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System Architectures for Real-time Bee Colony Temperature Monitoring

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Abstract

Beehive monitoring can provide useful information for people associated with beekeeping to help to manage their honey bee (*Apis mellifera*) colonies. The information obtained from the monitoring process can contain data about beehive's temperature, humidity, weight etc. Such a monitoring system is a practical tool in Precision Beekeeping. Honey bee colonies can be monitored using various system architectures that are different in methods and approaches. Since there are several monitoring system architectures, beekeeper himself should choose the one that suits his needs. To facilitate the beekeeper's choice of the suitable architecture, a selection algorithm was developed. This paper focuses on different automatic monitoring system architectures for real-time beehive temperature monitoring, distinguishing their advantages and disadvantages.

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Keywords: Precision Beekeeping; Precision Apiculture; Beehive temperature monitoring; System architecture.

1. Introduction

The fact that bees pollinate about 85% of flowers, make them as one of the most important insects[1]. Because of the importance, there is an increased interest in bee lives and behavior. Due to various reasons like pathogen (mentioned by Genersch et. al.[2]) impact on bee health, Colony Collapse Disorder, colony health assessment etc., beekeepers and scientists started to monitor beehives. Because of the bee disturbance with manual inspections,

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current technology is used for monitoring purposes as it can provide the information to manage bees and does not require manual inspections[3].

Precision Beekeeping (PB) or Precision Apiculture is individual branch of Precision Agriculture (PA)[4]. International scientists and practical beekeepers started to support its development by implementation of various technical systems for automatic and real time bee apiary and colony monitoring. Several international scientific projects (e. g., Application of Information Technologies in Precision Apiculture (ITAPIC): http://www.itapic.eu; Swarmonitor: http://www.swarmonitor.comze.com; E-Ruche: http://www.e-ruche.fr) have started to improve the availability of practical tools and technical means for usage in Precision Beekeeping. There is also available a remote monitoring system designed by beekeepers and bee-keeping enthusiasts, which allows a beekeeper to check data about hives through Internet[5].

Bee colonies can be automatically monitored using different approaches and methods. In system architectures sensor's data gathering can vary – data transmission (wired or wireless technologies), data storage and usage of intermediate devices. A particular monitoring system can also be supplemented with decision support system, which is responsible for data analysis, bee colony condition determination and appropriate decision selection.

Internet resource[3] provides beekeepers with information about other resources that are associated with honey bee monitoring technology. However, there is a need for further investigation about the system architectures that can be used for beehive monitoring.

Temperature is the factor that can be easily monitored and it is economically feasible. Bee colony temperature monitoring can be completed using various information technologies, systems and methods. This paper describes several approaches, including on-site and remote temperature monitoring, how bee colony temperature data can be transferred to the beekeeper for real-time data monitoring. Aim of this paper is to distinguish different system architectures for real time bee colony temperature monitoring.

2. Proposed system architectures

For description of all approaches predefined condition is that one digital sensor is used and it is placed into the beehive. Methodology for correct temperature sensor placement into the hive is not discussed within this paper.

2.1. First approach

This approach is based on on-site bee colony temperature monitoring. In this method data is not sent anywhere for storage and further analysis, and can be obtained only on site[6]. For this purpose, small display(s) can be placed outside the hive and beekeeper can see the colony temperature. To implement such monitoring method small iButtons sensors or other digital sensors are used.

Measured temperatures can also be observed remotely, by placing a camera towards the displays and ensuring a live video stream. A clock can be placed aside the sensor measurement displays, so the observer could keep a track of sensor measurements and register them manually if necessary. Advantages of such approach: this system is simply to develop and implement and it is economically cheap solution. Such system does not require any intermediate devices for sensor data transmission, as there is none. Disadvantages of such approach: temperature data is not automatically stored for further analysis, data is available only on-site, and there are no error notification options. To store data in such system, the beekeeper must manually register measurements. If a camera is used for remote data observation, then the camera and services to provide a live video stream is required.

