From Primitive to Cyber-Physical Beekeeping

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***Abstract* — Since application of information and communications technologies (ICT) to beekeeping is far from the potential, we are trying in this paper to systemize beekeeping process from the perspective of system control theory and detect appropriate points of possible innovations in beekeeping by application of modern ICT. We find that current - precision beekeeping – approach, focusing on monitoring and mostly treating sound factors of beekeeping process, neglects a number of aspects of the process, which can certainly be improved by ICT application.**

I. Introduction

Although the beginning of beekeeping is lost in the past it is evident that the first contact of man and bee had been sweet and painful. Since then, man had been trying to balance these two conflicting objectives, more sweetness and less pain, employing his knowledge about bee control. Man had made simple beehive to host bees in a known place where he could access bee products by destroying bee colony according to his needs. Such an approach of beekeeping is referred to as traditional beekeeping, Fig. 3.

Getting more knowledge about bees, man had set himself new objectives such as pollination related objectives and production of other than honey products of bees. About 200 hundred years ago some beekeepers recognized two fundamental properties of bee colonies: queen is significantly greater than worker bees and worker bees keep on building the nest until the pasture is exhausted. Since then, modern beehives, beehives that are commonly used worldwide today are built on the two properties, while the general description of the hive is given in Fig. 1, [10]. Brood and honey chambers are separated by queen excluder, which keeps queen in brood chamber while allowing worker bees to store unnecessary honey in honey chamber.

Current practice in beekeeping can be described as well-established rational beekeeping, Fig. 4, [3], where beekeeper can take bee products from a beehive, honey chamber, without disturbance of bees, sufficient to start their defence mechanism.

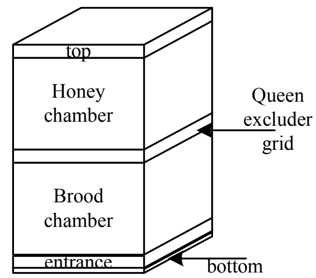

Figure 1. Schematic of a rational beehive

With development of modern information and communications technologies (ICT), such as wireless sensor networks (WSN), the idea of precision beekeeping (PB) rises. Rational beehives are equipped with a number of wirelessly connected sensors, Fig. 5, which can report measurements to Internet connected beekeeper, located anywhere. It is expected that PB should provide more precise, non-invasive measurement of a number of parameters related to inside/outside of beehives and apiaries [1, 4-6, 14]. However, PB lacks of a systematic approach and definition of qualifier "precision".

Since monitoring is the phase of Observe, Orient, Decide, and Act (OODA) control cycle, taking beekeeping as a process, we will try in this paper to characterize beekeeping from the perspective of dynamic multi-objective control in all OODA phases and set basis for Cyber-Physical Beekeeping (CPB) - controlled beekeeping that will enable sustainable beekeeping [7]. "Precision" in CPB relates to resolution improvement of variables, which describe spatial and temporal aspects of beekeeping, as well as, the level of details improvement of beekeeping process characterization. Normally, we build CPB concept on achievements in previous beekeeping approaches, Fig. 2.

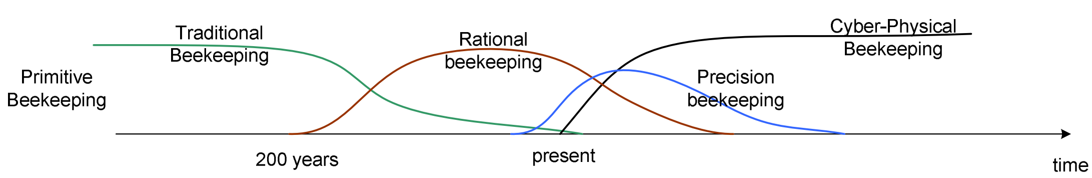

Figure 2. Beekeeping through time

Wild nest — Old hives in the ancient apiary — Roman apiary

Figure 3. Primitive and traditional beekeeping

Figure 4. Rational beekeeping

http://makezine.com/projects/bees-sensors-monitor-hive-health/

Figure 5. Precision beekeeping

II. Beekeeping as a System

Our CPB concept divides beekeeping into 7 layers, from single bee level to global beekeeping level. We present layers in Table I and provide the list of the most important or just give an example of decision makers for every layer. Bees are categorized as queen, drones and working bees. Current control at layer I is mainly focused on queen in the processes of swarming and queen selection. Average bee colony consists of 20-50 thousands of bees placed within a beehive. Currently, beehive at layer II is the most attracting unit of control for ICT society. Small/medium/large apiary at layer III can consist of several/tens/hundreds beehives, while groups of beehives can be stationary, which are coupled with a pasture or mobile, which beekeepers migrate to appropriate pastures. Further, beekeepers gather into local/national/regional/global level associations to facilitate information of interest interchange. Parallel with beekeepers associations there exist governmental and non-governmental bodies, which support beekeeping.

