ISSN 1870-4069

Video Surveillance of Beehives Using Computer Vision and IoT

Apolinar Velarde-Martínez, Gilberto Gonzalez-Rodríguez, Maria Teresa Ibarra-Rodríguez, Braulio Orozco-Cortéz

Tecnológico Nacional de México/Instituto Tecnológico El Llano Aguascalientes, Mexico

{apolinar.vm, gilberto.gr, maria.ir}@llano.tecnm.mx, 19900130@llano.tecnm

Abstract. Different animal species beneficial to the environment and human beings face imminent extinction due to different types of problems. The preservation of these species for the survival of humans and ecology is necessary. To preserve species, it is necessary to identify diseases and pests, through surveillance and observation by man. The honey bee (apis mellifera) is an endangered specie, and its care and preservation are already necessary. The Llano Aguascalientes region, Mexico faces problems of the extinction of this specie. This research work presents and describes a video surveillance system for the observation and care of hives using the Internet of Things and Computer Vision. The hardware prototype, the power supply system, the communication system between the apiary and the developed software system, as well as the developed software system, of this research work are described. Experiments were carried out in real environments for each part of the project and the software system which uses computer vision for the recognition of the bee in different positions is evaluated. The results obtained are described and the feasibility of this project which includes artificial vision and Internet of Things, as a support tool for the preservation of the apis mellifera species, is demonstrated. This research will allow in the near future the development of research projects applied to industry 4.0 for the conservation of this species.

Keywords: Apiary, beehive, cluster, computer vision, video surveillance.

1 Introduction

Environmental problems such as global warming caused by the destruction of flora, the disappearance of fauna, greenhouse gases, pollution and others that the planet currently faces, have been the reason for the issuance of government laws, and environmental organizations, to cite some references [1-4].

Currently, efforts have been directed towards the preservation of flora and fauna as measures to reduce the effects of environmental destruction. The preservation of beneficial fauna for humans, such as the honey bee, is carried out by the governments of different countries and organizations around the world by means of the implementation of special programs for its preservation.

The honey bee is a specie whose constant activity allows the pollination of different plants during the flowering process, and is cultivated for the production of food [5, 6, 8, 9] such as honey and propolis, as well as for support in the flowering of cultivable plants [14] such as corn [10], alfalfa [7] and beans [11].

Protecting and propagating the honey bee generates heated debates in the scientific environment because it is a species manageable by man; debates are generated due to competition with local wild pollinators [12], which it displaces from the spaces where is cultivated, but its preservation and care has become necessary.

Recent research shows bee populations have decreased considerably, due to different factors and diseases, such as the phenomenon of the disappearance of bee colonies [2, 15], the problem of the Varroa parasite which produces the Varroasis disease in bees [14, 16-18] and others.

Knowing the current problems of bees in the world, and considering the region of the Llano Aguascalientes, México as a producer of food from beekeeping and where crops depend largely on pollination by bees, field research, observations and interviews with beekeepers in this region were conducted; the objective of these investigations works is to know the diseases produced by the parasites which attack bees and the manual solutions applied to find these diseases; the results showed the existence of attacks by parasites and destructive insects of the hive that inhabit the spaces where the bee is cultivated; also the use of methods with the sacrifice of bees for the observation of parasites, such as those described in [13].

According to the above, it was found there is no system with computer technologies to automate hive inspection processes to avoid parasite infestation, nor a system to detect temperature and humidity levels in the hive, to avoid the appearance of bacteria which destroy bee brood queen.

In this research work, a real video surveillance environment with Internet of Things and computer vision for the preservation of the honey bee, in the region of El Llano Aguascalientes, México, is proposed. This real video surveillance environment is made up of a set of systems. The first system is related to the supply of normal electrical energy and solar electrical energy. A second system is the communications system between the apiary and the data processing center. The third system is the software which manages all the hardware devices, installed in the Liebres InTELigentes server cluster.

