities which can collect and process the image data.

It is possible to gain a large amount of information from monitoring the varying sounds occurring within a beehive. In this project the amplitude of the sound within the hive was monitored and the bee keeper was alerted by SMS when the sound levels within the hive increased substantially. A sudden rise in noise levels from the honey bees could reflect a variety of events which may result in loss of profit to the bee keeper, such as invasion by a pest or a hive reproduction event known as "swarming". Swarming is an activity where a honey bee colony splits in two to form a new hive. The term "piping" refers to the sounds made between queen bees during these events. [4]

Beehives are made of light materials such as wood, and are often located in remote areas with very little security. They are susceptible to being knocked over or disturbed by high winds, passing animals, or even sabotaged by humans. If the beehive was to fall or be opened, it could result in the loss of some if not all the population of the hive. In this paper a crucial event alert system within the hive is described, which alerts the beekeeper to the hive falling over or moving. This was achieved by integrating an accelerometer into the hive lid, this sensor is used to determine if the hive has fallen over, or if someone has removed the hive lid.

As the vast majority of beehives are kept in rural locations, where access to power lines and internet connections are extremely limited, GSM/GPRS networking was selected. This solution allowed the smart beehive to send texts to the beekeepers cell phone when the hive needs attention as soon as possible, as well as being able to upload collected images. This allows the beekeeper to reduce the frequency of hive visits, as the hive information can be accessed remotely.

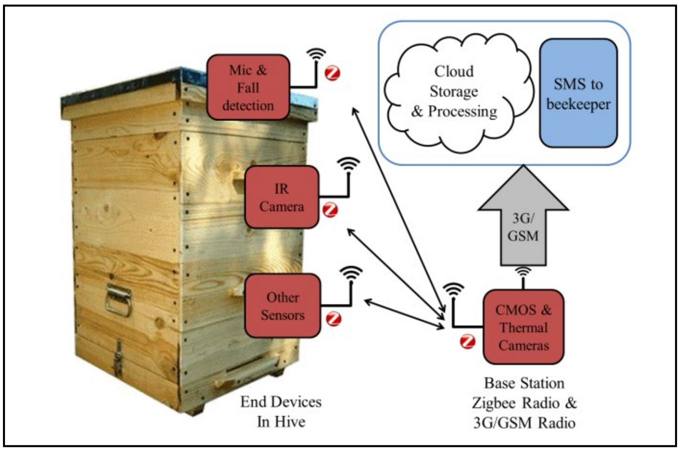


Fig. 1. Smart hive network concept

The aim of the work described in this paper was to develop a system utilising Wireless Sensor Network (WSN) technology, including sensors, low power processing, mobile networking and energy harvesting to monitor conditions and activity within an active beehive. WSN are the core technology of the "Internet of Things" concept and have found applications in nearly every aspect of human life [5] [6]. The final system is designed to work in conjunction with the existing Smart Beehive project developed jointly by the Embedded Systems Group and School of Biological Earth and Environmental Sciences at University College Cork [7]. This project was awarded first place in the "IBM/IEEE Smarter Planet Challenge: Student Projects Changing the World 2014". The contributions of this paper are as follows: utilising WSN technology in a novel application to monitor the sound levels, hive movement, and physical appearance of the bee colony; unobtrusive monitoring of the beehive during times when the beekeeper is unable to open it; development of a multi data source hive monitoring system; and a review of the system performance. The key feature of the system is its energy neutrality as well as the heterogeneous vision system implemented allowing monitoring in most diverse situations. This paper is organized as follows: section 2 describes the existing work in the area; section 3 justifies the sensor selection from a beekeeping perspective; section 4 outlines the systems functionality and features; section 5 shows some initial results of the implementation of the demonstration system; and section 6 concludes the paper.

