Precision beekeeping: essence and systems in the transfer of information in the manufacture

Tsvetan Tsvetanov

Chief assistant, Institute of Animal Sciences – Kostinbrod, Agricultural Academy – Sofia

E-mail: tsvetan28@abv.bg

Citation: Tsvetanov, T. (2022). Precision beekeeping: essence and systems in the transfer of information in the manufacture. *Zhivotnovadni Nauki*, *59*(3), 58-67 (Bg).

Abstract

One of the least intensified sectors of animal husbandry is beekeeping. This sector is closer to the natural habitat of the bees. The human influence on *Apis mellifera species* is so minimized and does not affect the biology or ethology of these productive insects. However, due to the great importance and benefits of rearing these insects, they make this sector extremely important to be indifferent to the development and implementation of the new information technologies. In our study we found that although under pressure of external factors, the information technologies started gradually to increase their influence and provide many solutions in four different directions (taking into account indicators characterizing: climatic conditions of the region, the microclimate in the bee colony, changes in the acoustic background, infrared image reading system and work condition of auxiliary equipment for providing remote control of apiary).

Key words: precision beekeeping, approaches, data transfer, digitization and architectural systems

Прецизно пчеларство: същност и системи при трансфера на информация в производството

Цветан Цветанов

Главен асистент, Институт по животновъдни науки – Костинброд,
Селскостопанска академия – София

E-mail: tsvetan28@abv.bg

Резюме

Един от най-ниско интензифицираните сектори на животновъдството е пчеларският сектор. Той се намира в състояние близко до естествения ареал на това насекомо, като човешката намеса в него не е довела до сериозни промени в биологията на пчелните колонии. Въпреки това обаче поради голямата значимост и ползи от отглеждането на тези насекоми го правят изключително важен, за да остане встрани от развитието и внедряването на новите информационни технологии. В направеното от нас проучване установихме, че е започнало макар и отскоро под влияние на външни фактори постепенно проникване и налагане на редица решения в четири различни направления: отчитане на показатели на средата и микроклимата в пчелната колония; отчитане на промените в акустичния фон при слушане на пчелните колонии;

система за разчитане на картинно изображение в инфрачервения спектър; системи за отчитане и контрол на спомагателната техника по обезпечаване отдалечения контрол на пчелина.

Ключови думи: прецизно пчеларство, подходи, трансфер на данни, дигитализация и архитектурни системи-

Introduction

The fact that bees pollinate about 85% of flowers makes them one of the most important insects both for plans (Warnke, 2009) and humans (Kviesis et al., 2015; Zacepins et al., 2012). Hence, there is a justified interest in the life and behaviour of bees. For various reasons affecting bee health (Genersch et al., 2010), science is trying to develop methods for assessing and monitoring the health status of entire bee colonies (Kviesis et al., 2015; Zacepins et al., 2011). Over time and the emergence of new technologies, these methods have evolved to allow beekeepers and scientists to monitor hives continuously, creating an archive of information allowing accurate of the manner and strength of certain controlled events in the bee family and their impact on the main productive and etiological parameters.

Due to disturbances in the ethology of bees during manual field inspections of the colonies (Krijan, 1975), a future digitized version of the current technology can be used for monitoring, providing information on the current state of bee colonies and is not accompanied by disturbances of its activities (http://colonimonitoring.com). According to Zacepins et al. (2012) Precision Beekeeping (PB) or Intelligent Beekeeping (IB), is a separate branch of Precision Agriculture (PA). PB includes the collection of information on many indicators which characterize the microclimatic conditions in the beehive, climatic environments on the area, behaviour and ethological plasticity of bee colonies, while they can accumulate this information in the digital archives, allowing chronological investigation of the changes in each of the usable groups of indicators

The future of traditional beekeeping is implementation of intelligent apiary management and automatic collecting of data, remote transfer and processing of data (Kviesis and Zacepins, 2015), archiving them and monitoring of the all necessary indicators related to the state of the bee family and changes in the climate environment on the apiary farm (Gil-Lebrero et al., 2016). This can only happen through certain tools for bee colonies monitoring combined with mechanisms for controlling of the beehives' microclimate (Zacepins et al., 2016; Žgank, 2018). In this way PB can be considered as part of the concept of precision farming (Ochoa et al., 2019).