There are 83 million of registered beehives worldwide, according to Food and Agriculture Organization (FAO) of the United Nations statistics and 3.6 million of registered beekeepers worldwide, according to Apimondia – International Federation of Beekeepers' Associations.

TABLE I. Layers of Beekeeping Organization with Decision Makers

Level Number	Beekeeping system level	Decision makers
VII	Global	UN, FAO, Apimondia, COLOSS
VI	Regional	EPBA, ABF, Balkan Federation of Apicultural Associations
V	National	National beekeepers' associations, National level governmental bodies
IV	Local	local beekeepers associations, local governmental bodies
III	Apiary	beekeepers, growers, transporters
II	Colony	beekeepers
I	Single bee	beekeepers

Being a complex process, beekeeping control can be presented by OODA loop, Fig. 6. Data are collected manually in observe/monitoring phase of beekeeping and current PB efforts are mostly focused on automatization of the phase. Some of measurable bee colony parameters are listed in table II. Data can be collected directly from the beekeeping system or obtained as open data. E.g. Arnia[1], from UK, provides data storage and WEB presentation of data to registered beekeepers. There are a number of new patented solutions for remote measurement of beehive weight, e.g. [15], market available[2]. Collected raw/semi-processed data are processed in data processing phase and

[1] http://www.arnia.co.uk
[2] http://www.smsvaga.com/

prepared to support decision making. Currently, ICT application in this phase is focused on processing of raw data collected from beehives and opening data belonging to public organizations. Processed data should help decision making phase. Currently, ICT solutions for decision making in beekeeping are rare and low TRL[3]. E.g. BeeWeb[4] platform, TRL 4, supports beekeepers, growers and transporters to make decisions on optimal distribution of beehives on pastures while minimizing use of transportation means. After the decision is made, appropriate actions should be conducted. Currently, main actuator in beekeeping is a beekeeper itself and actuation phase of beekeeping control is manual or semi-automatic. Some low TRL solutions are reported, such as devices for indoor climate control [11-13].

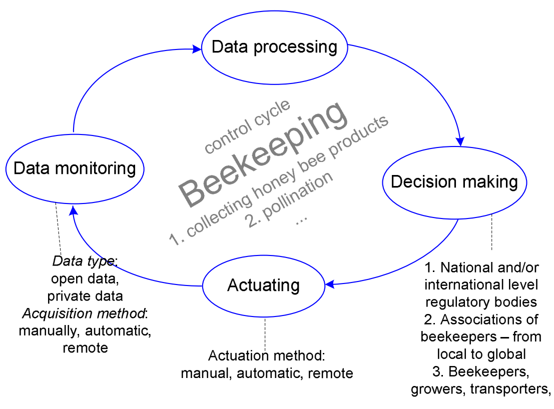

Figure 6. OODA beekeeping cycle

Generally, desirable objectives in beekeeping that should be achieved with control, qualitatively given, are:

i. Production efficiency maximization for all bee products
ii. Quality of products maximization
iii. Maximization of pollinated plants total amount
iv. Average transhumance cost per beehive
v. Knowledge improvement regarding algorithms bees behave according to [2]
vi. Apitherapy methods improvement

Once achieved and after that kept the objectives will bring beekeeping to sustainable beekeeping.

As the first step towards CPB we try to characterize subject system. Since the system is complex we present basic qualitative characterization at layers II and III that are the main area of beekeepers' control.

Process of beekeeping consists of the following sub processes: preparation for wintering, spring build-up, swarming, selection and queen breeding, selection of the target pasture and migration to it, extraction of bee products from hive, bee products storing, healthcare of bees and protection of bee enemies.

Bee products are: honey, beebread, pollen, royal jelly, propolis, beeswax, and bee venom.