## II. Previous Work

Using data collection to evaluate the conditions of bee hives has been a topic of high interest in academia in recent years. In [8] an invasive method for hive monitoring was proposed. In [9] Phillips et al. propose an open source WSN system for predicting swarming, but only in hot climates. The system described in this paper is effective in any climate and does not involve invasive methods. The range of commercially available technology for bee hives has expanded in recent years. Two such companies are "Arnia – remote hive monitoring" and "BeeWise". BeeWise allows beekeepers to get SMS updates of the weight of their hives. This is useful in deciding when to harvest the honey as well as understanding when the hive is not functioning properly [10]. Arnia takes in much more information with its system, which includes sound, vibration, temperature, humidity, hive weight, rainfall, and sunshine. [11] The system described in this paper achieves many of the above objectives, and can also detect swarming or other major sound events in the hive, and capture images of the hive routinely.

Some research has been carried out in the field of sound analysis within a hive. An example of such research is that of Eren et al. [12]. In their research, 3 separate hives were monitored for over 10 days, using both microphones and thermometers. The sounds were recorded with a sample rate of 2 KHz and analysed using various computer software. During the period, 9 different swarming events occurred. There were two major indicators of the swarming occurring, namely, an increase in the power spectral density at about 110 Hz and an increase in temperature from 33°C to 35°C. This was until the swarming actually occurred, when the temperature dropped to 32°C due to the ventilation from the bees' wings. Using these features it was possible to predict when a swarm was imminent. The second such research focused on the occurrence of piping within the hive. This work was carried out by recording the sounds made by a worker bee, then comparing this with the sounds made by a queen bee. It was concluded that the queen bee emanates sounds at relatively higher frequencies. Following this initial work, an attempt was made to control the queen bee's behaviour using computer simulated sounds [13].

In [3] Shaw et al. confirmed that long wave infrared (i.e. thermal) imaging of the hive exterior is an effective method for investigating the condition of honey bees in a non-invasive manner. Shaw et al. presented a solution which is susceptible to error when the hive is heated by the sun/cooled by wind, or if nearby objects are in frame. The platform described in this paper can use data from other nodes in the network to validate and improve the measurements from the FLiR sensor.

Energy harvesting and power management techniques [15] – [19] have become vitally important to WSN especially when power hungry sensors such as cameras are used [15] [16]. In [20] a combination of energy harvesting and wake up radio [21] to achieve an optimized power management to reduce the activity of the camera to extend the life time whole network.

The work described in this paper is designed to be used in conjunction with a larger sensor network designed and developed by the Embedded Systems group at UCC for monitoring the health of the beehive as shown in Fig. 1. This sensor network was capable of monitoring parameters such as temperature, $CO_2$, pollutants, $O_2$, $NO_2$, relative humidity, and dust. Weather conditions throughout the monitoring stage were recorded and a relationship between external weather conditions and hive conditions were observed. [7] The data collected were analysed from a biological perspective, by group members from the School of Biological Earth and Environmental Sciences (BEES). This allowed for the development of an algorithm for automatically detecting the state of the bee hive, without the need for human interaction. Following this a second algorithm was developed which predicted short term weather conditions in the area around the hive such as imminent rain fall. [14]

## III. Beekeeping Impact

Visual inspection of the hive is one of the most important activities in which a beekeeper engages, it is used to examine the condition of the honey bees, including the number of workers and drone bees, the development of the bees, and examine for queens. Visual inspection also allows the keeper to detect a range of diseases by removing frames and examining them. However, a thorough inspection is a time consuming and invasive process, which aggravates the honey bees, exposes the inside of the colony to the external weather conditions, and can lead to bees being crushed when the keeper moves frames. Infrared cameras providing high quality images of the hive interior to the beekeeper remotely, such as the ones described in this work, have the potential to provide information on colony condition and disease, thereby reducing the frequency of physical inspections.


Fig. 2. Development platforms and sensors used in work

Many beehives are kept in remote or rural locations. Inspections of hives in such locations require long journeys. They are also often placed in farmland or forests where they may be near livestock or other animals which can knock over a hive. Hives can also be knocked over in high winds. In all such cases it is vital to reassemble the hive as soon as possible after falling to minimise losses. The system in this paper eliminates the need to inspect every hive for such damage regularly.

