Energy harvesting devices for honey bee health monitoring

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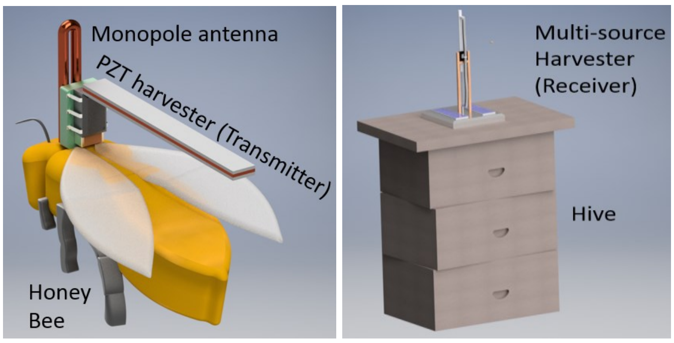
Abstract – A novel approach for real-time monitoring of honey bees across their entire foraging range is presented herein. Energy harvesting of bee mechanical vibrations is used to power the transmission of bee location data while ensuring minimal physical harm or flight hindrance. Additionally a 5.8 GHz receiver is integrated in a multisource energy harvesting unit which utilizes wind, solar and RF energy scavenging to monitor the location of the bees. Designs and considerations for the power circuitry, transmitter and receiver are discussed.

***Keywords*— Energy scavenging, honey bee, piezoelectric, multisource harvester, location monitoring**

I. Introduction

Understanding animal movement and behavior in response to environmental stimulation is fundamental to basic and applied ecology [1]. Over the past few years, honey bees (*Apis mellifera* L.) have suffered large-scale declines of colonies, however, no single cause has yet been identified [2]. Therefore, it is important to develop telemetry techniques for tracking of bee location and behavior around the hive and across its entire forage range. Current battery powered approaches can be expensive whilst also causing physical hindrance to the bees due to the devices large size and weight [1]. Battery removal through alternative energy production [3] can potentially enable light-weight "bee-wearable" tracking devices with an extended functional lifetime.



(a) (b)

Fig.1. Proposed technique for tracking bee movements. (a) Energy harvesting transmitter attached to a bee. (b) Multisource energy harvester next to bee hive to power the receiver

As a proof of concept, the design of a self-sustained communication link between a moveable transmitter and a stationary receiver is presented. The wearable transmitter will be attached to the bee's thorax and consist of a monopole antenna and a piezoelectric harvester, which utilizes the energy from the bee's own mechanical vibration. The stationary receiver is powered by a multi-source wind, solar and RF energy scavenging. The current link supports a logger monitoring bee's access to hives or feeders and can already be integrated in a smart greenhouse or polytunell using several receivers. The transmitter can be developed for long-range tracking provided it is coupled with a moveable receiver.

II. Bee Vibration Energy Harvesting Transmitter

A. Energy harvesting techniques for bees

Piezoelectric energy harvesting has shown the potential to convert insect's mechanical vibrations into constant electrical energy output [4] and has been selected to pursue aggressive weight reduction and device miniaturization. Honey bee wing beat rates vary between 208 and 277 Hz depending on physiological differences [5], temperature, humidity and tiredness [6]. This difference renders a resonant energy harvesting approach unrealistic as the vibrations will not match the resonant frequency of the harvester which could result in the generated power being orders of magnitude lower than resonance.

B. Non – resonant piezoelectric harvester

Using an external force to directly excite the tip of a cantilever beam can provide continuous deflection whilst eliminating the need to match actuation frequency and resonance. The energy scavenged is proportional to the excitation frequency, force and deflection applied by the source [4]. The power from the direct force can be estimated by:

$$P = \frac{V_{RMS}^2}{R_{LOAD}} = \frac{9}{64} \cdot \frac{E_p d_{31}^2}{\varepsilon} \cdot \omega_{ACT} \cdot K_{SPRING} \cdot Z_{PEAK}^2 \quad (1)$$