[3] Technology readiness level
[4] http://www.beeweb.co/

Currently used means in beekeeping control are numerous and can be divided into several categories:

i. Beehive characterized by capacity, the number and size of frames, the number of boxes, etc.
ii. Tools – bee smoker, bee brush, beekeepers knife, etc.
iii. Accessories –veils, jackets, suits and gloves, etc.
iv. Equipment – equipment for queen production, equipment for centrifugation of honey, equipment for fixing the foundations, beekeeping supplies for melting wax, etc.
v. Means of transportation (MoT):
    a. Inside/outside MoT
    b. Standard/adaptive/modified/specialized
vi. Buildings and infrastructure

Constants that determine beekeeping process and the system can be divided as follows:

i. Time – annual cycle, day/night cycle, queen/drone/worker bee life span, time schedule and duration of particular pastures, queen egg-laying rate, etc.
ii. Space – maximal range of worker flight, pasture size, etc.
iii. The amount of nectar in target plant

Parameters that beekeeping should adapt to, are:

i. Weather conditions – temperature, air pressure, humidity, illumination
ii. Pollution by non-organic gases such as CO_2, SO_2, NOx, particulate matter (PM), pesticides etc.
iii. Human factors affecting beekeeping such as:
    a. The amount of cultivated honey plants in agriculture,
    b. Market state of bee products
    c. etc.

A. *Challenges*

1. Although a number of particular aspects of beekeeping can be improved by ICT separately, an integral framework for ICT application in beekeeping is still missing.

2. Even if ICT solutions of particular beekeeping aspects exist their cost must be acceptable for use in beekeeping and cost vs. functionality tradeoff is inevitable.

3. The gap between ICT and beekeeping societies should be addressed by multi/interdisciplinary approach to the problem.

4. Legal aspects of human to machine migration of decision making should be arranged. So far, ICT can improve beekeeping up to semi-automatic level.

B. *Opprtunities*

1. To provide tracability of means used in beekeeping RFID and QR can be applied to every significiant single peace of means, e.g. beehives and even beehive frames.

2. Databases belonging to IV-VII layers can be opend.

3. State-of-the-art already provides solutions, which eventually have to be custumized, for automatization of simple actuation tasks at leyer III, e.g. robotized lawn mowers or robotized forklifts to manipulate with standalon beehives.

4. The second challenge can be adressed by rising the existing expensive solution to the upper layers, e.g. imageing by IR camera can be provided at layer IV by local beekeepers' organisation instead of a beekeeper itself at appiary layer III.

TABLE II. MEASURABLE BEE COLONY PARAMETERS

Parameter	**Method**
Weight and temperature	Mechanical balance and in-hive mercury thermometers
Weight	Mechanical balance
Weight	Electronic balance
Temperature	Electric thermocouples
Temperature, O_2 and CO_2	E-thermocouples, metabolic chamber, extracted air passed through external detectors
Temperature	Extracted air passed over thermometer
Temperature, CO_2, # of fanning bees	In-hive mercury thermometers, extracted air passed through external detectors
Temperature, O_2, # of fanning bees	Metabolic chamber with extracted air passed through external detectors
Temperature, O_2 and CO_2	Extracted air passed through detectors
Temperature, O_2 and CO_2, humidity	In-hive temperature sensors; extracted air passed through gas detectors
Vibration	In-hive sensors
Acoustics, temperature, relative humidity	In-hive sensors
Forager traffic	Hive entrance sensors
Forager traffic	RFID tags and entrance sensors[5]
Colony thermal image	2D outward IR camera
Atmospheric pressure	In-hive sensors/out-hive
PM 10	In-hive sensors/out-hive
The amount of mits	2D outward camera

III. CASE STUDY OF BEE DISEASE CONTROL AUTOMATIZATION

We provide an illustrative CPB case study, which analyzes how healthcare of bees, from proper diagnosis to appropriate measures, can be automatized.

Since, there are a variety of bee diseases we list in table III the most frequent ones [sec. 22 in 3, 9]. Diseases can be generally divided into contagious and non-contagious, while contagious can be viral/bacterial/fungal/parasitic caused. Column 2 lists diseases' symptoms, while column 3 lists appropriate corrective treatments by beekeepers. Column 4 lists potential sensors and methods for automatic diagnosis of disease and column 4 lists potential automatic actuators which could apply appropriate corrective treatments.