## IV. SYSTEM FUNCTIONALITY

### A. *Sensor Node Architecture*

Two different development platforms were used in the prototype. They and other hardware used can be seen in Fig. 2:

*1) Libelium Waspmote*

The Libelium Waspmote was an open source wireless platform. It was an ATmega based platform with an ultra-low power design, with a range of 70 sensors. It has been widely used in previous iterations of the UCC smart hive project, connecting it to different sensors within the hive. The main use within this work was to run the real time processing for the accelerometer and microphone, and to use these data to send warnings to the bee keepers in times of danger within the hive.

*2) Raspberry Pi*

For the camera to work simultaneously with the accelerometer and microphone, a second, more powerful processor was required. The controller chosen was the Raspberry Pi Model B. It had 512 MB of RAM, HDMI connection, 2 USB ports and 26 GPIO pins. It also had an SD card slot, which was used to store the image data.

*3) Networking*

The SIM900 (SIMCom) GSM/GPRS module was selected for networking. This module has ultra-low power operation (30uA) and provided phone call, SMS and FTP upload/download operations. GSM/GPRS networking was selected to suit the remote deployments of many beehives.

### B. *Camera*

In this project an infrared sensor allows the tracking of the activity in the hive throughout the winter months so as to gain a better picture of the overall activity in the hive. During the summer months the beekeeper often opens the beehive roof to visually inspect the colony. During the winter, bad weather, or at night opening the hive can damage the colony by allowing them to get cold or damp. A system comprising of a Raspberry Pi, an infrared camera and an array of IR LED's was developed which provides a clear picture in the low-light hive, without disturbing the bees. A thermal imaging camera node with a Raspberry Pi was also developed to provide the keeper with an image that describes the activity of the colony within the hive.

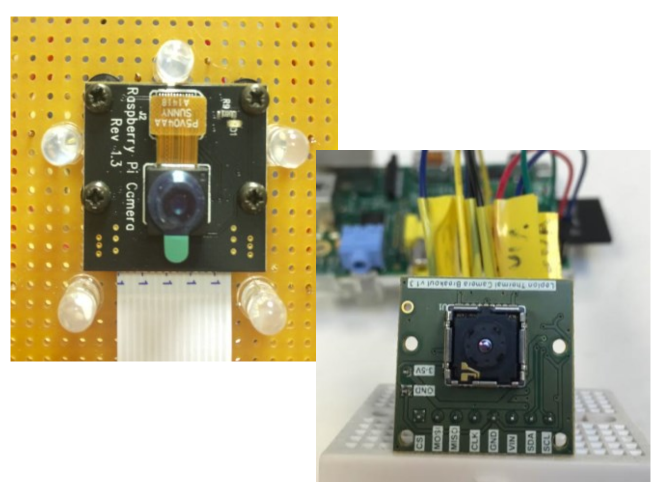


Fig. 3. Infrared camera module and thermal imaging module

*1) Sensors*

Bees are not able to see light in the infrared spectrum (1 mm – 750 nm). Using infrared light to flood the inside of the hive, then taking an IR picture of the colony's activities, allows monitoring of the bee hive, even during the night, while remaining completely undisruptive to the bees in a live deployment.

The camera chosen for the prototype was the Pi NoIR camera (Fig. 3). The sensor had a 5 megapixel resolution and supports video up to 1080p. The NoIR was designed to interface with the Raspberry Pi board, and there were many existing libraries available to use the camera and Pi together for video and image capture. A Lepton long wave infrared imaging sensor development kit was selected to provide thermal imaging for the deployment. It provided 80 X 60 pixel resolution images over an SPI connection and is sensitive to infrared radiation in the wavelength range of 8 – 14 µm.

*2) Implementation*

To implement both cameras into the design, the software deployed on the Raspberry Pi modules took a picture five times per day and stored them on an SD card with a time stamp. Each Raspberry Pi was then turned off and rebooted by a Waspmote, to maximise energy performance. The Waspmote handled the sleep modes as the Raspberry Pi does not have any such function. The image files were saved to the SD card so the beekeeper could collect them for inspection. The images could also be retrieved from the SD through the network by the GSM/GPRS module and uploaded to a server via FTP. It was calculated that with an average jpeg image size of 3 MB, and an SD card of 8 GB then the bee keeper would only have to replace the SD every 111 days. Another envisaged scenario is for event driven image capture and send using GSM, giving the user a better understanding of the causes of the event.