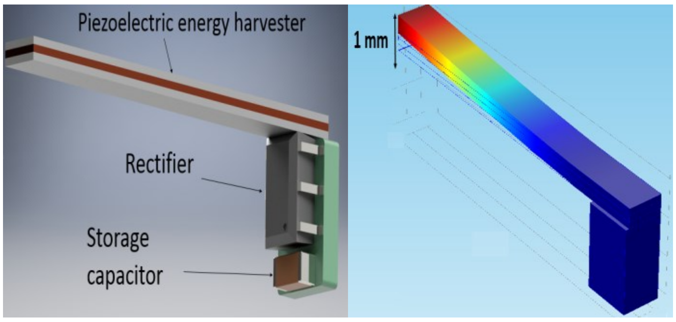
where E_p is the Young's modulus, d_{31} is the piezoelectric strain coefficient, ε is the dielectric constant, ω_{ACT} is the actuation frequency while K_{SPRING} is the stiffness of the beam and Z_{PEAK} is the maximum deflection of the beam.

III. Piezoelectric Harvester and Transmitter Prototype

A. Energy Harvester

The piezoelectric bimorph (Figure 2) [7], consists of two 130 µm thick PZT-5A layers with a 130 µm brass shim in-between. Despite PVDF (Polyvinylidene fluoride) offering advantages in terms of beam flexibility, PZT is favored for its superior power output. The device comprises a backpack attached to the bee's thorax where the power circuitry acts as a fixed post for the beam. The power circuitry consists of a rectifier chip and a small storage capacitor supporting power conditioning and bee location through a transmitting antenna.

For proof of concept and for optimization of the rectifier components, larger scale versions (36:1 and 3:1) of the bee energy harvester were realized and tested by connecting it to a mechanical shaker. Schottky diodes were chosen due to their low-voltage operation and highest rectifier output voltage.



(a) (b)

Fig.2. (a) Three dimensional model of piezoelectric harvester (top) and power circuitry (right). (b) Comsol simulation to provide displacement of piezoelectric beam

Figure 3 shows the measured power output for the scaled-up device for different values of the storage capacitor.

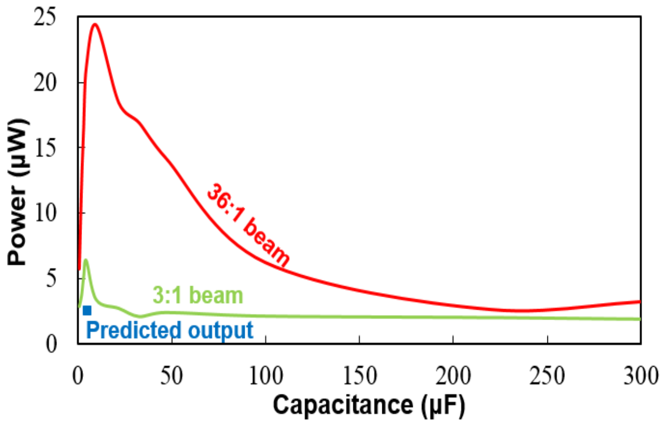


Fig. 3. Energy accumulation on storage capacitor when excited at 210 Hz for 2 seconds

While larger capacitance values would allow greater energy, storage values around 10 µF supply higher energy output with short (~ 1s) transmission periods. Multiphysics simulations provided an estimation for the beams maximum displacement and Equation 1 can be used to determine the power generated for the beam dimensions (10 mm x 1 mm x 0.51 mm). Since the estimated power does not include any losses through the rectifier, a low voltage drop of 800 mV is assumed to match a Schottky rectifier. The power output of the energy harvester is calculated to be 2.56 µW (Equation 1).

B. Transmitting antenna design

The antenna should be small, lightweight and as isotropic as possible to minimize hindrance to bee flight and transmission disruptions from direction changes. Integrating the antenna and harvester is impractical because antennas on high dielectric PZT substrates results in severe antenna loss in the material and reduced bandwidths [8]. A simple monopole configuration with a thin copper wire can ensure good directional coverage whilst minimizing the device weight, and has already been successfully employed for bee telemetry [1]. The monopole antenna prototype consists of a copper wire folded in half with a total length of 12mm and a diameter of 0.5mm. As there is a need for the devices to be commercially available for beekeepers and scientists an operating frequency of 5.8 GHz was chosen. The total efficiency was simulated to be 93%.

