APPLICATION OF INFORMATION TECHNOLOGIES IN PRECISION APICULTURE

A. Zacepins, E. Stalidzans

Department of Computer Systems
Faculty of Information Technologies
Latvia University of Agriculture
Liela iela 2, Jelgava,
LV-3001, Latvia

J. Meitalovs

SIA "TIBIT"
Rigas 52, Ozolnieki,
LV-3018, Latvia.

ABSTRACT

Precision Agriculture approach has proved to be successful in various agricultural subbranches like precision livestock farming, precision farming, precision horticulture and precision viticulture. Apiculture or beekeeping is one of the agriculture's sub directions, where Precision Agriculture (PA) methods can be successfully applied. Adaptation of PA methods and techniques into Apiculture, as well as integrating information technologies into beekeeping process can improve the beekeepers knowledge about behavior of individual bee colonies. We propose following definition: Precision Apiculture or Precision Beekeeping is an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees.

One of the objectives of Precision Apiculture in the field of monitoring is to develop real time on-line tools for continuous monitoring of bees during their life and production using the automatic solutions avoiding exposure of bees to additional stress or unproductive activities. The aim of these technical tools is not to replace but rather to support the beekeeper.

In passive wintering period it is important to recognize automatically such events as the death of the bee colony and have up to the date information about the state of the brood rearing and food consumption process. In summer period it is important to detect the preswarming, queenless, broodless and other states of a bee colony. Several individual bee colony related parameters currently can be continuously measured and used for Precision Apiculture purposes: temperature by temperature sensors or infrared imaging, air humidity, gas content, sound, vibration of hive, counting of outgoing and incoming bees, video oebservation and weighing. Practical application examples of Precision Apiculture enabling measurement systems both for winter and summer periods are mentioned.

Keywords: Precision Agriculture, Precision Apiculture, decision support, honey bee activity monitoring.

INTRODUCTION

Apiculture or beekeeping can be considered as one of the agriculture's sub directions, where Precision Agriculture (PA) methods (Berckmans, 2006; Mancuso and Bustaffa, 2006; Proffitt et al., 2006; Morais et al., 2008; López Riquelme et al., 2009b; a) can be successfully used. This paper is devoted to the Precision Apiculture scientific direction which is based on Precision Agriculture methods and definitions.

Practical application of Precision Apiculture methods can increase the efficiency of beekeeping and, by integrating information technologies into the beekeeping process, could bring it to the next technological level.

One of the main objectives of Precision Apiculture is to develop real time and on-line tools to continuously monitor bee colonies during their life and production stage using the automatic, automated and information technology based solutions, without exposing the bees to avoidable stress and waste of resources. The aim of all these technical tools is not to replace but rather to support the beekeeper that always remains the crucial factor in good bee's management.

Precision agriculture approach is adapted for beekeeping based on the continuous measurements of individual bee colonies all year round thus detecting different states of colonies and apiaries more generally enabling rapid reaction by the beekeeper in case of necessity. Generally several parameters of individual colonies can be continuously automatically measured and/or analyzed: temperature by temperature sensors (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; Eskov and Toboev, 2011), temperature by infrared imaging (Kleinhenz et al., 2003; Eskov and Toboev, 2009, 2011; Shaw et al., 2011), air humidity (Kraus and Velthuis, 1997; Vornicu and Olah, 2004; Human et al., 2006; Meitalovs et al., 2009) gas content (Southwick et al., 1990; Van Nerum and Buelens, 1997) sound (Dietlein, 1985; Ferrari et al., 2008; Eskov and Toboev, 2010), vibration of the beehive (Bencsik et al., 2011), counting of outgoing and incoming bees (Liu et al., 1990), video observation (Campbell et al., 2008; Meitalovs et al., 2009), weighing of the colony (Seeley and Visscher, 1985; Nickelson, 2010) and others. On the other hand costs of those measurements are very different thus limiting economically feasible solutions.

Nowadays rapid improvements in temperature, sound measurement systems and information technologies overall allow economically feasible applications in Precision Apiculture. Continuous data capture and analysis can be used to monitor individual bee hives and the data can be adapted for individual bee colony maintenance.

This paper is devoted to the applications of existing measurement, information processing and transmission technologies within the Precision Apiculture approach for automatic detection of necessary information to determine the state and needs of individual bee colonies.

PRECISION AGRICULTURE

PA could be defined and named in many ways, but the main concept remains the same. In simple terms, PA is defined as a holistic and environmentally friendly strategy in which farmers can vary input use and cultivation methods – including application of seeds, fertilizers, pesticides etc. (Srinivasan, 2006).