Since robotic actuators for corrective bee diseases treatments are not market available, we choose to apply one of the most effective preventive measures in healthcare of bees and protection of bee enemies, grass cutting around the hives, in this case study.

It can be seen from table III that most diseases can be detected by processing images of a beehive's outside or frames from the beehive. Since an average beekeeper is not a veterinary expert in bee diseases, some diagnosis service should support the process of disease diagnosis. Images obtained from a hive could be passed to the service, and the service should provide appropriate instructions for preventive/corrective treatment. If the

[5] Blue shaded parameters and methods are reported in [8]

instruction is preventive grass cutting around the hive, robotized lawn mower should be activated. Moreover, beside notifications send to a beekeeper, diagnosis service can issue notifications for the upper beekeeping layers; store results of precessed data for tracking purposes, etc.

TABLE III. POSSIBILITIES OF BEE DISEASES CONTROL AUTOMATIZATION

diseases			symptoms	treatment	Appropriate sensors	Appropriate actuators
contagious	viral	Acute bee paralysis virus	Black shiny bees without bristles	24 hour starvation and controlled antimycotic feeding	Visual camera and image processing	Controlled feeder
contagious	viral	Sacbrood	An uneven brood pattern with discoloured, sunken or perforated cappings scattered through the brood cells*	24 hour starvation and controlled antimycotic feeding, re-queening if >5% of brood is infected	Visual camera and image processing	Controlled feeder
contagious	bacterial	American foulbrood	Irregular and patchy brood pattern, sunken cappings, a sulphurous smell	Colony should be killed. Alternatively, gamma radiation or antibiotic treatment	Visual camera and image processing, artificial nose	Controlled feeder
contagious	bacterial	European foulbrood	patchy brood pattern, ammonia-like smell	infected frames incineration, controlled antimycotic feeding	Visual camera and image processing, artificial nose	Controlled feeder
contagious	fungal	chalkbrood	Presence of the hard, shrunken chalk-like white to grey mummies in the brood and in/around the entrance	Brood reduction, queen and comb replacement, controlled feeding with vitamin C and nystatin	Visual camera and image processing	Controlled feeder, robot manipulator
contagious	fungal	stonebrood	Whitish-yellow collar like ring near head end of the infected larva, after death, the infected larva becomes hardened and quite difficult to crush	Mandatory incineration of colony and comb	Visual camera and image processing	Robot manipulator and incinerator
contagious	parasitic	nosema	Brown diarrhoea on combs and the outside of the hive, bloated abdomens, crawling bees	indoor conditions control, comb disinfection, re-queening, combs replacement and brood reduction	Visual camera and image processing	Robot manipulator indoor conditions controller
contagious	parasitic	Varroa	Constant colony decrease, patchy brood pattern, colony collapse	Biological - regarding drone brood, physical - 10-15 minutes 46-48^{0}C treatment, chemical	Visual camera and image processing, the other observed colony state signals	Robot manipulator, thermic chamber, controlled atomizer
contagious	parasitic	acarine	Reduced bee lifespan, decreased over-wintering capability	Chemotherapeutic measures	Combination of colony state signals	controlled atomizer
non contagious	Chilled brood		Similar like European foulbrood	indoor conditions control	Visual camera and image processing	indoor conditions controller
non contagious	Dysentery		Dark-brown diarrhea on combs and the outside of the hive, bloated abdomens, crawling bees	Replacement of frames containing indigestible matter with frames containing sugar water or high fructose corn syrup	Visual camera and image processing	Controlled feeder, robot manipulator
non contagious	May disease		Grouping of bees with bloated abdomen	Controlled feeding with sugar water	Visual camera and image processing	Controlled feeder

	Chemical poisoning	Dead bees all around inside/outside beehive, on a pasture even on flowers	Colony reduction, indoor conditions control, controlled feeding with sugar water, Controlled pesticide application during blooming period	Visual camera, image processing, combination of colony state signals	indoor conditions controller, controlled feeder, robot manipulator

Architecture suitable for the case study is given in Fig. 7. Camera can be static and linked to a beehive or the set of beehives or it can be coupled with a movable robotic platform intended for imaging of beehives in an apiary. Moreover, the platform can be shared among beekeepers belonging to the local beekeepers association to reduce exploitation cost. Diagnosis service can be provided as cloud service, while robotized lawn mower can be arranged in the same fasion as the movable robotic platform for imaging.