2.2. Second approach

In this approach (see Fig. 1) data from sensors using wired or wireless communication is transferred to the local apiary computer[7,8,9]. Using specially developed software data can be demonstrated locally to the beekeeper. As well data can be automatically analyzed and decisions or conclusions about colony states and behavior can be sent directly to the beekeepers e-mail or mobile phone. For remote monitoring of collected data, remote connection to apiary's personal computer (PC) using standard remote connection options, e. g., windows remote connection or using specific software like TeamViewer or RAdmin can be used. As well local Web server can be developed for public access to the collected data[10].

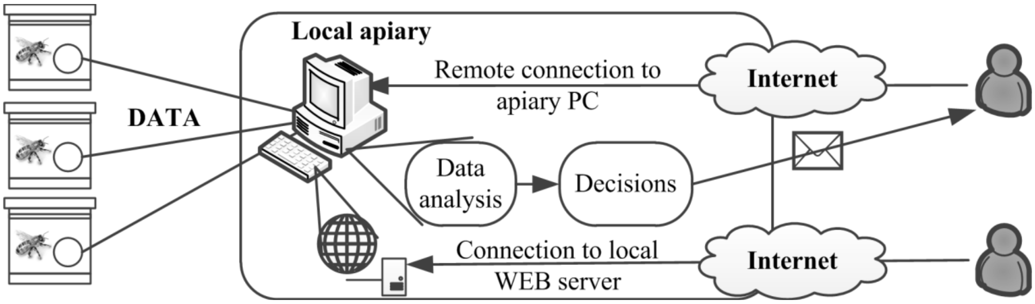

Fig. 1. Data from temperature sensors is stored on the local apiary computer.

Advantages of such approach: temperature data is stored locally and can be accessed remotely. Beekeeper can receive messages about beehive's behavior.

Disadvantages of such approach: apiary's PC is working all the time so there is additional need to use uninterruptible power supply (UPS) device to minimize effect of electrical power variations. Constant Internet connection is also needed to allow remote connection and public access to the data. If PC is turned off, data collection process is interrupted and data for public access is unavailable.

2.3. Third approach

Data from sensors using wired or wireless communication are transferred to the local apiary's PC for further data transmission to remote computational station (remote server, cloud service) (see Fig. 2). In this case, apiary's PC is used as intermediate device. There are several options of transmitting data. One option is usage of, e. g., Microsoft Access (MS Access) database and its copying to the remote server[11]. Second option is direct data transfer to remote database. On the computational center, Web server can be developed for public data access. As well data on the server can be automatically analyzed by specifically designed software and decisions or conclusions can be sent directly to the beekeeper.

The third system architecture's approach has been implemented within the international scientific ITAPIC project in Jelgava, Latvia. Data from the formed 1-Wire network is retrieved through a 1-Wire/iButton adapter DS9490R using an application written in C# programming language. As described above, data is stored in MS Access database, which is then duplicated on a remote server and data can be accessed publicly through a Web page.

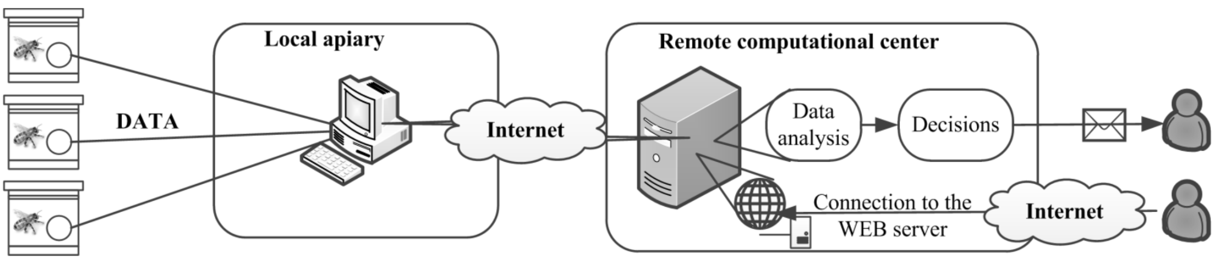

Fig. 2. Temperature data using PC as intermediate device is transferred to remote server.