Precision beekeeping as a concept is an emerging research field of the Internet of Things (Žgank, 2018; Ochoa et al., 2019), based on a management strategy for individual monitoring of colonies and the environment in order to minimize consumption resources (Žgank, 2018) and increase bee productivity (Zacepins et al., 2016). This is a new and challenging topic capable of generating its own added value in the apiary-consumer chain, realizing it in the price of the final product (Degrandi-Hoffman et al., 2019), increasing the security of assets by preserving species diversity (Calvillo et al., 2010; Rogers et al., 2014; Fründ et al., 2016), environment, contributes to the economic and social development of the territory in which it is introduced (Sumner et al., 2016). Žgank (2018) even specifies that the systems for acoustic monitoring and classification of sounds, not only provides great benefits for production, but also contributes to better health status (Luke et al., 2019; Pérez-Rodríguez et al., 2018) and improving animal welfare (Luke et al., 2019; Žgank, 2018).

To improve the productivity of bee colonies, it is appropriate to introduce and analyse various systems for monitoring and control of bee colonies. Data acquired is good to use not only in their absolute values, but also in parallel with their combinations (derivatives), thus controlling not only the processes but also the system in case of failure of the algorithm (Cejrowski et al., 2018).

The purpose of the review is to trace the level of improvement of the existing information systems used in beekeeping.

Basic types of systems for control and reporting of the microclimate and the condition of the bee family

The development of PB is carried out through the implementation of various technical systems for automatic monitoring and real-time control of the apiary. This includes systems for monitoring the condition of the microclimate in the beehive, as a key indicator for monitoring the condition of bee colonies. Several international research projects about 8 years ago (e.g.: "Application of information technology in precision beekeeping" (ITAPIC): http://www.itapic.eu; Swarmonitor: http://www.swarmonitor.comzme.co; E-Ruche: / http / www.e-ruche.fr) opened the door to improving the tools and technical means available in practice to implement the idea of monitoring the microclimate in the beehive, as part of the concept of "Precision Beekeeping". Some authors (Kolchakov, 2010; Alexandrov, 2005; Tashev, 2001; Jarimi et al., 2020) report the existence of a remote monitoring system designed by professional and amateur beekeepers in collaboration with IT specialists, but this is a case study rather than a routine practice. The use of similar control and reporting systems, according to Meitalovs et al. (2009 a), allows the beekeeper to verify beehive data via the Internet (http://www.arnia.co.uk).

For the first time in beekeeping, systematic architectural solutions have been used in practice, mainly to monitor the temperature of the apiary, and subsequently inside the hive (Kviesis and Zacepins, 2015). This is possible because of the well-developed methodology and architectural systems from other industries in temperature monitoring (incubation systems in poultry). For this reason, it is the most widely used factor. The leadership of the experience from other sub-branches of animal husbandry allows easy development of methodology and architectural system solutions that transmit real-time information. Also track the chronological development in the values of this indicator by building of chronological records, in combination with positive economic effect (gives added value or saves costs).

The approaches outlined by Kviesis and Zacepins (2015), are applicable not only for one indicator, but also for all main indicators measured in a similar way, such as humidity, audio signals and computing vision in spectral analysis.

Measurement of the temperature in the beehive is possible because the developed architectural systems are based on monitoring and chronological tracking of information, according to Zacepins et al. (2016). Differences in reporting systems indicators determining the parameters of the microclimate are considerable, due to the recently emerging issue and apply an automatic system for heating or cooling of the beehive in practice (Meitalovs et al., 2009 b). This would be important when wintering weaker families (Zacepins et al., 2016), as it is known that the insufficient number of worker bees that have to warm the combs in winter dooms the bee colony to starvation or frostbite (Nedyalkov, 1988; Nedyalkov et al., 1991).

Regardless of the ambient temperature, the microclimate in the central area of the hive where the bee brood is located should have an average optimum temperature of 32 °C–36 °C, (Seeley and Heinrich, 1981; Seeley and Visscher, 1985; Fahrenholz et al., 1989; Chuda-Mickiewicz and Prabucki, 1996; Van Nerum and Buelens, 1997; Seeley and Buhrman, 1999; Stalidzans et al., 2002; Vornicu and Olah, 2004; Meitalovs et al., 2009 a, b; Eskov and Toboev, 2010, 2011). When the temperature at the periphery of the beehive drops to 15 °C, the bees begin to gather to form a cluster (Southwick and Heldmaier, 1987). This is a natural reaction of the bee colony aimed at reducing the volume of air in the colony that they must–heat. The formation of clusters reduces the surface area of bee bodies exposed to cold air, thus reducing heat loss by convection with nearby 88% (Southwick, 1983; Southwick et al., 1990). As the ambient temperature drops, the cluster will become tighter and more compact (less porous), thus further reducing internal convection by closing the internal air ducts for ventilation (Southwick, 1983). All this will be reflected by an increase in temperature in one part of the hive at the expense of all other measured points (Jarimi et al., 2020). There are two main temperature layers in the bee cluster: insulating and endothermic. The further decreasing of the temperature below -10 °C, forces bees to increase their endothermic heating to stay warm (Bermejo-Busto et al., 2016). The other layer, which has a higher temperature and is located in the centre. of the bee cluster, mainly serves as the central heating system for the bee colony (Stabentheiner et al., 2003). The same layer was constructed from the same individual bees building the mantle layer and alternating to perform endothermic heating, blowers and prevent temperature losses in the cluster structure. They circulate from the middle to the mantle and back to the core of the bee cluster, protecting the queen bee and keeping the nest area warm and safe for the bee brood (Purdue Extension, 2017).