1.1 Justifications

This field research and the development of a real environment for video surveillance of the honey bee in the region Llano Aguascalientes, Mexico, is justified for the following reasons:

- This region is a producer of food from the cultivation of the honey bee, for which a set of surveys and interviews were carried out with beekeepers in the region to learn about and document the parasitic diseases of bees, and how the disease detection on bees is carried out manually.
- To propose an automated surveillance method to prevent the attack of parasites on honey bees, and protect bee colonies in this region because they are cultivated with the purpose of pollinating crops such as alfalfa, beans and sorghum.

- This research proposes and develops a solution made up of a hardware structure controlled by a software system, also a system to data acquisition and images which are transmitted to a Data Processing Center (DPC) made up of a cluster of servers for subsequent processing, and proposes development a system for mobile devices for end users (beekeepers).
- The prototype can be highly beneficial to stop and reduce a pandemic in a bee colony, making a timely diagnosis and preventing the hives from being in danger of dying due to parasitization.
- The Varroa parasite can be detected through image analysis; this parasite is highly destructive in bee colonies, which it attacks from birth to adulthood, a system with IoT technology and computer vision can support beekeepers to identify hives with bees infected by this parasite.

This work is composed of the following sections. The related works section describes some papers related to this research paper. The Basic Definitions section displays a list of definitions used in this work. Structure of the System is developed in section 4. Experimentations with the system in section 5 are described. The conclusions obtained so far are presented in section 6. Works currently being developed and will be presented in future papers are mentioned in section 7.

2 Related Works

There are several projects with video surveillance of bees for different purposes. In order not to extend this section, some research works are mentioned.

The bee surveillance project described in [21] sought information of the prevalence of honey bee colony losses. [22] presents a simple, non-invasive, system for pollen bearing honey bee detection in surveillance video obtained at the entrance of a hive; classifies into two classes: pollen-bearing honey bees and honey bees that do not carry pollen load; classification is performed using the nearest mean classifier, with a simple descriptor consisting of color variance and eccentricity features.

Inexpensive and modular system, to allow beekeepers to remotely observe the progress of their hives without opening them, is presented in [23]; this system sends sensor data acquired from beehives to a server for further analysis, obtains video and audio recordings which are used in some image and signal processing analysis.

In [24] video surveillance to monitor bee acitivity within male and female pumpkin flowers in 2011 and 2012 across a pollination window of 0600–1200 h was used. In [22] the importance of the use of video surveillance systems to understand and improve the health of bees, as well as the detection of parasites in hives, is highlighted.

According to the works mentioned, video surveillance has been adopted has a technology for the care and preservation of bees. A system which uses industry 4.0 technology is presented in this paper.

3 Basic Definitions

This section defines a set of terms related to the research described in this work. Knowledge of these terms enables the reader to understand the following sections.

– Bee. Hymenoptera insect Apis mellifera [3].
– Hive or brood chamber. Lodging of a colony or family of bees [3].
– Apiary. According to [13] an apiary is a space where the hives are located.
– Cluster LITEL. To define the cluster, let me use some previous definitions, then, this cluster is a set of loosely coupled, autonomous processing nodes [25]; each node may consist of a tightly coupled multiprocessor system [26].
– Data Processing Center (DPC). It is a cluster of servers with a high speed network, which works with free software, Linux operating system, C++, Apache2, PHP, HTML, OpenCV and Postgres [27].
– The system communication of multipoint point. An installation of a local computer network to allow communication between the DPC and the apiary; this system covers a distance of 800 meters, which complies with the regulation of the distances between the apiary and the passage of people or animals.
– Data and image acquisition device in the apiary (DADi). A device constructed with an Arduino board, an image acquisition camera, an electrical system operated with solar energy, and a Raspberri Pi device. The Raspeberri Pi (RasPi) device works as the Central Processing Unit and makes the set of devices work and allows communication between the DPC and the apiary. An electrical system for the acquisition of energy, consisting of a solar panel connected to a battery and an eliminator; this system provides power to the devices described in the following paragraphs installed in the hive. The Arduino Nano device is equipped with temperature, humidity, and motion sensors; the camera allows the acquisition of images of the hive entrance; a Raspberri Pi (RasPi) device is responsible for connecting to the Arduino and the camera, as well as for transmitting the information to the DPC.
– Liebre1 Software Agent. Software developed with the C++ programming language, the free distribution OpenCV (Open Computer Vision) image processing tool, Arduino language, the Postgres database management system and the web programming environment: PHP and HTML; the host operating system is the freely distributed Ubuntu Server.