### C. *Sound Detection*

Monitoring the sound a colony emits is a vital tool for a beekeeper. A variety of diseases, foraging activities, and colony events can be clearly identified through sound. Arguably one of the most important sounds a beehive emits takes is a large increase in sound levels which takes place during "swarming", which is the means by which a second new colony is formed form an existing hive. In this work a microphone was used to identify an increase of the sound levels within the hive. This could not only indicate swarming, but that the bees were showing aggression towards an intruder in the hive, for example a mouse creating a nest in the hive, or a larger animal or human approaching the hive.

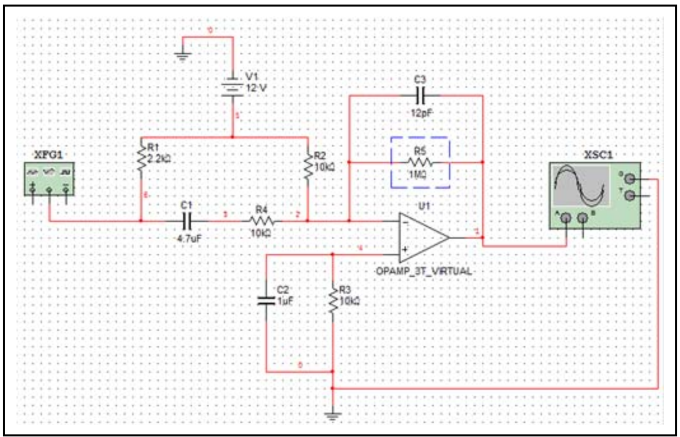


Fig. 4. Sound detection circuit

*1) Sensors*

The microphone used was the SparkFun Electret Microphone Breakout as seen in Fig. 2. Accompanying the microphone was a circuit with an op amp (OPA344) which was used to amplify the sound from the microphone so that the analogue input pins of the Waspmote microcontroller could sample them effectively.

*2) Implementation*

Fig. 4 illustrates a simulation of the circuit used for the microphone design. Using this microphone circuit, sound processing was implemented to allow for the detection of major acoustic events within the hive. As a major aim of the project was to provide a low power platform suitable for remote deployment, solutions for monitoring the sound without sampling at audio quality frequencies were selected. The signal processing techniques selected required sampling of the microphone at 100Hz.

*3) Signal Processing*

The objective of the sound detection node was to pick up major sound disturbances within the hive. Once a disturbance occurs, and is found to be sustained over several seconds, a text alert was sent to the bee keeper, to inform them to check on the hive as soon as possible. To design an algorithm to detect this, several recordings of calm, aggravated and swarming hives were analysed and compared. Tests were carried out in relation to distance of microphone from the sound source to give the best results and to reduce false positives. Once an optimum distance was reached, this distance would be set for the remainder of the analysis and be placed at that distance on deployment within the hive.

Software filters were used to detect elevated sound levels in the hive. This software was implemented on the Libelium Waspmote. The magnitude of the sound detected by the microphone was first calculated, and then a threshold was applied to each resulting data point where the value was kept if it met the threshold, or forced to zero if it did not. Finally the remaining points were put through a moving average filter. If the output of this filter confirmed that the increased noise levels were in fact sustained over time (rather than say one bee flying near the microphone), this would be seen as a sign that the colony was indeed increasing its volume and a warning text was sent to the bee keeper.

### *D. Fall and Movement Detection*

A GPRS enabled WSN node was developed (Fig. 5) to alert the beekeeper via SMS when crucial beehive events are detected. This was achieved with an accelerometer interrupt when the hive is found to be moving (for beehive security).

