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Research Paper

Remote detection of the swarming of honey bee colonies by single-point temperature monitoring

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Precision Beekeeping (or Precision Apiculture) aims to help beekeepers monitor bee colonies remotely and identify different colony states including deviant behaviour. One monitoring target is the remote identification of bee colony swarming since this is one of the factors that can significantly reduce profitability. To identify temperature dynamics and its patterns for swarming detection, ten colonies were constantly monitored for four months from 1 May to 31 August 2015. Nine swarms were observed during experiments. During the warm-up stage, in the last 10–20 min before take-off, a temperature rise by 1.5–3.4 °C from typical range 34–35 °C to range 37–38 °C was registered by a temperature sensor placed above the polyethylene foil covering the upper hive body under the pillow. For all swarming events it was common that a bee colony needs a relatively small amount of time (from 8 to 20 min) to warm up before take-off. It was concluded that a single temperature sensor above the bee nest combined with a proposed decision support algorithm can be used for automatic remote detection of swarming at take-off stage.

1. Introduction

Bee colony swarming is a natural way of proliferation of the bee colony. It is when the queen leaves the colony with a group of worker bees to establish a new colony in a different place at least some kilometres away from the current abode. Thus, the original single colony reproduces two or more colonies (Heinrich, 1981; Michener, 1974; Seeley, 1982; Winston, 1987).

Swarming is a highly stochastic process that depends on genetics and the individual peculiarities of a particular bee colony (Conradt & Roper, 2005; Seeley & Buhrman, 1999). The main challenge of swarming detection is that the bee colonies often are placed away from the beekeepers' sight. The pre-swarming condition of a colony may be detected by regular inspection through opening hives but this causes additional labour costs and disturbs bee colonies.

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Symbols

t_{base}	The lowest temperature value, from which to start analysing temperature data.
t_{th}	Temperature threshold - if the temperature difference is greater than this value, it is considered that this is the starting point of the temperature rise.
Δt	Temperature difference.

It is important for beekeepers to minimise the unmanaged colony swarming. Swarming affects beekeeping profitability by at least three factors: 1) reduction of bee population in colony by swarming bees 2) decrease in egg-laying before swarming and interruption of brood rearing until the egg-laying by the new queen after successful mating and 3) potential after-swarming of colonies (Winston, 1980). Instant detection of swarming enables to reduce the impact of the first factor: after leaving the hive, a honey bee swarm usually spends a few days hanging from a tree in a beardlike cluster (Lindauer, 1955; Seeley & Buhrman, 1999), giving additional time for beekeeper to catch the swarm if needed. Impact of the second and third factor can be reduced by managing or uniting swarmed colonies by adding egg-laying queen to restore brood rearing soon after receiving a swarming signal.

Automatic remote detection of honey bee colony states, including swarming related events is one of Precision Beekeeping (PB) aspects. PB promotes apiary management strategy based on the monitoring of individual bee colonies to minimise resource consumption and maximises the productivity of bees (Zacepins, Brusbardis, Meitalovs, & Stalidzans, 2015; Zacepins, Stalidzans, & Meitalovs, 2012). Different methods of monitoring the microclimate changes of a bee colony can be used for automatic bee colony state detection, when the measured behaviour is similar to the microclimate changes observed earlier at the same bee colony stage.

Many attempts and techniques have already been developed and tested for swarming and pre-swarming identification, but it appears that still there are no reliable, simple and convenient systems for swarming recognition. Honey bee swarming detection and prediction has studied since the 1950s. Woods based his device "Apidictor" on the detection of different sounds since sounds emitted differ when bees are under various conditions. The device consisted of a microphone (placed in a beehive) and an electrical acoustic detecting and amplifying apparatus to distinguish the frequency of sound inside the beehive (Woods, 1959). The approach, inspired by Woods, for detection of swarming by using microphone and a recently developed mobile phone application was presented recently (http://www.instructables.com/id/iphone-apidictor-for-acoustal-beehive-swarm-detect/). Research by Ferrari, Silva, Guarino, and Berckmans (2008) was based on sound, temperature and humidity analysis in the beehive aiming to detect swarming periods. It was concluded that there are some frequency shifts and temperature changes during the swarming period. In another research, the authors used a k-means clustering technique in order to detect pre-swarming state, where they distinguish several climate patterns that are compared with real-time temperature hive data (Kridi, de Carvalho, & Gomes, 2014). Continuous weighing was shown to provide useful information and possible swarming detection (Buchmann & Thoenes, 1990; Meikle, Hoist, & Mercadier, 2006). Bencsik has identified patterns of vibration signals in colonies during swarming with specific sensors for detecting the frequency of vibrations (Bencsik, Baxter, Lucian, Romieu, & Millet, 2011). However, the above mentioned approaches are not widely adopted in practical beekeeping possibly due to complicated measurements, data processing and decision procedures required.

Authors have linked the advantages of continuous temperature measurements (Meikle & Holst, 2014; Zacepins & Karasha, 2013) with temperature rise due to the warming of bees flight muscles about 10 min before swarm take-off as measured by Seeley, Kleinhenz, Bujok, and Tautz (2003). Warm-up based temperature increase can be used as swarming indicator remotely and automatically if the temperature increase before take-off can be detected, and a decision support algorithm can recognise swarming. Simple installation and use of temperature-based swarming indicator linked to beekeepers mobile devices is another important issue to facilitate its practical implementation.

Research here aimed at developing a swarming detection algorithm that can identify a swarming event (warm-up of bees before take-off of swarm) based on measurements of a single temperature sensor placed above the upper hive body of a bee colony. The concept was to remotely detect swarming at its take-off moment and catch the swarm before it has left the apiary. The colonies would be treated after swarming by uniting colonies or adding egg-laying queens to bring the colonies back to brood rearing stage as soon as possible. A successful swarming detection algorithm could be implemented in existing bee colony monitoring systems (Kviesis, Zacepins, & Riders, 2015; Kviesis, Zacepins, Durgun, & Tekin, 2015). Also, other automatic hive control systems such as water sprinkling could be triggered by swarm indicator since bees do not swarm in rainy conditions giving the beekeeper more time to control the swarming process.

2. Materials and methods

To identify temperature dynamics and its patterns for detection of colony warm-up before take-off of swarm, ten hives of *Apis mellifera mellifera* were continuously monitored for four months from 1 May to 31 August 2015. Bee colonies were placed in an open environment under a hood. The experiment took place at Strazdu iela 1, Jelgava, Latvia (N 56°, 39′, 45″ and E 23°, 45′, 15″). Norwegian-type hive bodies made of wood with external size 470 × 470 × 270 mm and internal size 380 × 380 × 270 mm, with a wall thickness of 45 mm, were used in the experiment.

All bee colonies were equipped with Digital Thermometers Dallas DS18S20 (Maxim Integrated, San Jose, CA 95134, USA). Temperature was monitored by Raspberry Pi (Farnell, Leeds, LS12 2QQ, UK) based measurement system (Kviesis et al., 2015). The temperature was measured every 60 s and data was transferred to a remote MySQL database. One