Precision Agriculture is based on detailed information on the status of monitored objects. In the past few years new trends have emerged in the agricultural sector. Precision agriculture concentrates on providing the means for observing, assessing and controlling agricultural practices. It covers a wide range of agricultural concerns from daily herd management through horticulture to field crop production (Mancuso and Bustaffa, 2006).

Such agricultural processes like crop protection, field watering, fertilization need frequent data updates. Sensors and continuous data acquiring play an important role in preserving environment by reducing pesticide usage and maximizing quality. Today when it is possible to use information technologies such as Global Positioning System (GPS), Geographic Information System (GIS), remote sensing, intelligent devices, computers and other tools all needed tasks could be done by automatic machines or robots and human role is only to monitor them.

Precision agriculture can be considered as a three-phase cycle (Fig. 1)(Terry, 2006). The first phase is data collection. It also compares the measurement of parameters characterizing the agricultural object. Data collection is the process of determining objects to be mapped and collecting data about those objects. Examples of the data typically collected in PA are yield mapping, soil sampling and crop scouting.

The second phase is data interpretation or data analysis. Data analysis is the process of organizing, manipulating, querying and summarizing. Raw data can be a large amount of numbers and extremely hard to understand by itself. Using specific tools can help to summarize and identify relationships between variables that the farmer can use to make a decision. This step is very hard to automate, that means that farmer still have to personally make the decision.

The third phase is the application. It involves the adjustment of important parameters and making the needed actions. This phase also can be called as data utilization, since it is at this point that a decision is made and put into practice.

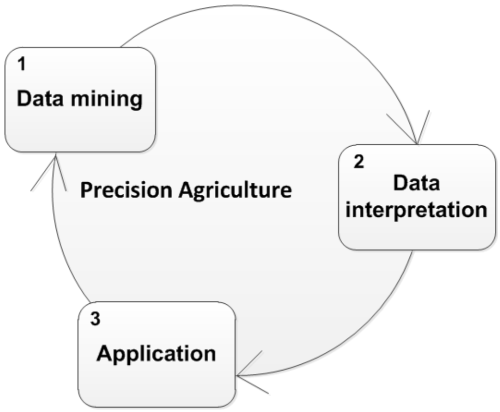

Fig. 1. Three-phase cycle in PA

PRECISION AGRICULTURE SUBFIELDS

Searching for similar PA approaches in other agricultural directions it is found that also Precision Viticulture (PV) term is widely used (Morais et al., 2008).

PA and PV are production systems that promote variable parameter management practices within a field according to specific production site conditions (Morais et al., 2008).

Precision viticulture is precision agriculture approach applied to optimize vineyard performance, in particular maximizing grape yield and quality while minimizing environmental impacts and risk (Proffitt et al., 2006). This is accomplished by measuring local variation in factors that influence grape yield and quality (soil, topography, microclimate, vine health, etc.) and applying appropriate viticulture management practices (trellis design, pruning, fertilizer application, irrigation, timing of harvest, etc.) (Bramley and Hamilton, 2004).

Precision Livestock Farming (PLF) is also widely used. Modern society is concerned about food safety and quality, efficient and sustainable animal farming, healthy animals, guaranteed animal well-being and acceptable environmental impact of livestock production.

As a consequence, there is a growing need to monitor many variables during the entire production process in order to reach these targets. Precision Livestock Farming involves temperature measurements, predictions and data-analyses of animal variables. PLF offers totally new possibilities to collect and analyze data from farm animals in a continuous and fully automatic way (Berckmans, 2006).

PRECISION APICULTURE

We offer to introduce Precision Apiculture term. It means that main agricultural objects are bees. The main objective of Precision Apiculture is to monitor and control bee behavior and activity using an individual access to objects. It is not possible and even necessary to observe each and every bee.

That's why bee colonies are considered to be an individual Precision Apiculture objects. Bees are one of the social insects. Therefore the behavior of a bee colony is equivalent to an individual in case of other species. To stress the point - beekeepers performs medical treatment of the whole bee colony in the hive rather than of a specific bee. This can be compared to PA objects, when agricultural specialist instead of observing each individual flower monitors flower beds.

We propose following definition: Precision Apiculture or Precision Beekeeping is an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees.

Modern measurement systems can provide beekeeper with actual and real time data and information about important bee colony parameters as mentioned earlier. Based on this information beekeepers can make important conclusions and in case of need perform some additional actions. Also the development of wireless communication technologies is demonstrated in measurements of individual colonies (Mezquida and Martinez, 2009).