Another strategy applied by worker bees to protect the hive is by absorbing the excess heat from the bee brood area of the cluster and other hotter parts in the beehives, by pressing the ventral side of their bodies against the heated side (Bonoan et al., 2014). Combined with flying effect and body cooling they transfer the heat in the nest area which is cooler. This would be reflected as a huge temperature difference between the temperature sensors implemented in the centre of the cluster and those implemented in any other side from the beehive. Using the location of the sensors, the quadrant of the hive where the bee cluster is located can be known, and will be possible to predict the movement and condition of the bee colony.

The temperature monitoring of bee colonies according to some authors (Fahrenholz et al., 1989; Chuda-Mickiewicz and Prabucki, 1996; Van Nerum and Buelens, 1997; Stalidzans et al., 2002; Vornicu and Olah, 2004; Meitalovs et al., 2009 a, b; Eskov and Toboev, 2011) must be generally performed through combination of various information technologies (hardware solution), systems (software solution) and methodologies (action plan and techniques for its implementation).

Relative humidity in the beehive. Relative humidity is particularly important for the proper development of the bee colony, and specifically for the development of the bee brood (Human et al., 2006). The importance of humidity affects the entire rearing period of the bee brood, starting with the effect on egg hatching (Doull, 1976) at a relative humidity of about 75% (Ellis et al., 2008), to its sealing and hatching of the bee workers (Hossam et al., 2012). In the case of external influence, such as opening of the hive, no clear direct impact of relative humidity on honey bees, including in time actively feeding of bee larvae (Joshi and Joshi, 2010) was found. At low levels of relative humidity, within bee colonies, bee workers try to increase humidity by various means, including evaporation of water from the collected nectar in combination with carrying and spraying water in the dry sectors of the beehive (Human et al., 2006). Humidity is also directly related to temperature, as bees exposed to high temperatures increase water consumption and this way increasing the relative values of the moisture in the hive (Free and Spencer-Booth, 1958). This leads some authors to believe that the integrated using of temperature and relative humidity data is very important for the proper reporting of bee family activity data (Hossam et al., 2012). Combined implementation of sensors to monitoring of the relative humidity in the bee colony together with those used for monitoring of the temperature can give us a much better image for the work of the bee colony and its current behaviour (Seeley and Heinrich, 1980; Kraus and Velthuis, 1997; Vornicu and Olah, 2004; Human et al., 2006; Meitalovs et al., 2009).

Using an image in the infrared spectrum. Using infrared spectrum camera devices is also one of the options for monitoring the condition and behaviour of the colony (Kleinhenz et al., 2003; Eskov and Toboev, 2009, 2011; Shaw et al., 2011), as the infrared images duplicates the measurement at the temperature in the beehive, and in terms of predicting the behaviour of the colony can give more accurate information compared to the using of temperature sensors. For example, during the active season, areas with abnormal temperature values can be observed, due to the way of wax excretion from the abdominal lamellar glands in worker bees and generated in the process of abnormally high temperature. Each gram of wax produced by worker bees requires burning of 6 grams of carbohydrates in the form of honey (Mathis and Tarpy, 2007), which is accompanied by the release of a large amount of heat, as worker bees not only release the energy during this process, but also are collected to further increase their body temperature to 37 °C. The separated wax must be additionally chewed to make it plastic and allow it to form into typical hexagonal shapes, which is also accompanied by the release of a large amount of heat (Jarimi et al., 2020). All this can lead to increase in the beehive temperature to 37 °C during the day or to observe the formation of abnormal temperature zones with higher temperature in the lower side of honeycomb on the external infrared image of beehive. This is what gives the image of infrared cameras, which many authors (Abou-Shaara et al., 2017) named as ”Zones with abnormally high temperatures”.

