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Overview of Intelligent Bee Hive Research: Analysis from Multi-dimensional Perspectives

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Abstract: *Bees have ecological, economic, scientific, edible, medical, cultural, and tourism values. Beekeeping is the most important link in all industry chains, not just for producing honey. The beehive is one of the most important equipment in beekeeping work, so how to improve the intelligence level of the beehive in the new era has always been a research hotspot in the field of scientific research. Although there have been some technological research on smart beehives or review papers related to smart beehives, these are not comprehensive enough for interdisciplinary readers. This overview paper analyzes the research on bees and beehives from different perspectives, especially beneficial for newcomers in this field.*

Keywords: *Bee; Intelligent Hive; Research Institutions; Beekeeping*

1. Introduction

China's bee industry occupies an important position globally, with bee colony numbers and bee product exports consistently ranking first worldwide. In China, apiculture falls under the primary industry and is classified as a specialized economic animal breeding within the livestock industry [1]. Beekeeping has a significant positive impact on farmers' economic income. In fact, the work of beekeeping and producing honey is globally significant and receives attention [2-5]. Although the bee industry accounts for a small proportion of agriculture, it is an indispensable and crucial component in modern agriculture and the construction of ecological civilization. As we all know, bees can not only produce honey but also pollinate fruit trees [6]. In addition, scientists have developed a new method of autonomous navigation by studying the behavioral characteristics of bees [7]. The bee industry, which requires small investment, yields quick returns, and offers high profits, stands as one of the distinctive industries in agriculture and animal husbandry, playing a significant role in rural revitalization, especially in Guizhou Province where the terrain is predominantly mountainous and hilly. Figure 1 shows the bees and bee hives.

Figure 1: Bees and bee hive.

However, China is not yet a strong country in beekeeping, and the overall efficiency is not high. There is a significant gap between China and other countries in terms of per capita beekeeping. In foreign

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countries, each person typically keeps hundreds or even two to three thousand colonies, while in China, couples generally keep 120 to 150 colonies, indicating a lower level of large-scale and intensive beekeeping. Furthermore, due to the hard work and unstable income of beekeepers, young people are reluctant to engage in this profession, leading to a severe aging problem. Consequently, the number of beekeepers will gradually decrease in the future, especially, elderly beekeepers are gradually withdrawing from the scene.

The traditional beekeeping model heavily relies on manual experience and periodic opening of beehives for inspection, presenting numerous inherent shortcomings. Firstly, manual inspection is time-inefficient and has limited coverage, making it difficult to achieve round-the-clock continuous monitoring of the micro-environment of beehives and the state of bee colonies. It fails to capture timely key state changes such as abnormal temperature and humidity, pest and disease breeding, wasp invasion, and colony division. Secondly, frequent opening of beehives for inspection can easily cause stress and disturbance to the bee colonies, disrupting their normal breeding and honey-collecting rhythms, and affecting colony health and honey production capacity. Thirdly, the traditional breeding model incurs high labor costs and low management efficiency, making it difficult to adapt to the development needs of large-scale and intensive beekeeping industries. Furthermore, the aging problem of beekeeping labor further restricts the quality improvement and upgrading of the traditional beekeeping industry.

To address the issues described above, in the era of informatization and artificial intelligence, how to intelligently breed bees has become the focal point of the smart agriculture era. Many research institutes and enterprises at home and abroad have conducted research on smart beehives [8], but there is still no comprehensive review paper, especially for beginners in this research field. In order to enable university teachers and students to conduct interdisciplinary research and reduce the time required for collecting basic knowledge related to bees, we have conducted a review of this article, including domestic and foreign bee research institutions, universities with undergraduate majors, intelligent bee hive functional requirements, public datasets, and well-known bee hive products.

2. Institutions Offering Undergraduate Majors or Professional Research on Honeybees

In China, the majority of beekeeping work is done by low-educated farmers rather than research institutes. This is determined by certain historical reasons and conditions. The main reasons are as follows.

(1) There is no mandatory educational threshold in the industry, and experience is far more important than textbook knowledge. Beekeeping does not require a mandatory diploma and does not rely on academic exams for employment. Disease prevention, bee separation, overwintering, determining flowering period, responding to bee theft, and controlling the strength of bee colonies all rely on years of practical exploration.