4 Structure of the System

The general structure of the video surveillance system (prototype) using the Internet of Things and Computer Vision, is composed of:

– Brood chamber (hive). Meets the environmental requirements for use with live honey bees.
– Electric power supply system for the apiary antenna and the brood chamber.
– Communication system between apiary, data processing center and the end user.
– Software system using open source tools and operates in the server cluster.

In the following paragraphs, each of the parts is explained in detail for the reader's understanding.

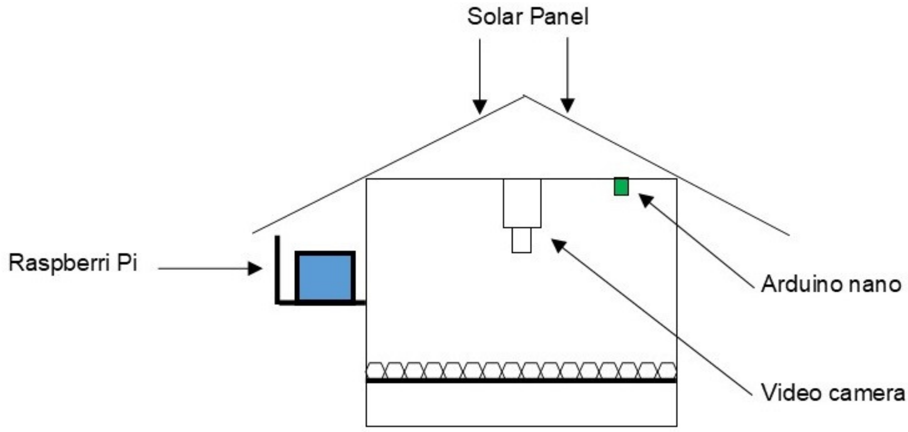

Fig. 1. General scheme of the hive.

4.1 Brood Chamber (Hive)

This part of the project consists of a brood chamber with the environmental requirements to be used with live honey bees, and contains the following special attachments for data and image acquisition:

1. Two solar panels placed on the top of the hive, built crosswise for the acquisition of solar energy which feeds the Arduino devices, Raspberry Pi, video camera and humidity and temperature sensors.
2. A Raspberri Pi device, for sending and receiving information between the apiary and the DPC.
3. A video camera for the acquisition of images in the hive entrance.
4. An arduino nano to connect the humidity and temperature sensors of the hive.
5. A wireless antenna to communicate the hive with the communication antenna router.

This brood chamber is located at a distance of 800 meters from the university campus, to avoid contact between people and honey bees. It works 12 hours a day to transmit information to the DPC. To carry out the tests, 10 bee racks were installed inside the chamber with approximately 3,000 bees, according to the beekeeper's estimates. Figure 1 shows the general scheme of the hive.

4.2 Electrical Power Supply System

The electrical power supply system consists of two types of power: the power supply from the electrical network to enable functionality of the antennas installed in the apiary, and the solar energy system installed in the hives-prototype (brood chamber).

For the supply of electrical energy in the brood chamber, the system was designed as follows: two solar panels connected to a deep-cycle battery to guarantee the supply to the installed hardware. The energy consumption is 20 watts per hour; the solar panels manage an energy of 120 watts per hour for a cycle of 12 hours, which guarantees devices will maintain their full functionality.

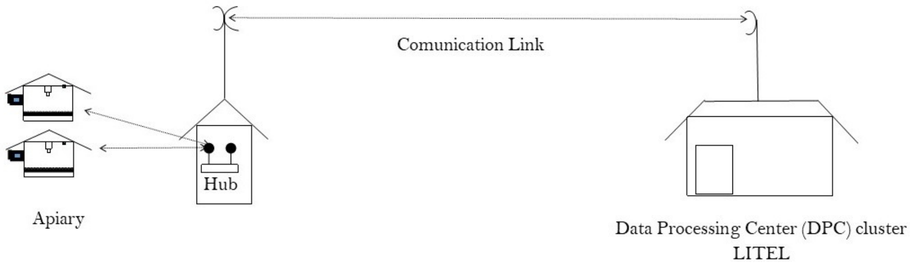

Fig. 2. The communication system between the CPD and apiary.