Acoustic reading systems have their analogous origin in the percussion-auscultation method described in the middle of the last century by Rozov (1948). He tested the condition of the bee colony and predicted its strength through stress testing and observation of bees behaviour in the colony during the autumn-winter period, when the beekeeper has to establish the colony viable level, the presence of queen bee and the presence of traces or pests (Jukan et al., 2017). Even then, it was found that there are significant differences in the sound background between families which have bee queen and those with missing bee queen, and the difference existed in the duration and frequency of the common sound (Radoev, 1998; Boys, 2019). The healthy families with a bee queen, this sound is solid and continues for almost 10 seconds (Radoev, 1998; Jukan et al., 2017; Zang et al., 2011). In a bee family that has lost its bee queen, the common sound was monotonous and weak, resembling anxious sound, but continuing nearby 10–15 minutes (Radoev, 1998; Ryu et al., 2015). In some cases it can continue for a few hours, but with a very low intensity (Rozov, 1940; Radoev, 1998). Also a similar sound is observed in the season with active honey collection when hive ventilation is very intensive due to honey vaporization (Jayaraman et al., 2016). The presence of the pest during the spring and autumn season after percussion can be detected by the beekeeper as a very aggressive sound for a short time resembling a hissing sound with a frequency of about 3000 Hz according to Jukan et al. (2017), accompanied by a cluster of large quantity of bees worker ready to attack the enemy in front of the entrance to the hive, regardless of external temperature fluctuations (Rozov, 1940; Radoev, 1998).

Acoustic monitoring in connection with analysing the bees activity (Zang, 2021) combines simultaneously analysis of activity for the bee colony as a whole organism. At the same time it can visualize the presence and behaviour of each of the parts of the bee colony (bee queen, bees workers and drones), and also have possibility to differentiate the sound background emitted by the young and the old bee workers. Therefore, a common classifier (Zacepins et al., 2016) is built in the systems for monitoring and control of acoustic indicators, which can classify the normal and swarming bee activity (Ferrari et al., 2008, 2016; Zgank, 2021), the presence and absence of a bee queen in the hive (Radoev, 1998; Ryu et al., 2015), the presence of drones in the autumn-winter period and the presence of pests, as other physiological changes and deviations in behaviour (Žgank, 2018), by recording and comparing with certain matrix records of the captured audio signal, which is different for the bee queen, drones, and worker bees (Cejrowski et al., 2018). Thus, the signals are transformed into cepstral mell-frequency coefficients, which are used for training in the form of models (Žgank, 2018). The classification of activities is done in the form of a recognition architecture based on principles applied to speech modality. Acoustic models can be trained directly through a two-step approach, using open audio data provided by an open source archive, thus achieving flexibility and the highest classification accuracy of 80.89% (Žgank, 2018). In the acoustic method, some previously known methods can be introduced through a microphone. In a similar way percussion-auscultation method to the beehive in winter was applied, creating controlled irritation for a short time (Rozov, 1948), which provokes the family to respond (David, 1985). Depending on the frequency and strength of the reported response, the condition of bee colony can be determined and further development until the spring can be predicted (Cecchi et al., 2018).

When monitoring the background sound in the beehive, an active type of ultrasound monitoring (Souza et al., 2020) can also be used to calculate the empty space in the beehive, thus calculating the total quantity of bee cluster or empty spaces. However, this method is not yet fully developed and remains only with a purely scientific application.

Additional systems recommended for precision beekeeping

Many different systems can be added to the main ones that perform monitoring, recording, chronological archiving of data for a different number of important indicators, which are essential for the implementation of constant remote control of many systems in apiary farm, but all of them can be distinguished as additional. Similar determination can be given of the systems for ensuring the energy autonomy of the apiary, the system for accounting for environmental indicators, the security system of the apiary farm, the system for monitoring of CO_2 levels and many others.

Autonomy power supply systems. Because apiaries are usually located outside of rural areas, important parts of intelligent beekeeping were connected with using of hardware consuming electricity. Thus it is very important for the apiary farm to have access to the electricity network or to use alternative energy to power all devices (Zacepins and Karasha, 2012). The most suitable alternative power supply at this time is the solar or photovoltaic energy with solar or photovoltaic panels that can be attached directly on the beehive (Zacepins, 2012; Hansen and Vad Mathiesen, 2018). On the other hand, this gives independence to the apiary (Alpaslan, 2012), but also requires the construction of additional separated systems for monitoring and control of the activity of photovoltaic panels (Wei et al., 2020), current electricity converters (Altun et al., 2012), the condition of the batteries needed for the dark phase of the day and monitoring the mains voltage (Bordin et al., 2017) and software for hourly forecasting of energy balance of the apiary farm (Zabasta et al., 2019). Along with the hardware part, most authors (Bordin et al., 2017; Zabasta et al., 2019; Wei et al., 2020) recommend developing a software part of the monitoring of the important data. The software part can be developed as a web-based platform or mobile application (Zabasta et al., 2019). Also it is possible to use cloud system with different solution supporting functionality of additional options to preliminary signalization which will give to the beekeepers early information about possible future changes in the condition and behaviour of the bee colonies (Al-Ali et al., 2019).