Advantages of such approach: data can be saved both in local and in remote databases. Beekeeper can receive messages about beehive's behavior. If apiary's PC is turned off, stored data is still available publicly on the Web server, using Web or local applications.

Disadvantages of such approach: there is still a need for a PC in local apiary thus it is advisable to use UPS device. Constant Internet connection is needed to allow data transmission. Long-term electrical power interruptions may disturb beehive monitoring, because if PC is turned off, data collection process is interrupted.

2.4. Fourth approach

By the usage of a specific interface device data from sensors using wired or wireless communication is transferred to the remote computational station (remote server, cloud server) for further analysis (see Fig. 3). In this case, e. g., Raspberry Pi (device that is a small size computer[12]) or Arduino (a microcontroller based computing platform[13]) can be considered as the interface devices.

On the computational center, Web server can be developed for public data access. As well data on the server can be automatically analyzed and decisions or conclusions can be sent directly to the beekeeper.

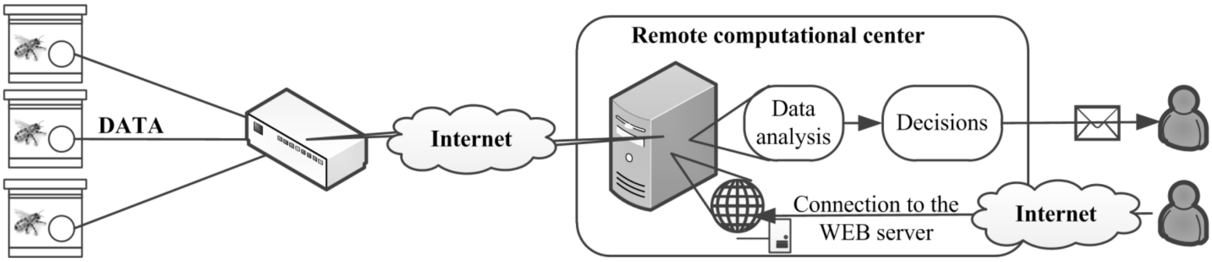

Fig. 3. Temperature data is saved directly on remote server.

When using Raspberry Pi as an interface device (see Fig. 4), it is not complicated to add a 1-Wire network to this device, because it has a driver module for it. Sensor temperature logging can be programmed using several programming languages, like Python, Ruby, C/C++. The main issue is the 1-Wire network's sensor count limit that can be connected to the Raspberry Pi. By default there can only be ten 1-Wire network sensors connected in the network due to the fact, that the sensor count is hardcoded in the Raspberry Pi's 1-Wire network driver. The count can be changed by applying a specific patch or by updating/upgrading Raspberry Pi's firmware and kernel.