4.3 Communication System

The communication model is constituted by the system communication of multipoint point, which allows the DPC to communicate with the apiary permanently. The system works for a period of 12 hours during the day; all data is collected in the Liebre1 software agent system and is stored on high-speed devices for later processing.

The acquisition of data such as images, video and hive parameters from the apiary to the DPC is performed every minute, namely, the DADi sends images to the DPC for processing as shown in figure 2. This system was installed exclusively to carry out this research project, so it is not used for the transmission of any other type of information.

4.4 Software System

The Liebre1 software agent system is responsible for processing the data and images collected from the hives. Once the temperature and humidity parameters are collected and stored in a database, the images are sent to an subdirectory on the host server.

To carry out the video surveillance, a web page is provided for the beekeeper; this page shows the temperature and humidity data, as well as the images extracted from the hive. In addition to the above, in the DPC a preprocessing of the images is carried out to detect intrusions in the hive. This detection is done with image processing, which is explained in the paragraphs below.

Image Processing. The images are acquired from the apiary, specifically from the hives where the DADi is installed and they are sent to the DPC where each hive is identified by the registry provided by by the government office Agricultura [28]. The objective of this part of the project is to develop a sufficiently robust technique for contour detection; this technique must be tested with different images of the possible positions of the bees in the entrance, as well as considering the lighting with sunny days, cloudy days and rainy weather.

The image is acquired with a Raspberri Pi device, every minute; in the DPC, the image is processed with the following steps: crop the image, gray scale generation, frequency histogram creation, image recognition and contour generation [29-31]. On next paragraph every step is describen in reduced form:

a) Crop the image. This process segments the image into partitions; this partitions will be used on following processing phases.

Fig. 3. Phases of image processing.

b) Gray scale generation. The grayscale of an image is generally used as a preprocessing step of the image to prepare it for more complex image processing.
c) Creation of the frequency histogram. histogram of the image is created.
d) Shape recognition of the bee with convolutional neural networks (CNN).

Figure 3 shows the phases of image processing. The above steps are capable of issuing an alert in case of the following detections: the insect detected by the system is not a bee in the entrance (there is an intruder), or the insect detected by the system is a bee in the entrance. The proposed system runs on the Liebres InTELigentes server cluster (LITEL cluster), considered as the DPC. The cluster is made up of 3 high-end servers, with a high-speed network. The basic characteristics of the LITEL cluster are:

a) DELL Power Edge server, R330.
b) DELL Power Edge server, R540.
c) HP Proliant DL320E Gen 8 v2 server.
d) CISCO SG350-28 switch with 24 Gigabit ethernet ports.

All the hardware of the LITEL cluster is concentrated in a communications rack, located 800 meters from the central apiary of the campus.

5 Experimentations

The experiments of the video surveillance system have been carried out in the apiary of the Instituto Tecnológico del Llano, Aguascalientes, Mexico with 2 prototype hives, which are registered in in Agriculture Government Office and installed at the regulatory distance from the campus. The experiments was carried out with the three developed systems explained before, namely, the electrical power supply system, the communication system and the software system. The experiments described in this research work are carried out in controlled scenarios with the calibration of the camera.

The prototype is currently being developed in a real scenario. By space reasons, only the experimentations with the software system are described. To carry out the experiments with the data processing system, generation of the image database was built; this database contains 400 images of bees in different positions; figure 4 shows the bee in different positions based on the quadrants. For each quadrant 100 images were generated. For all images the background remains the same. In subsequent experiments, the background will be changed.

For this research work, a single kind of bee was used, Italian honey bee; Italian honey bee lives in the region of the Llano Aguascalientes, México. It is clear that, by changing the bee class, the image database must be changed or the number of images must be increased.