More primitive already developed systems, with their combinations, can successfully manage the processes on the field, turning the bee farms into "intelligent apiaries" (Zacepins et al., 2016).

System reported climate environment indicators. This is done by installing meteorological stations in a selected place in the apiary farm or in the area around the apiary where honey crops are planted, such as Blue Phacelia (*Phacelia tenacetifonia Benth.*), which is often used for planned feeding of bee colonies during periods when there is no flowering of other plants or has a flowering of plants such as tobacco, which are toxic to bees. This type of system is useful in forecasting the work of the apiary, in order to inform beekeeper for weather and the environment conditions. The remote control of information allows making of preliminary plan for the work on the apiary, accompanied by the opening of beehives that is allowed at temperatures diapason above 18 °C and below 30 °C. The wind score is important too, because the power of the wind measured preliminary on the apiary, and must also allow the work with beehives even at within the optimal temperatures diapason.

Apiary security system. The security system is aimed to prevent the invasion of humans, animals and some pests like a bears on the territory of the apiary farm. The security systems most often include a video surveillance system with cameras and motion sensors connected to the luminaires and the cameras. The system for restricting access to apiary includes fencing the area of the farm with an electric shepherd which prevent invasion of the animals. These systems also include security systems of the bee colonies themselves. Most often a system comprises an open low voltage circuit wrapped around the hive, which is connected to alarm system activated only when the low voltage circuit is interrupted which will give to the beekeeper immediate information which beehive is open. This type of system only makes sense when the apiary is located in a remote place where the beekeeper does not have a constant view and direct observation.

System for reporting critically high levels of CO_2. This type of system is applicable only to areas with high rainfall in winter, such as mountainous and semi-mountainous areas of Bulgaria, and the Danube river valley. They resemble critically high level gas analyse systems in the poultry houses that are connected to alarm, which must turn on emergency ventilation in the houses, thus preventing the accumulation of toxic gases in poultry houses. Here the action is analogous except that ventilation is not activated, but the beekeeper is notified of the condition of the bee family. Preliminary alarm must signal to beekeeper to clean the flight board and to open the front opening of the hive (Edwards-Murphy et al., 2016). As they are only applicable in the winter season, when fresh snow has covered the hives, stopping the access of fresh air to the inside of the hive, this system is needed in areas with heavy snowfall and completely redundant in areas with rare rains in winter.

There are a number of other similar systems, but the need for their application must be well adapted to the flora, fauna and climatic characteristics of the area where the apiary is located.

Conclusion

From the literature reference we found that we can summarize 4 separate main types of systems and many other additional types of systems in enterprises for monitoring and control, which form separate sections for the introduction of digital technologies. The introduction of the information in practice for each of the abovementioned sections can be done at many different approaches and were directly related to the character of information stream to the enables us to collect, transfer, process and archive all need information.

Acknowledgements

The article pressented the results from research activity as part from project DIAGRO with agreement № КП-06-Н-26/10 from 19.12.2018, funded by Bulgarian National Science Fund (BNSF), Ministry of Education and Science (MSE).

References

Abou-Shaara, H. F., Al-Ghamdi, A. A., & Mohamed, A. A. (2012). Tolerance of two honey bee races to various temperature and relative humidity gradients. *Environmental and experimental Biology*, *10*(4), 133-138.

Abou-Shaara, H. F., Owayss, A. A., Ibrahim, Y. Y., & Basuny, N. K. (2017). A review of impacts of temperature and relative humidity on various activities of honey bees. *Insectes sociaux*, *64*(4), 455-463.

Alexandrov, A., & Monov, V. (2015). ZigBee smart sensor system with distributed data processing. In *Intelligent Systems' 2014* (pp. 259-268). Springer, Cham.

Al-Ali, A. R., Al Nabulsi, A., Mukhopadhyay, S., Awal, M. S., Fernandes, S., & Ailabouni, K. (2019). IoT-solar energy powered smart farm irrigation system. *Journal of Electronic Science and Technology*, *17*(4), 100017. https://doi.org/10.1016/j.jnlest.2020.100017.

Altun, A. A. (2012). Remote control of the temperature-humidity and climate in the beehives with solar-powered thermoelectric system. *Journal of Control Engineering and Applied Informatics*, *14*(1), 93-99.