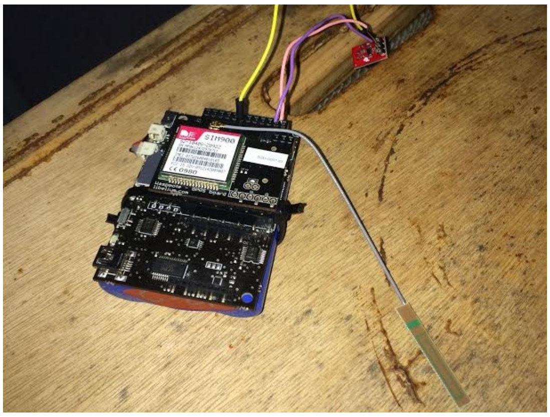

Fig. 5. Sound and movement detection node

*1) Sensors*

The accelerometers used in this project measure the tilt and orientation of the hive lid, and, using these data the sensor node can alert the bee keeper if this tilt reached a critical point. The accelerometer used was the LIS331DLH. This is a “nano” 16 bit digital output, low-power, linear accelerometer which detects up to ±8g.

*2) Architecture*

The accelerometer in this work measured acceleration values in the range of ±2g at a 16 bit resolution. The equation used to calculate the angle of tilt of the hive was as follows:

$$\text{Angle}=180/\pi(\text{Sin}^{-1}(\text{AV}/100))$$

Using this it was possible to find the angle of tilt. This angle was monitored and, if it was found to be changing, an interrupt was generated and an alert was sent to the bee keeper. This is accomplished within the design by either sending a message through the Zigbee network or an SMS.

## V. RESULTS

### *A. Infrared Camera*

A test was run of the camera within an empty hive in a laboratory for 4 days, the result of which seen in Fig. 6. It can be seen that there is little to no change in quality of the pictures throughout the course of the day, even though the amount of light in the surrounding room changes. These images are clear and are of high enough quality for the keeper to identify bees and assess their condition. Careful placement of the cameras within the hive space to capture the frames at an angle which would be of most use to the keeper is required.

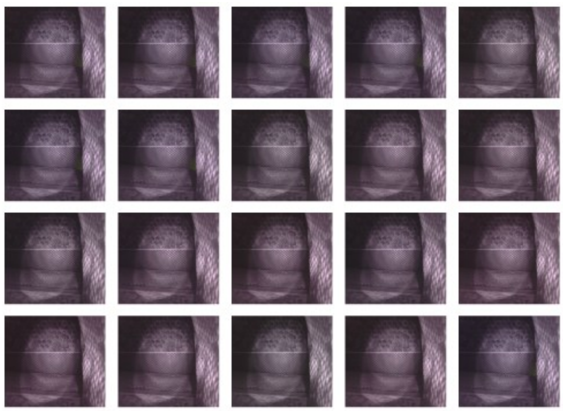

Fig. 6. Images captured by infrared module

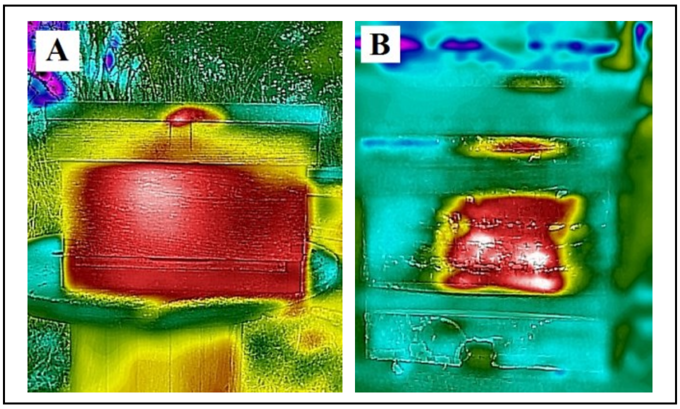


Fig. 7. Images captured by thermal imaging node

## B. *Thermal Imaging Node*

The thermal imaging node was tested by bringing it to the site of the live apiary used in previous experiments by the group and capturing an image on several different days to capture the changing hive conditions during different weather patterns. Two such images can be seen in Fig. 7. In Fig. 7A the temperature of the hive is much higher and the hot air escaping through vents at the top of the hive allowing the bees to control their conditions can be seen. In Fig. 7B the ambient temperature is far cooler and the bees gathering together in the centre of the hive can be clearly seen. In both images the lower temperature of the surrounding environment is easily distinguishable from the hot areas created by the honey bee clusters in the hive. Image processing to estimate the size of these "hot spots" could be used in conjunction with the data from the other sensors (temperature, humidity, sound, CO2) to estimate a variety of factors, such as: number of bees foraging, health of the hive, hibernation, or swarming.