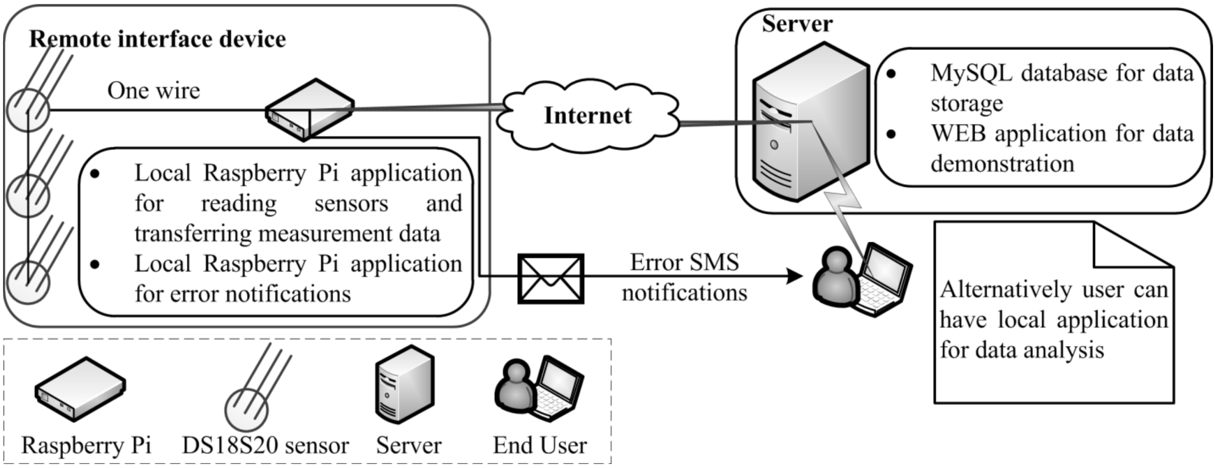

Fig. 4. System architecture with Raspberry Pi as an interface device.

Since some Raspberry Pi model's (model B, model B+) has an Ethernet (computer networking technology) port[14], gathered data from sensors can be transferred to a remote database (DB) (e. g., MySQL) without a need for an additional networking device (e. g., Wi-Fi adapter). Raspberry Pi can be accessed remotely using ssh network protocol. This ensures that, applications running on this interface device can be modified and improved remotely. Data can also be transferred using wireless technology, but then, as mentioned before, and additional networking device is needed. In specific cases beekeeper can be informed about beehives conditions by receiving SMS or e-mail messages, generated by developed error notification application on Raspberry Pi.

The system architecture, where Raspberry Pi model B is used as an intermediate device, was implemented within ITAPIC project in Jelgava, Latvia. The system was set up in wintering building for temperature monitoring in ten beehives.

Although Arduino has no Ethernet capability, it may also be used as an interface device. In this case an additional device for networking is required (e. g., Arduino Ethernet Shield).

Advantages of such approach: there is no need for PC in the apiary for data collection and transfer. There is lower electrical power consumption, when using an interface device. In some cases it is possible to modify or improve interface device's applications remotely. If the interface device is turned off, stored data can still be accessed using Web or local applications.

Disadvantages of such approach: if interface device is turned off (electrical power variations), data collection process is interrupted. If there are problems with Internet connection, new data cannot be saved to remote database. Additional configuration for specific interface devices may be required. Some interface devices may not have Ethernet capability.

2.5. Fifth approach

Data from sensors (measurement nodes) using wireless communication is directly transferred to remote computational station (remote server, cloud server) (see Fig. 5). In this case each measurement node (sensor in each hive) can obtain Internet Protocol (IP) address from network router and use this device for transmission of data or can use additional 3G or 4G modems to send data. Concept of the remote computational center remains the same. Specific sensor network devices (called as "motes") can be used as measurement nodes. Previously mentioned Raspberry Pi and Arduino devices can also be adapted as measurement nodes in this architecture.

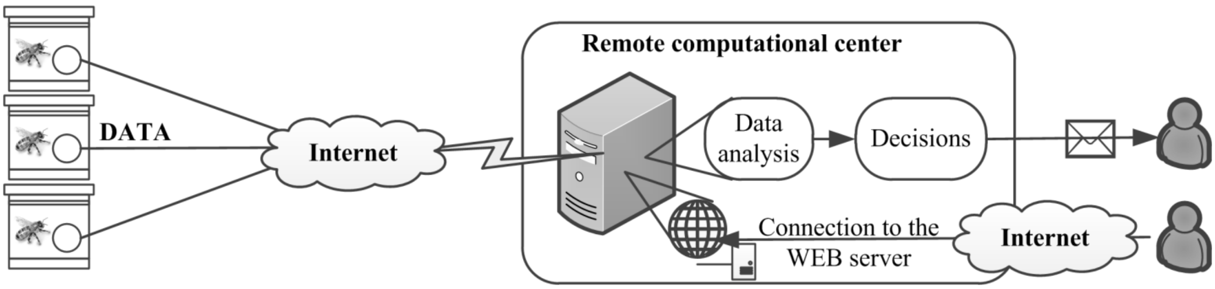

Fig. 5. Temperature data from measurement node is saved directly on remote server.