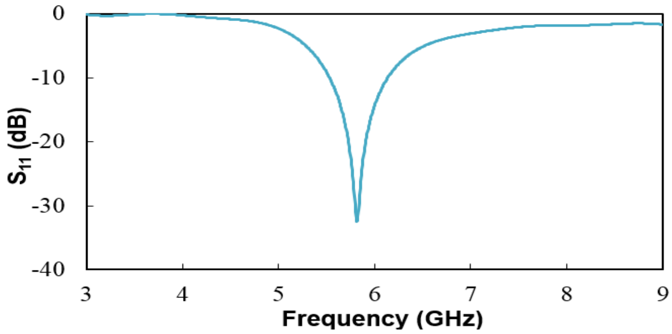


Fig.4. Simulated reflection coefficient for prototype monopole antenna

IV. MULTISOURCE ENERGY HARVESTING POWERED RECEIVER

A. The need for a multisource harvester

The receiver unit is required to store energy and log data for later use rather than for instantaneous communications as in the transmitter device. The lack of weight and size constraints for the receiver also permit the use of rechargeable batteries rather than a capacitor. A commercially available 5.8 GHz receiver is integrated to the energy harvester and powered by wind, solar and RF energy at 2.4 GHz. Although the voltage generated from the RF energy harvester is expected to be in the mV range, the 2.4 GHz antenna can also be used as a communication hub for various surrounding sensor systems to monitor the environment.

B. Multisource energy harvester prototype

The multisource energy harvester consists of a base which houses the receiver and solar cells. The base also acts to support the RF harvester. The RF harvester scavenges WIFI signals at 2.4 GHz and consists of a 620 mm aluminum rod with a 6 mm diameter. A Teflon sleeve ($\varepsilon_r = 2.1$) of length 300 mm and diameter 14 mm is placed on the top of the monopole.

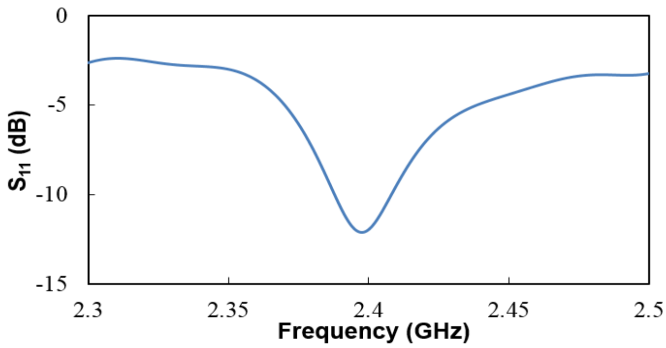


Fig.5. Simulated reflection coefficient of RF harvester monopole

The monopole also acts as a support for the windbelt as demonstrated in Figure 7. Posts are connected near the top and bottom of the monopole and a long strip of VHF tape is added between them. By placing magnets on the tape a gust of wind causes the magnets to move through a transformer thus generating energy through Faraday's induction law. The windbelt and RF energy harvester outputs are combined through a simple power processing unit.

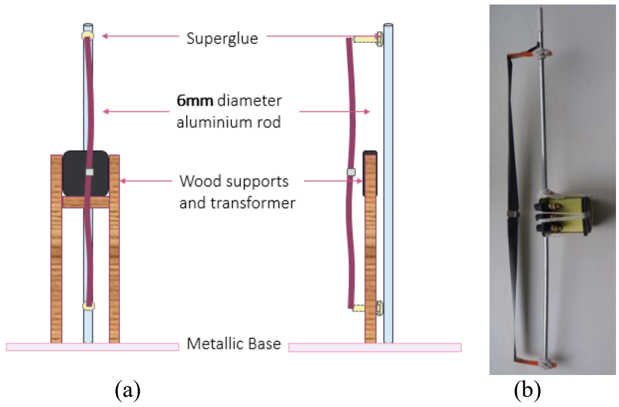


Fig.6. (a) Schematic of the implementation of the windbelt. (b) Prototype windbelt

The commercial receiver, power processing unit and solar cells will be placed on the metallic base of the device.