## C. *Sound Recording*

The response of the sound detection node to a high quality recording of a "piping" beehive is shown in Fig. 8. In Fig. 8 the elevated noise levels during the piping can be clearly seen, as well as the response of the filter which triggered an alert.

## D. *Fall/movement detection*

To test the fall/movement detection node several laboratory tests were run of the hive being knocked over and opened. The resulting movement detected by the node is shown in Fig. 9. It can be seen that initially the device is at rest. It is then moved in space, corresponding to the various peaks and troughs in the plot. Finally it is brought to rest again. This clarifies that the accelerometer can detect movement in all 3 dimensions.

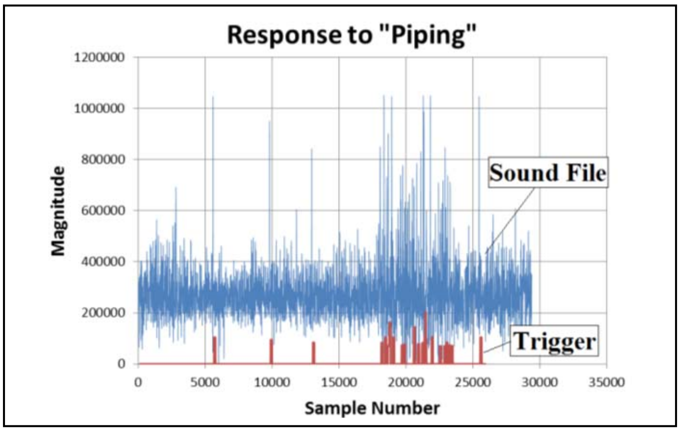


Fig. 8. Response of sound detection node to "piping"

## E. *Text alerts*

A series of tests were carried out on the text alert function to test the time it took for the bee keeper to receive a text alert after an event. This generated the results found in Table 1.

TABLE I. ALERT DELAY TEST

| Test | Time Delay (s) |
|---|---|
| 1 | 4.5 |
| 2 | 6 |
| 3 | 7 |
| 4 | 8 |
| 5 | 10.2 |
| 6 | 5.4 |
| 7 | 8 |
| 8 | 9.3 |
| 9 | 6 |
| 10 | 11.2 |

The average time from bee hive to bee keeper, from the data, was found to be approximately 7.56 seconds. This is appropriate for the design, as without which, bee keepers would not notice problems within the hive until they visit the hive and inspect it, which could be up to several days.

## F. *Power & Energy Analysis*

For the system to be truly autonomous it was necessary for it to be energy neutral. This was achieved through the implementation of energy harvesting through solar panels and energy storage in a 1000 mAh battery (storage in the case of several days with no sunshine). To test that the system would be energy neutral for long deployments in an environment with little sunshine such as Ireland a power analysis and energy budget were undertaken. This power analysis assumed the worst case scenario of maximum current draw for each of the nodes' operations over 5 samples per day.

For the energy budget the total energy used by the nodes in the worst case was calculated. Sufficient energy was harvested by the solar panel (525 x 345 mm max operating output of 20W) in 2 hours of typical direct sunshine in Ireland, where a efficiency of $\eta$=0.44 can be expected (determined through previous work in this area [7]). The result was that the energy provided by the solar panel exceeded the requirements, and the system was energy neutral. The results of the power and energy analysis are shown in Table 2 and Table 3.