Within the ITAPIC project a wireless monitoring system is implemented as well. This system (see Fig. 6) is based on fifth approach and monitors temperature and humidity. For now, the system is implemented in Tokat, Turkey for local bee apiary monitoring.

The monitoring system (see Fig. 6) consists of three main components:

- Measurement node – system's element that is responsible for sensor measurements at a specific hive and those sensor data transmissions to the main unit. This element consists of microcontroller, wireless transceiver, sensors and power source;
- Main unit – a system's element that listens to measurement nodes and transfers data to cloud database server. The main unit consists of several integrated blocks: a low-power microcontroller, a wireless transceiver, peripheral

extension connectors, an external storage device (optional) and a power source (5 V power adapter is used as energy source);

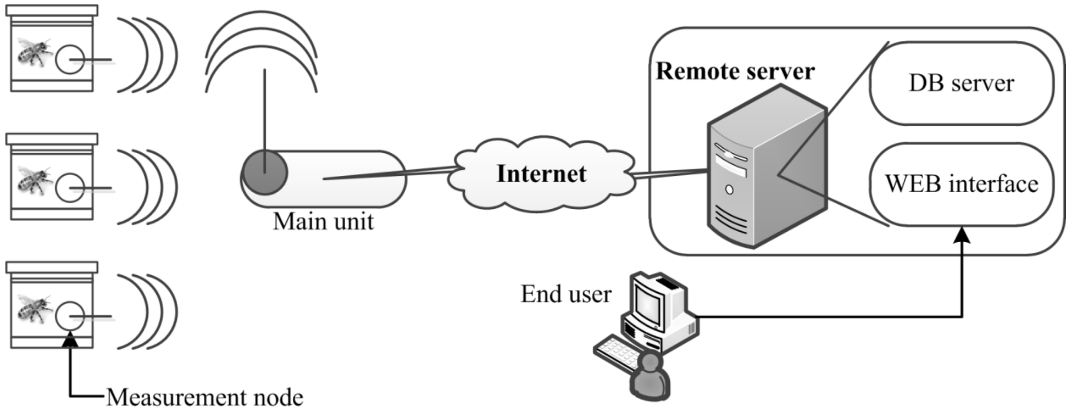

Fig. 6. Wireless measurement system used in ITAPIC project.

- Remote database server – data from measurement units is directly saved in cloud database for further analysis and demonstration. For access to stored data additional php Web system was developed. Web system can be adjusted to beekeepers need by implementing different graphical elements for data demonstration and data analysis also can be added.

Similar to fifth approach a remote control system for temperature and humidity monitoring in beehives was developed by Altun[15]. The system contains wireless sensor network, a GSM-supported central system and thermoelectric heating and cooling system. In Altun's monitoring system data from sensors is transmitted using wireless network. The central system processes sensor data using specifically developed software and warns the beekeeper in emergency situations.

Advantages of such approach: there is no need for PC or previously mentioned interface devices for data collection. Each measurement node is transferring data independently and in case of error only one node's data can be lost.

Disadvantages of such approach: power source for each of measurement nodes should be provided. If using batteries as a power source, a regular battery control is necessary, to prevent node from unexpected shutdown. In case of usage of 3G or 4G modems individual SIM card should be provided for each individual hive.

2.6. Sixth approach

Data from sensors are not sent anywhere for further analysis, but is analyzed directly on individual measurement node and decisions are sent directly to the beekeeper (see Fig. 7). This approach should use wireless connections. Additionally it can be possible to develop individual Web server for each measurement node for remote data access. Realization of such approach can be done using multiple Raspberry Pi or Arduino devices, or developing a specific circuit.