Similar to PA also Precision Apiculture can be considered as a three-phase cycle, where data acquisition plays a big role. In this case, also comparing with PA, achievements in sensor network technology can help. Sensor technologies can be applied in Precision Apiculture to measure needed bee parameters.

The next step is data analysis, where based on actual measurement data, on predefined models and on expert knowledge it is possible to conclude about bee colony behavior and activity trends.

In the third stage, based on decision making it is possible to make some needed actions to impact or influence the individual bee colony.

Similar to PA also Precision Apiculture approach suggests that there are at least three elements critical to the success: information, technology and management.

Regarding bees it is considered that in the annual cycle of bee colony in cold climates two very different periods of behavior can be observed: passive wintering period and active summer period. These two periods can be characterized more precisely (Ambrose, 1992; Stalidzans et al., 2002; Schmickl and Crailsheim, 2004). And in each of them PA methods can be used with different aims to improve the collaboration between beekeeper and bees.

In the passive wintering period it is proposed to use temperature measurements for detection of events like increased food consumption, start of brood rearing or death of the colony (Stalidzans et al., 2002; Zacepins et al., 2011; Zacepins, 2012).

In summer period it is important to detect the preswarming, broodless, queenless and other states of a bee colony. So far mostly automatic preswarming state detection systems have been developed. Swarming is a natural mechanism of proliferation of bee colonies. Swarming is a highly stochastic process which depends on genetically and other peculiarities of a particular bee colony (Seeley and Buhrman, 1999; Conradt and Roper, 2005). As a result of swarming part of the bee colony leaves the existing hive and establish a new colony in a new place at least several kilometers away from the previous place of living making serious damages of the beekeepers plans. There are no direct indications of preswarming conditions that would be clearly visible for a beekeeper without opening the hive. So the best option to detect this process is to apply Precision Apiculture methods to individual colonies. Several attempts have been made to detect preswarming state by sound measurements of colonies (Ferrari et al., 2008; Mezquida and Martinez, 2009) and vibration measurements of a beehive (Bencsik et al., 2011). Monitoring of dynamics of humidity and temperature inside the individual beehive also can give indications about preswarming state (Meitalovs et al., 2009).

Death or disappearance of individual bee colonies can be registered in most different ways. Still the simplest and cheapest way seems to be temperature measurements (Zacepins, 2012). The colony is not alive in the hive if the hive temperature repeats environmental temperature.

PRACTICAL EXAMPLES OF SYSTEMS FOR PRECISION APICULTURE

Several Precision Apiculture methods enabling systems are developed for application during winter and summer periods.

During the winter precision methods are applied to monitor the activity of bees inside each individual hive during the passive indoor wintering period in a closed environment as it is honeybee wintering building, where it is possible to grant stable and convenient microclimate conditions for bees. Figure 2 demonstrates the developed monitoring and control system architecture (Zacepins and Stalidzans, 2012)

One-wire temperature sensor network has been developed to measure the temperature changes in honey bee hive (Zacepins et al., 2011).