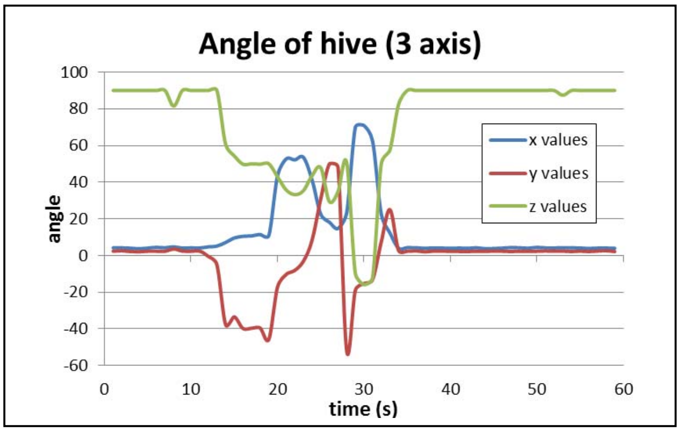


Fig. 9. Results of movement detection test

TABLE II. POWER ANALYSIS

| Unit | Power Results | | | |
|---|---|---|---|---|
| | *Task* | *Current (mA)* | *Voltage (V)* | *Power (mW)* |
| **Sound & Movement** | µC on + Sense | 30 | 3.7 | 111 |
| | µC Sleep | 0.55 | 3.7 | 2.03 |
| | Send | 220 | 3.3 | 726 |
| **Thermal Imaging** | µC on + Sense | 780 | 5 | 3,900 |
| | µC Sleep | 0.55 | 5 | 2.75 |
| | Send | 220 | 3.3 | 726 |
| **Infrared Imaging** | µC on + Sense | 765 | 5 | 3,820 |
| | µC Sleep | 0.55 | 5 | 2.75 |
| | Send | 220 | 3.3 | 726 |

TABLE III. ENERGY BUDGET CALCULATIONS

| Unit | Energy Budget for one 24 hour cycle | | | |
|---|---|---|---|---|
| | *Task* | *Power (mW)* | *Function Time (min)* | *Energy (J)* |
| **Sound & Movement** | Sense | 111 | 15 | 99.9 |
| | Send | 726 | 5 | 217.8 |
| | Sleep | 2.03 | 1420 | 175.3 |
| **Thermal Imaging** | Sense | 3,900 | 5 | 1,170 |
| | Send | 726 | 5 | 217.8 |
| | Sleep | 2.75 | 1430 | 237.6 |
| **Infrared Imaging** | Sense | 3,820 | 5 | 1,146 |
| | Send | 726 | 5 | 217.8 |
| | Sleep | 2.75 | 1430 | 237.6 |
| Total Expenditure: | | | | 3,719 |

## VI. CONCLUSIONS

An autonomous bee hive monitoring system has been developed and presented. With the use of a microphone, accelerometer, infrared and thermal cameras, the prototype system monitors the bees for emergency events, as well as providing beekeepers with imagery and sound data which they can use to observe the condition of the colony. Three nodes were tested and found to be suitable for the beekeeping applications for which they were designed. The final design is low power and is self-sustainable with the aid of energy harvesting via solar panels. This was confirmed through a power analysis and energy budget.

The next step will be to set up the project in a live apiary to see how the system responds in a real world deployment. This would also deliver valuable real world data from the bee hive, which can be used to further research into bee keeping. Combining the work in this paper with the existing smart hive described in [14] monitoring humidity, CO2, temperature etc. will be an important future step. Combining these data with the sound and visual data collected by the system in this paper, would to build up an in-depth picture of the hive.

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## REFERENCES

[1] M. Aizen and L. Harder, 'The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination', Current Biology, vol. 19, no. 11, pp. 915-918, 2009.

[2] N. Bradbear, Bees and their role in forest livelihoods. Rome: Food and Agriculture Organization of the United Nations, 2009.

[3] J. Shaw, P. Nugent, J. Johnson, J. Bromenshenk, C. Henderson and S. Debnam, 'Long-wave infrared imaging for non-invasive beehive population assessment', Opt. Express, vol. 19, no. 1, pp. 399-408, 2010.

[4] J. Simpson, "The mechanism of honey-bee queen piping." Zeitschrift für vergleichende Physiologie, vol. 48 no.3, pp. 277-282, 1964

[5] J. Fernández-Berni, R. Carmona-Galán, J. Martínez-Carmona and Á. Rodríguez-Vázquez, 'Early forest fire detection by vision-enabled wireless sensor networks', Int. J. Wildland Fire, vol. 21, no. 8, pp. 938 - 949, 2012.

[6] M. Delamo, S. Felici-Castell, J. Pérez-Solano and A. Foster, 'Designing an open source maintenance-free Environmental Monitoring Application for Wireless Sensor Networks', Journal of Systems and Software, vol. 103, pp. 238-247, 2015.