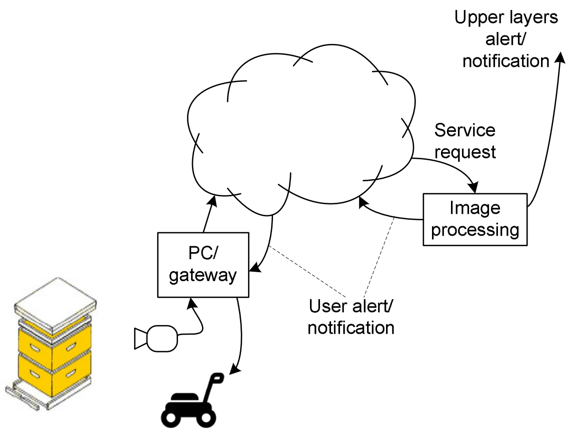

Figure 7. Image based bee disease diagnostics service

IV. Conclusion

We try in this paper to provide time perspective of beekeeping from its beginning and how state-of-the-art can contribute to future progress from the perspective of control in the process of beekeeping. Our position is that beekeeping will evolve from the current state, which can be described as well-established rational with many low TRL attempts in moving toward precision beekeeping, to CPB, which will enable control of the whole beekeeping process and achievement of sustainability objective. We present beekeeping process and the system characterization from single bee to global level. Some, general challenges and opportunities on the CPB founding way are given.

Moreover, we provide a case study describing how healthcare of bees, from proper diagnosis to appropriate measures, can be turned into CPB concept.

Finally, just with 10 IoT units per beehive and also 10 per apiary for monitoring and manipulation, an estimate of 866 million, at least, of IoT units worldwide is the potential of IoT application in the field of beekeeping.

Acknowledgment

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References

[1] Zacepins, Aleksejs, et al. "Challenges in the development of Precision Beekeeping." *Biosystems Engineering* 130 (2015): 60-71.

[2] Xing, Bo, and Wen-Jing Gao. "Bee Inspired Algorithms." *Innovative Computational Intelligence: A Rough Guide to 134 Clever Algorithms*. Springer International Publishing, 2014. 45-80.

[3] M. Mladenović, S. Rašić, "Pčelarenje", University EDUCONS, Faculty of ecological agriculture, Sremska Kamenica, Serbia, 2016

[4] Ferrari, Sara, et al. "Monitoring of swarming sounds in bee hives for early detection of the swarming period." *Computers and electronics in agriculture*64.1 (2008): 72-77.

[5] Bencsik, Martin, et al. "Identification of the honey bee swarming process by analyzing the time course of hive vibrations." *Computers and electronics in agriculture* 76.1 (2011): 44-50.

[6] Chen, Chiu, et al. "An imaging system for monitoring the in-and-out activity of honey bees." *Computers and electronics in agriculture* 89 (2012): 100-109.

[7] Tilman, David, et al. "Agricultural sustainability and intensive production practices." *Nature*418.6898 (2002): 671-677.

[8] Meikle, W. G., and Niels Holst. "Application of continuous monitoring of honeybee colonies." *Apidologie* 46.1 (2015): 10-22.

[9] Ritter, W., and P. Akratanakul. "Honey bee diseases and pests: A practical guide, agricultural and food engineering technical reports." *Rome, Italy: FAO, Food and Agriculture Organization of the United Nations* (2006)

[10] Langstroth, L. "Beehive." U.S. Patent No. 9,300. 5 Oct. 1852.

[11] de Souza, et al. "Device for hygienizing, warming, and dehumidifying a beehive." U.S. Patent No. 7,666,057. 23 Feb. 2010.

[12] Stearns, Gary D. "Solar-powered beehive cooler and ventilator." U.S. Patent No. 5,575,703. 19 Nov. 1996.

[13] Bulanyy, Igor. "System for controlling climate and moisture in beehive." U.S. Patent Application No. 14/606,527.

[14] Gil-Lebrero, Sergio, et al. "Honey Bee Colonies Remote Monitoring System." Sensors 17.1 (2016): 55.

[15] N. Jovanovic, "SMS Scales", RS Patent Application No. MP-2014/0064