Advantages of such approach: fully customizable solution in case of a specific circuit developing. Each measurement node is transferring data independently and in case of error only one node data can be lost. There are no raw data transferring, only conclusions are sent.

Disadvantages of such approach: power source for each measurement node should be provided. A regular control for each measurement node is required to ensure that there is no unexpected shutdown (e. g., due to battery discharge). In case of usage of 3G or 4G modems individual SIM card should be provided for each individual hive. Sometimes it is better to have all raw data available, not only analyzed data is useful. Costs for such system will be higher comparing to wired based solutions.

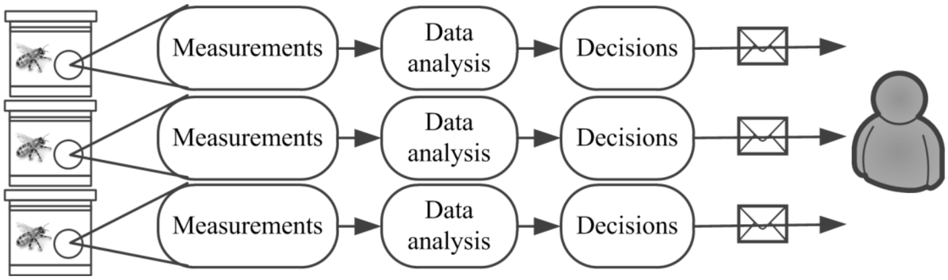

Fig. 7. Temperature data from measurement node is analyzed on site and only decisions are sent to the user.

3. Results

The system architectures that were described in this paper were compared. For comparison purposes following criteria were chosen: PC in local apiary; usage of interface device; data storing; data analysis and possibility of decision support system (DSS) implementation; remote computational center; constant 220 V power connection and Internet connection accessibility.

Some of the criteria can be optional for specific system architectures (see **Error! Reference source not found.**). One of those criteria is Internet connection requirement – in on-site bee colony monitoring system it is optional. It is required only when a live video stream is used for remote data observation. It is optional also in second approach, because the Internet is only required when accessing data remotely, but if it is not available, data can still be accessed locally. Likewise, a constant 220 V power connection is not required in bee colony monitoring where measurement nodes are used, as such devices can be powered using alternative energy or batteries.

Table 1. Comparison of system architectures for beehive monitoring.

	System architecture, approach					
Criteria	1	2	3	4	5	6
PC in local apiary	-	+	+	-	-	-
Usage of interface device	-	-	-	+	-	+
Data storing	-	+	+	+	+	-
Data analysis and possibility of DSS implementation	-	+	+	+	+	+
Remote computational center	-	-	+	+	+	-
Constant 220 V power connection	-	+	+	Optional	-	-
Internet connection	Optional	Optional	+	+	+	+

Note. "+" – required; "-" – not required; "Optional" – can be used, but not an obligatory requirement.

The simplest system architecture that can be implemented for bee colony temperature monitoring is the on-site monitoring system as it does not require any additional components except temperature sensor with a display.

The costs to implement second and third system architecture are higher, compared with other architectures, due to the fact, that a PC and constant 220 V power connection is required in the local apiary. Costs required to implement fifth and sixth approach are dependent on the count and type of measurement nodes.

System architectures that uses remote computational center (3-5 approach) ensures that previously gathered data is accessible even when the monitoring process is interrupted (Internet connection is lost, problems with measurement nodes etc.). Unlike the second approach, where data is stored on local apiary's PC and cannot be accessed remotely, if Internet connection is interrupted (access is only locally) or there are problems with the PC (data cannot be accessed).

It can be rather time consuming for beekeeper to choose the suitable approach for beehive temperature monitoring. To facilitate the beekeeper’s choice, a business process model and notation diagram that represents selection algorithm (see Fig. 8) was developed.