[7] F. Edwards Murphy, E. Popovici, P. Whelan, and M. Magno, "Development of an heterogeneous wireless sensor network for instrumentation and analysis of beehives," 2015 IEEE International Instrumentation and Measurement Technology Conf., Pisa, Italy, 2015.

[8] J. Odoux, P. Aupinel, S. Gateff, F. Requier, M. Henry and V. Bretagnolle, 'ECOBEE: a tool for long-term honey bee colony monitoring at the landscape scale in West European intensive agroecosystems', J. of Api. Res, vol. 53, no. 1, pp. 57-66, 2014.

[9] R. D. Phillips, J. Blum, M. A. Brown, and S. L. Baurley "Testing a grassroots citizen science venture using open design, the bee lab project," CHI'14 Extended Abstracts on Human Factors in Computing Systems, ACM, pp. 1951–1956, 2014.

[10] Beewise.eu, 'Bee hive monitoring, bee keeping equipment - Beewise', 2015. [Online]. Available: http://www.beewise.eu. [Accessed: 17- Apr- 2015].

[11] Arnia.co.uk, 'Remote Bee Hive Monitoring System', 2015. [Online]. Available: http://www.arnia.co.uk/. [Accessed: 17- Apr- 2015].

[12] S. Ferrari, M. Silva, M. Guarino and D. Berckmans, 'Monitoring of swarming sounds in bee hives for early detection of the swarming period', Computers and Electronics in Agriculture, vol. 64, no. 1, pp. 72-77, 2008.

[13] H. Eren, L. Whiffler, and R. Manning, "Electronic sensing and identification of queen bees in honeybee colonies," in IEEE instrumentation and Measurement Technology Conference, Ottawa, Canada, pp. 1052 – 1055, 1997.

[14] F. Edwards Murphy, M. Magno, P. Whelan, and E. Popovici, "b+WSN: Smart Beehive for Agriculture, Environmental, and Honey Bee Health Monitoring - Preliminary Results and Analysis" Sensors Applications Symposium (SAS), 2015, Zadar, Croatia, 2015

[15] M. Magno, D. Brunelli, L.Thiele, and L. Benini, "Adaptive power control for solar harvesting multimodal wireless smart camera," Distributed Smart Cameras, 2009. ICDSC 2009. Third ACM/IEEE International Conference on , pp. 1-7, 2009

[16] A. E. Șușu, M. Magno, A. Acquaviva, D. Atienza, and G. De Micheli "Reconfiguration strategies for environmentally powered devices: theoretical analysis and experimental validation." Transactions on High-Performance Embedded Architectures and Compilers I. Springer Berlin Heidelberg, pp. 341-360, 2007.

[17] A. Kerhet, F. Leonardi, A. Boni, P. Lombardo, M. Magno, and Luca Benini. "Distributed video surveillance using hardware-friendly sparse large margin classifiers," Advanced Video and Signal Based Surveillance, 2007. AVSS 2007. IEEE Conference on , pp. 87-92, 2007

[18] E. Popovici, M. Magno, and S. Marinkovic. "Power management techniques for wireless sensor networks: a review." Advances in Sensors and Interfaces (IWASI), 2013 5th IEEE International Workshop on., pp. 194-198, 2013.

[19] V. Jelicic, M. Magno, D. Brunelli, V. Bilas, and L. Benini. "An energy efficient multimodal Wireless Video Sensor Network with eZ430–RF2500 modules," Pervasive Computing and Applications (ICPCA), 2010 5th International Conference on , pp. 161-166, 2010

[20] M. Magno, D. Boyle, D. Brunelli, E. Popovici, L. Benini, "Ensuring Survivability of Resource-Intensive Sensor Networks Through Ultra-Low Power Overlays," Industrial Informatics, IEEE Transactions on , vol.10, no.2, pp.946-956, 2014

[21] M. Magno, S. Marinkovic, B. Srbinovski, and E. M. Popovici. "Wake-up radio receiver based power minimization techniques for wireless sensor networks: A review." Microelectronics Journal vol. 45, no. 12, pp. 1627-1633, 2014.