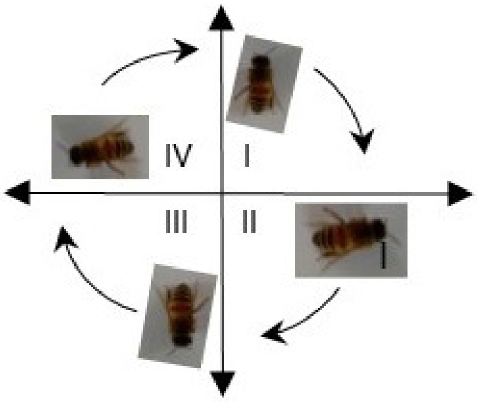

Fig. 4. Positions of the bee in the entrance.

Image database allows the recognition of the bee, placed in different positions; the recognition of the bee in different positions is necessary because when the bee leaves the hive, it can do so in different ways and the camera can acquire images of the bee every minute, without considering the position that the bee can take. In paragraphs below the software testing and experiments are going to explain.

Software testing. For the recognition of the bees in the hive entrance, the following experiments were considered, using solar lighting and in a scenario without solar lighting (cloudy); these scenarios were considered because the prototype will be installed in a real environment. Also different loads of images was considered. Only first three experiments with loads will be explained. Similar results was obtained with subsecuent experiments.

100 presentation images to the system (one by one). 50 images were acquired when there was sunlight on the stage, and 50 images when the weather was cloudy. The percentage of recognition was 56% and 61% respectively. In these experiments we have found that the system fails to acquire (generate) the thoracic part of the lower legs; it's an essential part for shape recognition. Figure 5 shows a loss of the thoracic part of the bee.

150 presentation images to the system (one by one). The number of images presented to the system was increased to determine the recognition percentage and detect false positives. For this phase of experimentation, a new filter was added to the image processing; this filter seeks to make the contours more visible. The results obtained show a higher recognition percentage. In the case of images with sun, a 69% assertiveness of the system was obtained and for images with a cloudy scenario (there was no sunlight), a recognition of 70% was obtained.

300 presentation images to the system. In an iteration of 300 cycles the system sought to recognize the bee. The recognition percentages remain lower than in the two previous experiments. By adding a new filter to image processing, the number of images containing more sunlight was increased, resulting in lower recognition percentages. The results obtained are 51% recognition with images containing direct sunlight on the hive. 53% recognition by avoiding direct sunlight.

Fig. 5. Image showing the loss of the thoracic part of the bee.

Figure 6 shows the percentages of recognition of the three experiments explained, and others with different amounts of images.

The experiments show the brightness of the image is decisive in the recognition of the shape of the bee. It has been found in these experiments, the introduced images to the system with brightness of sunlight are likely to not be recognized, while images with low lighting may have a higher probability of being recognized. Although controlled environments are not an optimal system test, they do provide information for verification of system functionality. Other experimentation pending is the acquisition of images with rain.

NOTE. All the experimentations carried out in this research work were carried out with bees had already perished in the hive; no insect was sacrificed under any circumstances. All experiments are in compliance with the Law for the Protection of Animals for the State of Aguascalientes, Mexico, of Principle I and those emanate from it: Every animal has the right to live and be respected.

6 Conclusions

This research work presents the architecture of a system based on the Internet of Things and Computer Vision, for the preservation of the honey bee in the region of the Llano Aguascalientes, México. Experiments carried out for the recognition of the bee in the hive entrance are presented and described.

Very interested issues related to illumination in the scenarios where experiments was executed, was found. The thoracic part of the honey bee is an important part in the recognition phase; different filters was used to enhance the contours and let to the software system determine the presence or not presence of the bee in the entrance of hive. Altough our results are not so good so far due to the factors of movements of the bee, we are continue to improve both.

The electrical design and the data transmission speed tests between the apiary and the data processing center, due to space issues, were not presented. With this research applied to beekeeping, it is possible to demonstrate, the technologies used are feasible to prevent parasite invasions in hives and help in the preservation and care of the honey bee.