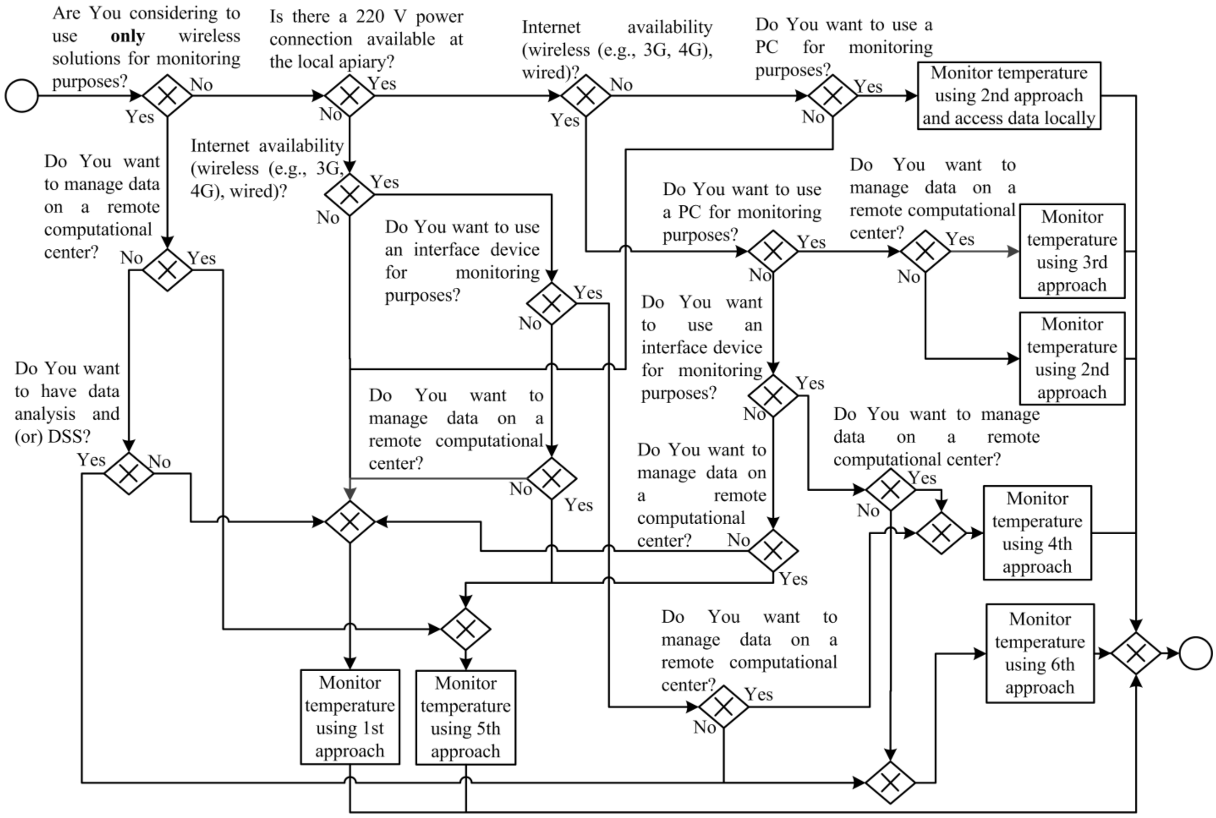

Fig. 8. Selection algorithm for system architectures.

In this algorithm only the general conditions were used. The first condition describes situation, when the beekeeper must consider if the monitoring process will be done wirelessly. One reason for that may be the large distances between the hives where wireless solutions can facilitate the implementation of the monitoring system. Selection algorithm was validated by comparing the choices that were made to use system architectures within the ITAPIC project.