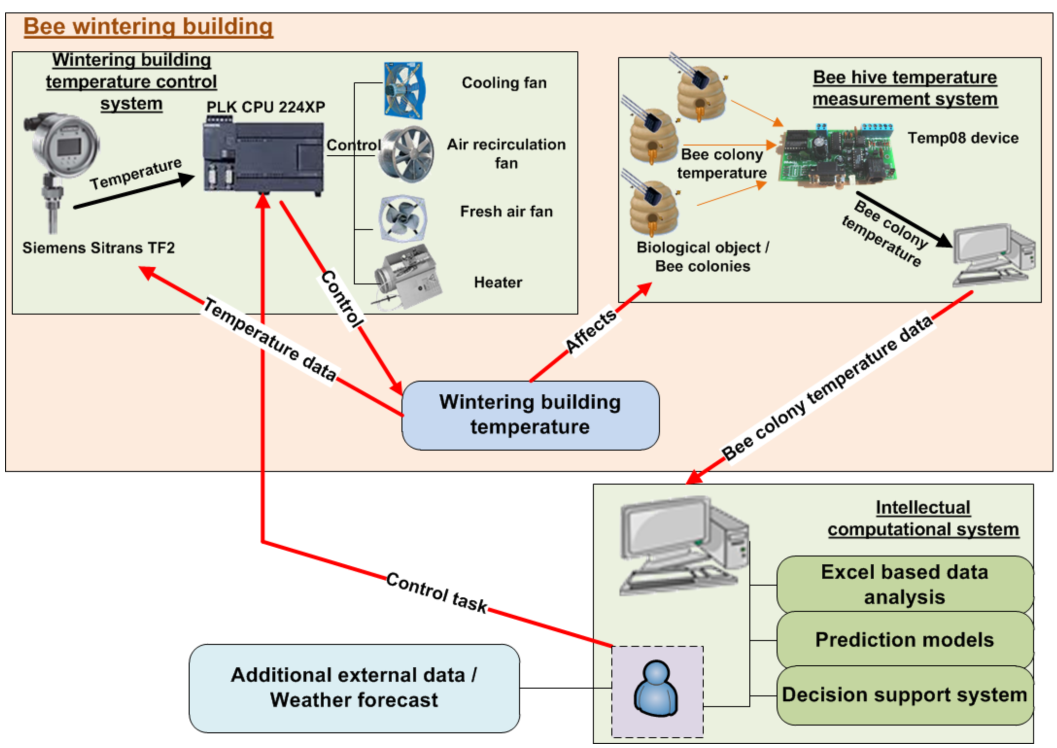

Fig. 2. Architecture of temperature control system in bee wintering building with integrated
temperature measurement system in individual colonies and decision support system.

Another example of Precision Apiculture related system is the automatic measurement and monitoring system of temperature and humidity in the bee hive aiming to detect the preswarming condition (Meitalovs et al., 2009). Other temperature and humidity measurement systems are described as well (Vornicu and Olah, 2004).

Bee flight activity, temperature and weight of individual colonies as well as the temperature, humidity, solar radiation and wind speed are measured in the monitoring system reported by Liu and coworkers (Liu et al., 1990).

Large scale bee colony weighing project (Nickelson, 2010) has been performed to study global warming. At the same time the system could be applied also for Precision Apiculture approach.

Sound measuring systems are proposed by several authors (Dietlein, 1985; Mezquida and Martinez, 2009; Bencsik et al., 2011).

Wireless technologies are important precondition of Precision Apiculture development. A ZigBee technology (http://www.zigbee.org/ visited 01.03.2012) based wireless platform architecture for sound analysis of bee colonies has been practically applied to detect various states of bee colonies (Mezquida and Martinez, 2009). The wireless ZigBee communication technology can be used also for other measurements.

CONCLUSIONS

Precision Apiculture as a subbranch of Precision Agriculture involves measurements of individual colonies, information analysis and decision making or decision support for management of activities in apiary. Precision Apiculture or Precision Beekeeping is an apiary management strategy based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees. Prerequisite of Precision Apiculture are possibilities of collecting and analyzing data about bees in a continuous, real time and automatic way.

A number of individual bee colony related parameters currently can be continuously measured and used for Precision Apiculture purposes: temperature by temperature sensors or infrared imaging, air humidity, gas content, sound, vibration of hive, counting of outgoing and incoming bees, video oebservation and weighing. Wireless technologies can facilitate the development of Precision Apiculture approach.

The application of this technology offers new possibilities for developing efficient and sustainable beekeeping. Therefore, efforts should be increased for bringing this challenging approach of Precision Apiculture into practice, but this will only be possible when research teams from different research disciplines such as engineering, mathematics, physics, ethology etc. work together.

Adaptation of Precision Agriculture methods and technics into Apiculture, as well as integration of information technologies into beekeeping process can change and improve the beekeepers understanding of bee behavior features.

ACKNOWLEDGMENT

Academic study and publication financed by the project „Support for doctoral studies in LUA" / 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017/ agreement Nr. 04.4-08/EF2. D1.09.

Publication and business trip is financed by the ERAF project "Promotion of the scientific activities in LUA", agreement Nr.2DP/2.1.1.2.0/10/APIA /VIAA/020.

Technological support is granted by SIA "TIBIT".

REFERENCES

Ambrose, J. 1992. Management for honey production. p. 230-257. In Graham, J. (ed.), The Hive and the Honey Bee. 5th ed. Dadant and Sons, Hamilton, Illinois.

Bencsik, M., J. Bencsik, M. Baxter, A. Lucian, J. Romieu, and M. Millet. 2011. Identification of the honey bee swarming process by analysing the time course of hive vibrations. Computers and Electronics in Agriculture 76(1): 44-50.

Berckmans, D. 2006. Automatic on-line monitoring of animals by precision livestock farming. Livestock production and society: 51-54.