Bermejo-Busto, J., Martín-Gómez, C., Zuazua-Ros, A., Ibáñez-Puy, M., Miranda, R., & Baquero Martín, E. (2016). Improvement of an integrated Peltier HVAC system integrated using beehive and stigmergy strategies/Mejora de un sistema de climatización con células Peltier a partir de la colmena de abejas: una aproximación teórica. *DYNA INGENIERIA E INDUSTRIA, DYNA-ACELERADO* https://doi.org/10.6036/7865

Bonoan, R. E., Goldman, R. R., Wong, P. Y., & Starks, P. T. (2014). Vasculature of the hive: heat dissipation in the honey bee (Apis mellifera) hive. *Naturwissenschaften*, *101*(6), 459-465. DOI: https://doi.org/10.1007/s00114-014-1174-2

Bordin, C., Anuta, H. O., Crossland, A., Gutierrez, I. L., Dent, C. J., & Vigo, D. (2017). A linear programming approach for battery degradation analysis and optimization in offgrid power systems with solar energy integration. *Renewable Energy*, *101*, 417-430. https://doi.org/10.1016/j.renene.2016.08.066.

Boys, R. (2019). Beekeeping in a Nutshell—Listen to the Bees. Self Published Work, Availableonline(accessedon18December2019): https://beedata.com.mirror.hiveeyes.org/data2/listen/listenbees.htm

Cecchi, S., Terenzi, A., Orcioni, S., Riolo, P., Ruschioni, S., & Isidoro, N. (2018, May). A preliminary study of sounds emitted by honey bees in a beehive. In *Audio Engineering Society Convention 144*. Audio Engineering Society. http://www.aes.org/e-lib/browse.cfm?elib=19498

Cejrowski, T., Szymański, J., Mora, H., & Gil, D. (2018, March). Detection of the bee queen presence using sound analysis. In *Asian Conference on Intelligent Information and Database Systems* (pp. 297-306). Springer, Cham. https://doi.org/10.1007/978-3-319-75420-8_28.

Chuda-Mickiewicz, B., & Prabucki, J. (1996). Temperature in winter cluster bee colony wintering in a hive of cold comb arrangement. *Pszczelnicze Zeszyty Naukowe (Poland)*. *40*(2), pp.: 71-79

DeGrandi-Hoffman, G., Graham, H., Ahumada, F., Smart, M., & Ziolkowski, N. (2019). The economics of honey bee (Hymenoptera: Apidae) management and overwintering strategies for colonies used to pollinate almonds. *Journal of economic entomology*, *112*(6), 2524-2533.

Doull, K. M. (1976). The effects of different humidities on the hatching of the eggs of honeybees. *Apidologie*, *7*(1), 61-66.

Edwards-Murphy, F., Magno, M., Whelan, P. M., O'Halloran, J., & Popovici, E. M. (2016). b+ WSN: Smart beehive with preliminary decision tree analysis for agriculture and honey bee health monitoring. *Computers and Electronics in Agriculture*, *124*, 211-219.

Ellis, M. B., Nicolson, S. W., Crewe, R. M., & Dietemann, V. (2008). Hygropreference and brood care in the honeybee (Apis mellifera). *Journal of Insect Physiology*, *54*(12), 1516-1521.

Eskov, E. K., & Toboev, V. A. (2009). Mathematical modeling of the temperature field distribution in insect winter clusters. *Biophysics*, *54*(1), 85-89.

Eskov, E. K., & Toboev, V. A. (2010). Analysis of statistically homogeneous fragments of acoustic noises generated by insect colonies. *Biophysics*, *55*(1), 92-103.

Eskov, E. K., & Toboev, V. A. (2011). Seasonal dynamics of thermal processes in aggregations of wintering honey bees (Apis mellifera, Hymenoptera, Apidae). *Entomological review*, *91*(3), 354-359.

Fahrenholz, L., Lamprecht, I., & Schricker, B. (1989). Thermal investigations of a honey bee colony: thermoregulation of the hive during summer and winter and heat production of members of different bee castes. *Journal of Comparative Physiology B*, *159*(5), 551-560.

Ferrari, S., Silva, M., Guarino, M., & Berckmans, D. (2008). Monitoring of swarming sounds in bee hives for early detection of the swarming period. *Computers and electronics in agriculture*, *64*(1), 72-77.

Free, J. B., & Spencer-Booth, Y. (1958). Observations on the temperature regulation and food consumption of honey-bee (Apis mellifica). *Journal of Experimental Biology*, *35*(4), 930-937.