4. Conclusion

The described six system architectures for bee colony temperature monitoring showed how different the monitoring systems can be, e. g., from monitoring when using only a sensor with a display (first approach), to approach when using specific devices for each hive (sixth approach) and performing data analysis. Beekeepers individually should choose the appropriate system architecture for bee colony monitoring, based on their needs and financial calculations and available technologies in the apiary’s location. The developed selection algorithm can reduce the time that is needed to choose the appropriate system architecture because it offers the key conditions that are necessary for specific system architecture. The algorithm does not provide information about the financial calculations while choosing the system architecture, as the calculations depend on different factors (the count of hives, chosen technologies (in the case of interface devices – type and count) etc.). Thereby the algorithm can be supplemented by this type of information.

If it is necessary to store measured temperature data, it is recommended to use system architectures that stores data on a remote database (approach third to fifth). If the monitoring process is stopped data can still be accessible and will not be lost in case of apiary's PC problems as it can be when using second system architecture.

Important issue is power source in apiary location, if a constant 220 V connection is not available, then alternative power supplies should be considered (e. g., solar energy). In case of use of a solar power and if data transmission is being done by wireless technology, it should be considered to minimize the data flow from measurement node to remote server, to minimize power consumption.

In architectures where beekeeper requires receiving SMS about beehives conditions (swarming, colony death etc.) and following decisions, a decision support system should be applied for generating such messages. Such a system should timely predict upcoming situations by detecting the tendency of bee behavior (e. g., slowly decreasing temperature should mean the death of the colony).

Proposed system architectures are applicable not only in beekeeping branch, but also in other branches where it is needed to monitor object temperature in real time.

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References

1. Warnke U. 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; 2009.
2. 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. The German bee monitoring project: a long term study to understand periodically high winter losses of honey bee colonies. *Apidologie* 2010; 41:332–352.
3. Welcome to colonymonitoring.com! Retrieved: 18.05.2014, URL: http://colonymonitoring.com/cmwp/.
4. Zacepins A, Stalidzans E, Meitalovs J. Application of information technologies in precision apiculture. *Proceedings of the 13th International Conference on Precision Agriculture (ICPA 2012);* 2012.
5. Listening to bees. Retrieved: 20.05.2014, URL: http://www.arnia.co.uk/.
6. Romanov B. Bee Hive Live Camera. Retrieved: 06.01.2013. URL: http://www.beebehavior.com/livecam.php.
7. Zacepins A, Meitalovs J, Komasilovs V, Stalidzans E. Temperature sensor network for prediction of possible start of brood rearing by indoor wintered honey bees. *Proceedings of the 12th International Carpathian Control Conference (ICCC 2011);* 2011. p. 465–468. doi:10.1109/CarpathianCC.2011.5945901
8. Vornicu OC, Olah I. Monitorizing System of Bee Families Activity. *7th International Conference on Development and Application Systems;* 2004. p. 88–94.
9. Meitalovs J, Histjajevs A, Stalidzans E. Automatic Microclimate Controlled Beehive Observation System. *8th International Scientific Confernce "Enginieering for Rural Development,"*, Latvia University of Agriculture; 2009. p. 265–271.
10. Zacepins A, Karasha T. Web based system for the bee colony remote monitoring. *Proceedings of the 6th International Conference "Applied Information and Communication Technologies" (AICT 2012);* 2012. p. 155–158.
11. Zacepins A, Meitalovs J. Implementation of multi-node temperature measurement system for bee colonies online monitoring. *Control Conference (ICCC), 2014 15th International Carpathian;* 2014. p. 695–698. doi:10.1109/CarpathianCC.2014.6843694
12. Raspberry Pi. Retrieved:18.05.2014, URL: http://www.raspberrypi.org/.
13. Arduino - Home. Retrieved: 18.05.2014, URL: http://arduino.cc/.
14. Model B+ | Raspberry Pi. Retrieved: 18.05.2014, URL: http://www.raspberrypi.org/products/model-b-plus/.
15. Altun AA. Remote Control of the Temperature-Humidity and Climate in the Beehives with Solar-Powered Thermoelectric System. *J. Control Eng. Appl. Informatics* 2012; 14: 93–99.