Bramley, R., and R. Hamilton. 2004. Understanding variability in winegrape production systems. Australian Journal of Grape and Wine Research 10(1): 32-45.

Campbell, J., L. Mummert, and R. Sukthankar. 2008. Video Monitoring of Honey Bee Colonies at the Hive Entrance. Visual observation & analysis of animal & insect behavior, ICPR 8: 1-4.

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

Conradt, L., and T.J. Roper. 2005. Consensus decision making in animals. Trends in ecology & evolution 20(8): 449-56.

Dietlein, D.G. 1985. A method for remote monitoring of activity of honeybee colonies by sound analysis. Journal of Apicultural Research 24(3): 176-183.

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

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

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

Fahrenholz, L., I. Lamprecht, and B. Schricker. 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, Biochemical, systemic, and environmental physiology 159(5): 551-560.

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

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

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

Kraus, B., and H.H.W. Velthuis. 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.

Liu, C., J.J. Leonard, and J.J. Feddes. 1990. Automated monitoring of flight activity at a beehive entrance using infrared light sensors. Journal of Apicultural Research 29(1): 20-27.

López Riquelme, J.A., F. Soto, J. Suardíaz, P. Sánchez, A. Iborra, and J.A. Vera. 2009a. Wireless Sensor Networks for precision horticulture in Southern Spain. Computers and Electronics in Agriculture 68(1): 25-35.

López Riquelme, J.A., F. Soto, P. Sánchez, A. Iborra, J. Suardiaz, and J.A. Vera. 2009b. Development of a sensor node for precision horticulture. Sensors (Basel, Switzerland) 9(5): 3240-55.

Mancuso, M., and F. Bustaffa. 2006. A wireless sensors network for monitoring environmental variables in a tomato greenhouse. In 6th IEEE International Workshop on Factory Communication Systems. Torino, Italy.

Meitalovs, J., A. Histjajevs, and E. Stalidzans. 2009. Automatic Microclimate Controlled Beehive Observation System. p. 265-271. In 8th International Scientific Confernce "Enginieering for Rural Development." Latvia University of Agriculture, Jelgava, Latvia.

Mezquida, A.D., and L.J. Martinez. 2009. Short communication.: Platform for bee-hives monitoring based on sound analysis. A perpetual warehouse for swarm s daily activity. Spanish journal of agricultural research 7(4): 824–828.

Morais, R., M. a. Fernandes, S.G. Matos, C. Serôdio, P.J.S.G. Ferreira, and M.J.C.S. Reis. 2008. A ZigBee multi-powered wireless acquisition device for remote sensing applications in precision viticulture. Computers and Electronics in Agriculture 62(2): 94-106.

Van Nerum, K., and H. Buelens. 1997. Hypoxia-Controlled Winter Metabolism in Honeybees (Apis mellifera). Comparative Biochemistry and Physiology Part A: Physiology 117(4): 445-455.

Nickelson, J. 2010. HoneyBeeNet. NASA.

Proffitt, T., R. Bramley, D. Lamb, and E. Winter. 2006. Soil sensing in precision viticulture-A new era in vineyard management and wine production. Winetitle Ed: 51-55.

Schmickl, T., and K. Crailsheim. 2004. Costs of Environmental Fluctuations and Benefits of Dynamic Decentralized Foraging Decisions in Honey Bees. Adaptive Behavior 12(3-4): 263-277.

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

Seeley, T.D., and P.K. Visscher. 1985. Survival of honeybees in cold climates: the critical timing of colony growth and reproduction. Ecological Entomology 120(1): 826-88.

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

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

Srinivasan, A. 2006. Handbook of Precision Agriculture: principles and applications. Food Products Press, an imprint of The Haworth Press.

Stalidzans, E., V. Bilinskis, and A. Berzonis. 2002. Determination of development periods of honeybee colony by temperature in hive in latvia, year 2000. Apiacta: 4-8.

Terry, B. 2006. Precision Agriculture. Thomson Delmar learning.

Vornicu, O.C., and I. Olah. 2004. Monitorizing System of Bee Families Activity. p. 88-94. In 7th International Conference on Development and Application Systems. Iasi, Romania.

Zacepins, A. 2012. Application of bee hive temperature measurements for recognition of bee colony state. In Applied Information and Communication Technologies. Accepted for publication, Jelgava, Latvia.

Zacepins, A., and E. Stalidzans. 2012. Architecture of automatized control system for honey bee indoor wintering process monitoring and control. In 13th International Carpathian Control Conference (ICCC). Accepted for publication.

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