Fründ, J., Dormann, C. F., Holzschuh, A., & Tscharntke, T. (2016): Bee diversity effects on pollination depend on functional complementarity and niche shifts. Wiley. Collection. https://doi.org/10.6084/m9.figshare.c.3306144.v1

Genersch, E., Von Der Ohe, W., Kaatz, H., Schroeder, A., Otten, C., Büchler, R., Berg, S., Ritter, W., Mühlen, W., Gisder, S., Meixner, M., Liebig G., & Rosenkranz, P. (2010). The German bee monitoring project: a long term study to understand periodically high winter losses of honey bee colonies. *Apidologie*, *41*(3), 332-352.

Hansen, K., & Mathiesen, B. V. (2018). Comprehensive assessment of the role and potential for solar thermal in future energy systems. *Solar Energy*, *169*, 144-152.

Human, H., Nicolson, S. W., & Dietemann, V. (2006). Do honeybees, Apis mellifera scutellata, regulate humidity in their nest?. *Naturwissenschaften*, *93*(8), 397-401.

Jarimi, H., Tapia-Brito, E., & Riffat, S. (2020). A review on thermoregulation techniques in honey bees'(Apis mellifera) beehive microclimate and its similarities to the heating and cooling management in buildings. *Future*

Cities and Environment, *6*(1). DOI: http://doi.org/10.5334/fce.81

Jayaraman, P. P., Yavari, A., Georgakopoulos, D., Morshed, A., & Zaslavsky, A. (2016). Internet of things platform for smart farming: Experiences and lessons learnt. *Sensors*, *16*(11), 1884.

Joshi, N. C., & Joshi, P. C. (2010). Foraging behaviour of Apis spp. on apple flowers in a subtropical environment. *New York Science Journal*, *3*(3), 71-76.

Jukan, A., Masip-Bruin, X., & Amla, N. (2017). Smart computing and sensing technologies for animal welfare: A systematic review. *ACM Computing Surveys (CSUR)*, *50*(1), 1-27.

Kleinhenz, M., Bujok, B., Fuchs, S., & Tautz, J. (2003). Hot bees in empty broodnest cells: heating from within. *Journal of Experimental Biology*, *206*(23), 4217-4231.

Kolchakov, K. (2010, October). An approach for synthesis performance improvement of non-conflict schedule by decomposition of the connections matrix in the switching nodes. In *Proceedings of the International Workshop DCCN* (pp. 168-173).

Kraus, B., & Velthuis, H. H. W. (1997). High humidity in the honey bee (Apis mellifera L.) brood nest limits reproduction of the parasitic mite Varroa jacobsoni Oud. *Naturwissenschaften*, *84*(5), 217-218.

Kviesis, A., & Zacepins, A. (2015). System architectures for real-time bee colony temperature monitoring. *Procedia Computer Science*, *43*, 86-94.

Listening to bees. Retrieved: 20.05.2014, URL: http://www.arnia.co.uk/.

Meitalovs, J., Histjajevs, A., & Stalidzans, E. (2009, May). Automatic microclimate controlled beehive observation system. In *Proceedings of International Conference "The 8th International Scientific Conference Engineering for Rural Development", Jelgava, Latvia: Latvia University of Agriculture* (pp. 265-271).

Meitalovs, J., Histjajevs, A., & Stalidzāns, E. (2009b). Automatic microclimate controlled beehive observation system. Engineering for rural development Jelgava, 28.-29.05.2009.file:///D:/Users/User/Downloads/MeitalovsHistjajevsStalidzans-2009-AutomaticMicroclimateControlledBeehiveObservationSystem.pdf

Extension, P. (2017). The complex life of the honey bee. Available: https://ppp.purdue.edu/resources/ppp-publications/the-complex-life-of-the-honey-bee/

Radoev, L. (1998). Calendar reference book on beekeeping. Dionysus, Sofia, pp .: 17-23.

Rogers, S. R., Tarpy, D. R., & Burrack, H. J. (2014). Bee species diversity enhances productivity and stability in a perennial crop. *PloS one*, *9*(5), e97307. https://doi.org/10.1371/journal.pone.009730

Rozov, A. (1948). Beekeeping. Selkhozgiz, pp .: 342-345

Ryu, M., Yun, J., Miao, T., Ahn, I. Y., Choi, S. C., & Kim, J. (2015, November). Design and implementation of a connected farm for smart farming system. In *2015 IEEE SENSORS* (pp. 1-4). IEEE.

Seeley, T. & Heinrich, **B.** (1980). Regulation of the temperature in the nests of social insects. Insect Thermoregulation, John Wiley, New York (1980)

Seeley, T., & Heinrich, **B.** (1981). Insects thermoregulation, New York: Wiley.

Seeley, T. D., & Visscher, P. K. (1985). Survival of honeybees in cold climates: the critical timing of colony growth and reproduction. *Ecological Entomology*, *10*(1), 81-88.