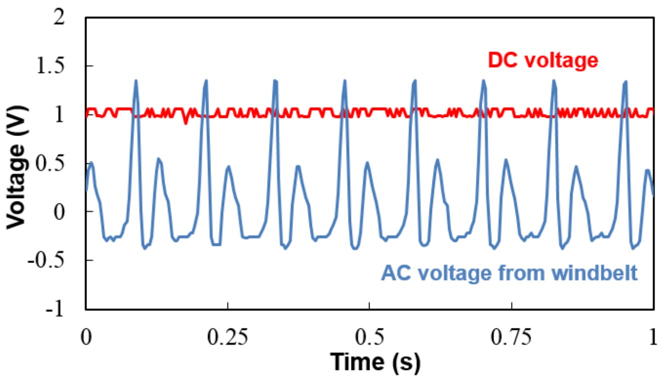


Fig.7. Measured voltage output of windbelt before and after rectifier circuit at a wind speed of 1.37 m/s

The wind plus RF harvester was measured in a laboratory environment and produced a 1V constant voltage output for a modest wind speed of 1.37 m/s. With the addition of commercially available miniature solar cells, which can produce slightly higher output voltages [9], the charging of batteries to power the integrated receiver when required is feasible even under discontinuous wind energy availability.

C. Range of the receiver

The power transmitted for a piezoelectric beam excited at 210 Hz is 2.56 µW. The gain of the transmitter is simulated to be 2.05 dBi while the commercially available receiver has a sensitivity of -90 dBm and 13 dBi gain. Frii's formula can be used to calculate the predicted the communication range for different bee wings vibration frequencies. This was repeated for 240 Hz and 270 Hz using the same process as before to calculate the power output of the piezoelectric energy harvester, resulting in 4.84 µW and 8.41 µW respectively. For a piezoelectric beam excited at various frequencies, the maximum range can vary between 37m and 68m depending on the flapping frequency of the bee exciting the piezoelectric harvester. This demonstrates the concept of monitoring honey bees in close proximity to hives or feeders but reiterates the point that a moveable receiver or an array of stationary receivers must be employed for long-range tracking.

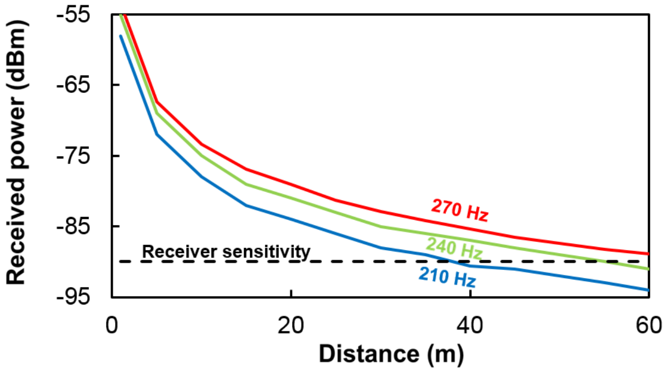


Fig.8. Calculated received power to determine maximum range between transmitter and receiver.

V. Conclusions

A novel method for energy harvesting powered monitoring of honey bees around the hive has been proposed. A wearable device harvests energy from a bee's own mechanical movements replacing the need for bulky batteries, whilst providing a renewable power source. The key issues surrounding energy harvester design have been discussed. A multisource energy harvester provides sustainable energy to operate the integrated 5.8 GHz receiver. Once the system is installed it will require minimal maintenance and ultimately provide bee keepers and scientists with an easy to use, real time data stream of the location of bees with the potential to successfully monitor colony health.

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