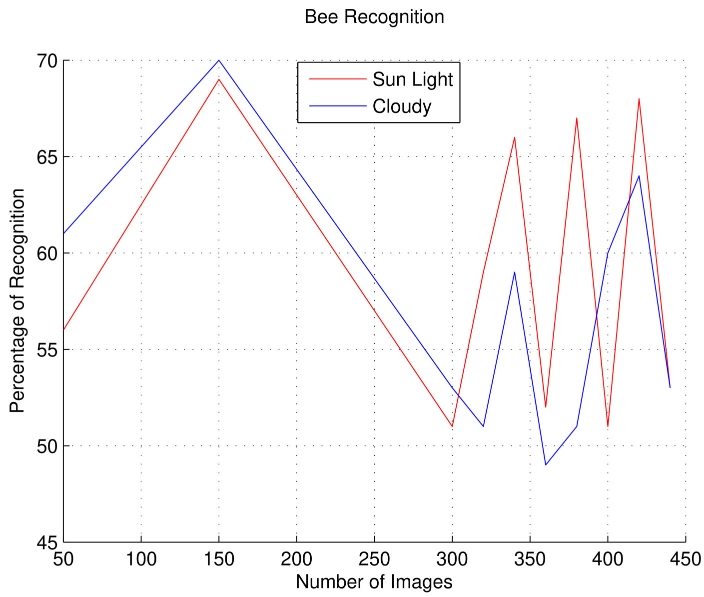

Fig. 6. The recognition percentages of the bees in each of the three experiments carried out and using different amounts of images.

7 Future Works

The future works of this research have been proposed in three important developments. First, the acquisition of real-time video of the hive, which will be sent to the DPC and placed on a web page to allow the beekeeper to view the video. Second, it is the recognition of the thoracic structure of the honey bee for the early detection of the Varroa parasite using Computer Vision.

Third, design of a system in software and hardware for the transmission of the audio from the hive to the data processing center, to retransmit the audio to the mobile devices through the web page, because according to the explanation of the experts, the movement (behavior) generated by the bees allows detecting the current status of the hive in terms of unwanted visitors.

Aknowledgments. This project is supported by IDSCEA Instituto para el Desarrollo de la Sociedad del Conocimiento del Estado de Aguascalientes, México. Special Thanks to Instituto Tecnológico el Llano Aguascalientes, México.

References

1. LXV Legislatura del Estado de Aguascalientes: Iniciativa con carácter de decreto de la nueva “Ley de protección y fomento apícola del estado de Aguascalientes”. Diputado Cuauhtemoc Escobedo Tejada (2022)