Seeley, T. D., & Buhrman, S. C. (1999). Group decision making in swarms of honey bees. *Behavioral Ecology and Sociobiology*, *45*(1), 19-31.

Shaw, J. A., Nugent, P. W., Johnson, J., Bromenshenk, J. J., Henderson, C. B., & Debnam, S. (2011). Long-wave infrared imaging for non-invasive beehive population assessment. *Optics Express*, *19*(1), 399-408.

Southwick, E. E. (1983). The honey bee cluster as a homeothermic superorganism. *Comparative biochemistry and physiology Part A: Physiology*, *75*(4), 641-645. DOI: https://doi.org/10.1016/0300-9629(83)90434-6

Southwick, E. E., & Heldmaier, G. (1987). Temperature control in honey bee colonies. *Bioscience*, *37*(6), 395-399. DOI: https://doi.org/10.2307/1310562

Southwick, E. E., Roubik, D. W., & Williams, J. M. (1990). Comparative energy balance in groups of Africanized and European honey bees: ecological implications. *Comparative Biochemistry and Physiology. A, Comparative Physiology*, *97*(1), 1-7.

Souza Cunha, A., Rose, J., Prior, J., Aumann, H. M., Emanetoglu, N. W., & Drummond, F. A. (2020). A novel non-invasive radar to monitor honey bee colony health. *Computers and Electronics in Agriculture*, *170*, 105241. ISSN 0168-1699, https://doi.org/10.1016/j.compag.2020.105241.

Stabentheiner, A., Pressl, H., Papst, T., Hrassnigg, N., & Crailsheim, K. (2003). Endothermic heat production in honeybee winter clusters. *Journal of Experimental Biology*, *206*(2), 353-358.

Stalidzans, E., Bilinskis, V., & Berzonis, A. (2002). Determination of development periods of honeybee colony by temperature in hive in Latvia, year 2000. *Apiacta*, *3*, 4-8.

Sumner, D. A., Matthews, W. A., Medellín-Azuara, J., & Bradley, A. (2014). The economic impacts of the California almond industry. *University of California Agricultural Issues Center.* http://aic.ucdavis.edu/almonds/Economic%20Impacts%20of%20California%20Almond%20Industry_Full%20Report_FinalPDF_v2.pdf

Tashev, T. D., & Hristov, H. R. (2001). Modeling and Synthesis of Information Interactions. *"Problems of Technical Cybernetics and Robotics", Sofia, No 52,* pp. 75-80.

Van Nerum, K., & Buelens, H. (1997). Hypoxia-controlled winter metabolism in honeybees (Apis mellifera). *Comparative Biochemistry and Physiology Part A: Physiology*, *117*(4), 445-455.

Vornicu, O. C., & Olah, I. (2004, May). Monitorizing system of bee families activity. In *7th International Conference on Development and Application Systems* (pp. 88-94).

Warnke, U. (2009). Bees, birds and mankind. *Destroying Nature by'Electrosmog': Effects of Wireless Communication Technologies. A brochure Series by the Competence Initiative for the Protection of Humanity, Environment and Democracy. Kempten*. https://ecfsapi.fcc.gov/file/7521097894.pdf

Wei H., Zhang, S., Hu, Z., Zhang, J., Liu, X., Yu, C., & Yu, H. (2020). Field experimental study on a novel beehive integrated with solar thermal/photovoltaic system. *Solar Energy*, *201*, 682-692. https://doi.org/10.1016/j.solener.2020.03.054

Zabasta, A., Zhiravetska, A., Kunicina, N., & Kondratjevs, K. (2019, June). Technical Implementation of IoT Concept for Bee Colony Monitoring. In *2019 8th Mediterranean Conference on Embedded Computing (MECO)* (pp. 1-4). IEEE.

Zacepins, A., & Karasha, T. (2012, October). Web based system for the bee colony remote monitoring. In *2012 6th International Conference on Application of Information and Communication Technologies (AICT)* (pp. 1-4). IEEE.

Zacepins, A., Stalidzans, E., & Meitalovs, J. (2012, July). Application of information technologies in precision apiculture. In *Proceedings of the 13th International Conference on Precision Agriculture (ICPA 2012)*. https://www.ispag.org/abstract_papers/papers/abstract_1023.pdf

Zacepins, A., Meitalovs, J., Komasilovs, V., & Stalidzans, E. (2011, May). Temperature sensor network for prediction of possible start of brood rearing by indoor wintered honey bees. In *2011 12th International Carpathian Control Conference (ICCC)* (pp. 465-468). IEEE.

Zgank, A. (2021). IoT-based bee swarm activity acoustic classification using deep neural networks. *Sensors*, *21*(3), 676.