2. Marcelino, J., Braese, C., Christmon, K., Evans, J. D., Gilligan, T., Giray, T., Nearman, A., Niño, E. L., Rose, R., Sheppard, W. S., vanEngelsdorp, D., Ellis, James, D.: The Movement of Western Honey Bees (Apis mellifera L.) Among U.S. States and Territories: History, Benefits, Risks, and Mitigation Strategies. Frontiers in Ecology and Evolution, vol. 10 (2022). DOI: 10.3389/fevo.2022.850600.
3. H. Congreso del Estado de Guanajuato: Desarrollo apícola para el estado de Guanajuato. LXIV Legislatura Publicada: P.O. Num. 235, Segunda Parte (2019)
4. Regulation (EC) no 1107/2009 of the European Parliament and of the Council of 21 October 2009 Concerning the Placing of Plant Protection Products on The Market and Repealing Council Directives 79/117/EEC and 91/414/EEC. Oficial Journal of the European Union, pp. 309/1–309/50 (2009)
5. Ullah, A., Shahzad, M. F., Iqbal, J., Baloch, M. S.: Nutritional Effects of Supplementary Diets on Brood Development, Biological Activities and Honey production of Apis mellifera L. Saudi Journal of Biological Sciences, vol. 28, no. 12, pp. 6861–6868 (2021). DOI: 10.1016/ j.sjbs.2021.07.067.
6. Machado-De-Melo, A. A., Almeida-Muradian, L. B., Teresa-Sancho, M., Pascual-Maté, A.: Composition and Properties of Apis Mellifera Honey: A Review. Journal of Apicultural Research, vol. 57, no. 1, pp. 5–37 (2017). DOI: 10.1080/00218839.2017.1338444.
7. Hagler, J. R., Mueller, S., Teuber, L. R., Machtley, S. A., Van-Deynze, A.: Foraging Range of Honey Bees, Apis mellifera, in Alfalfa Seed Production Fields. Journal of Insect Science, vol. 11, no. 1 (2011). DOI: 10.1673/031.011.14401.
8. Soares, S., Grazina, L., Mafra, I., Costa, J., Pinto, M. A., Duc, H. P., Oliveira, M. B., Amaral, J. S.: Novel Diagnostic Tools for Asian (Apis cerana) and European (Apis mellifera) Honey Authentication. Food Research International, vol. 105, pp. 686–693 (2018). DOI: 10.1016/ j.foodres.2017.11.081.
9. Almeida-Muradian, L. B., Barth, O. M., Dietemann, V., Eyer, M., Freitas, A., Martel, A. C., Marcazzan, G. L., Marchese, C. M., Mucignat-Caretta, C., Pascual-Maté, A., Reybroeck, W., Sancho, M. T., Gasparotto-Sattler, J. A.: Standard Methods for Apis Mellifera Honey research. Journal of Apicultural Research, vol. 59, no. 3, pp. 1–62 (2020). DOI: 10.1080/ 00218839.2020.1738135.
10. Smart, M. D., Otto, C. R., Carlson, B. L., Roth, C. L.: The Influence of Spatiotemporally Decoupled Land Use on Honey Bee Colony Health and Pollination Service Delivery. Environmental Research Letters, vol. 13, no. 8 (2018). DOI: 10.1088/1748- 9326/aad4eb.
11. Garratt, M. P., Coston, D. J., Truslove, C. L., Lappage, M. G., Polce, C., Dean, R., Biesmeijer, J. C., Potts, S. G.: The Identity of Crop Pollinators Helps Target Conservation for Improved Ecosystem Services. Biological Conservation, vol. 169, pp. 128–135 (2014). DOI: 10.1016/j.biocon.2013.11.001.
12. Russo, L.: Positive and Negative Impacts of Non-Native Bee Species Around the World. Insects, vol. 7, no. 4 (2016). DOI: 10.3390/insects7040069.
13. Food and Agriculture Organization of the United Nations: TECA - Technologies and Practices for Small Agricultural Producers. https://www.fao.org/teca/es/technologies/8663
14. Traynor, K. S., Rennich, K., Forsgren, E., Rose, R., Pettis, J., Kunkel, G., Madella, S., Evans, J., Lopez, D., vanEngelsdrop, D.: Multiyear Survey Targeting Disease Incidence in US Honey Bees. Apidologie, Springer Verlag, vol. 47, no. 3, pp.325–347 (2016). DOI: 10.1007/s13592-016-0431-0.
15. VanEngelsdorp, D., Traynor, K. S., Andree, M., Lichtenberg, E. M., Chen, Y., Saegerman, C., Cox-Foster, D. L.: Colony Collapse Disorder (CCD) and Bee Age Impact Honey Bee Pathophysiology. PLoS ONE, vol. 12, no. 7 (2017). DOI: 10.1371/journal.pone.0179535.
16. Traynor, K., Mondet, F., Miranda, J., Techer, M., Kowallik, V., Oddie, M., Chantawannakul, P., McAfee, A.: Varroa Destructor: A Complex Parasite, Crippling Honeybees Worldwide. Preprints (2020). DOI: 10.20944/preprints202002.0374.v1.

17. Higes, M., Martín-Hernández, R., Hernández-Rodríguez, C. S., González-Cabrera, J.: Assessing the Resistance to Acaricides in Varroa Destructor from Several Spanish Locations. Parasitology Research, vol. 119, no. 11, pp. 3595–3601 (2020). DOI: 10.1007/s00436-020-06879-x.
18. Schäfer, M. O.: Varroosis of Honey Bees (infestation of honey bees with Varroa spp.): Chapter 3.2.7. Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 2021: OIE Terrestrial Manual 2021, OIE - Office International des Epizooties (2021)
19. Martelli, A.: An Application of Heuristic Search Methods to Edge and Contour Detection. Communications of the ACM, vol. 19, no. 2, pp. 73–83 (1976). DOI: 10.1145/359997.360004.
20. Lee, K., Steinhauer, N., Travis, D. A., Meixner, M. D., Deen, J., vanEngelsdorp, D.: Honey bee surveillance: A Tool for Understanding and Improving Honey Bee Health. Current Opinion in Insect Science, vol. 10, pp. 37–44 (2015). DOI: 10.1016/j.cois.2015.04.009.
21. Hendrikx, P., Chauzat, M. P., Debin, M., Neuman, P., Fries, I., Ritter, W., Brown, M., Mutinelli, F., Le-Conte, Y., Gregorc, A.: Bee Mortality and Bee Surveillance in Europe. SCIENTIFIC REPORT submitted to EFSA, vol. 6, no. 9 (2009). DOI: 10.2903/sp.efsa.2009.EN-27.
22. Babic, Z., Pilipovic, R., Risojevic, V., Mirjanic, G.: Pollen Bearing Honey Bee Detection in Hive Entrance Video Recorded by Remote Embedded System for Pollination Monitoring. In: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 51–57 (2016). DOI: 10.5194/isprsannals-III-7-51-2016.
23. Tashakkori, R., Hernandez, N. P., Ghadiri, A., Ratzloff, A. P., Crawford, M. B.: A Honeybee Hive Monitoring System: From Surveillance Cameras to Raspberry Pis. SoutheastCon 2017, pp. 1–7 (2017). DOI: 10.1109/SECON.2017.7925367.
24. Phillips, B. W., Gardiner, M. M.: Use of Video Surveillance to Measure the Influences of Habitat Management and Landscape Composition on Pollinator Visitation and Pollen Deposition in Pumpkin (Cucurbita pepo) agroecosystems. PeerJ, vol. 3, pp. e1342 (2015). DOI: 10.7717/peerj.1342.
25. Tannenbaum, A., Van-Steen, M.: Distributed systems: Principles and paradigms. Prentice Hall (2007)
26. Nehmer, J., Haban, D., Mattern, F., Wybranietz, D., Rombach, H. D.: Key Concepts of the INCAS Multi Computer Project. IEEE Transactions on Software Engineering, vol. SE-13, no. 8, pp. 913–923 (1987). DOI: 10.1109/TSE.1987.233510.
27. Velarde-Martinez, A.: Implement of a high-performance Computing System For Parallel Processing of Scientific Applications and the Teaching of Multicore and Parallel Programming. In: International Conference on Innovation, Documentation and Education, pp. 203–213 (2018). DOI: 10.4995/INN2018.2018.8908.
28. Secretaría de Agricultura y Desarrollo Rural: fortalecen méxico y belice acciones de cooperación en el sector agroalimentario. Agricultura https://www.gob.mx/agricultura/aguascalientes. (2017)
29. Liu, Z., Wang, H., Zhou, T., Shen, Z., Kang, B., Shelhamer, E., Darrell, T.: Exploring Simple and Transferable Recognition-aware Image Processing. IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 45, no. 3, pp. 3032–3046 (2022). DOI: 10.1109/TPAMI.2022.3183243.
30. Yang, Z., Li, Y., Yang, J., Luo, J.: Action Recognition with Spatio–temporal Visual Attention on Skeleton Image Sequences. IEEE Transactions on Circuits and Systems for Video Technology, vol. 29, no. 8, pp. 2405–2415 (2019). DOI: 10.1109/TCSVT.2018.2864148.
31. Haralick, R. M.: Glossary and Index to Remotely Sensed Image Pattern Recognition Concepts. Pattern Recognition, vol. 5, no. 4, pp. 391–403 (1973). DOI: 10.1016/0031-3203(73)90029-0.