(2) Natural adaptation for rural left behind population, urban high educated population unwilling to endure hardship. Professional beekeeping is extremely difficult: migrant beekeepers live in metal sheds and tents all year round, exposed to wind and sun, bitten by mosquitoes and insects, and have no fixed abode. They stay at home for less than one month a year; Wilderness loneliness, fluctuating sleep patterns with the flowering period, and also bearing the risks of bee colony diseases, natural disasters leading to reduced yields, and honey price fluctuations.

(3) Low starting capital threshold, suitable for farmers' limited savings. The starting cost for retail investors is very low: a few boxes of bees can cost a few thousand yuan to open, without the need for factories or large farmland; Wasps can be released on idle slopes, in front and behind houses, and in the mountains and forests in mountainous areas, without occupying good farmland and with zero rent on the land. Highly educated entrepreneurs often pursue scale and brand processing, starting from tens of thousands or even hundreds of thousands, with higher risks; Ordinary farmers have less trial and error pressure in small-scale investment, making it suitable for small-scale livelihoods.

(4) Differences in employment substitution options: Low educated farmers have fewer options to choose from. Middle aged farmers with low education have limited opportunities to earn stable income: traditional farming methods have low profits, limited working age, and physical labor becomes increasingly difficult as they age; Beekeeping belongs to light physical special breeding, and the daily management intensity of bees is not high. At the age of fifty or sixty, if their health is still good, they can do it for a long time. Many assistance policies specifically promote beekeeping to low-income farmers, left behind elderly, and weak labor groups. The highly educated population has a wide range of career choices: education, enterprise, technology, civil service, and service industries are extremely diverse, and

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there is no need to root in agriculture and animal husbandry.

From a professional perspective, beekeeping intersects multiple fields such as entomology, genetic breeding, plant protection, animal husbandry, and smart farming, requiring a systematic and complete theoretical system to support scientific research and development. In addition, universities and research institutes have experimental sites, testing instruments, germplasm banks, project funding, and academic collaboration networks, which can ensure the long-term and large-scale breeding experiments. Therefore, we have compiled a list of renowned domestic and international institutions for apiculture personnel training and bee research, to offer reference information for individuals intending to pursue further academic study.

Table 1 shows famous research institutions and universities related to bees both domestically and internationally, with official websites attached. In fact, there are more research institutions or universities conducting bee research work that should not be ignored. In China, only two universities, Fujian Agriculture and Forestry University and Yunnan Agricultural University, offer undergraduate majors in Apiculture.

Table 1: Famous research institutions and universities related to bees.

Institutions	Research or Education category	Websites of Official Institutions
Carl Hayden Bee Research Center: Tucson, AZ, Agricultural Research Service (ARS) , USA	Reducing Colony Loss in a Changing Climate by Improving Nutrition, Overwinter Survival, and Queen Health; The Honey Bee Microbiome: Social and Reproductive Functions in Health and Disease	https://www.ars.usda.gov/pacific-west-area/tucson-az/carl-hayden-bee-research-center
Harry H. Laidlaw Jr. Honey Bee Research Facility, USA	Bee Research and Education	https://beebiology.ucdavis.edu/
Bee Lab, University of Minnesota, USA	Undergraduate Professional Education, Master's and Doctoral Student Training	https://beelab.umn.edu/
Honeybee Research Center, INSTITUT FÜR BIENENKUNDE, Germany	Bee colony vitality study (EU)	https://institut-fuer-bienenkunde.de/home
Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, China	Research institutions of Master's and Doctoral Student Training	https://iar.caas.cn/
Honeybee Research Institute, Jiangxi Agricultural University, China	Research institutions of Master's and Doctoral Student Training	https://bee.jxau.edu.cn/
Fujian Agriculture and Forestry University, China	Undergraduate Professional Education	https://fxxy.fafu.edu.cn/
Yunnan Agricultural University, China	Undergraduate Professional Education	https://dky.ynau.edu.cn/

In fact, most countries around the world have institutions and universities dedicated to bee related research [9-11], and this paper cannot list them all. As it should be, academic exchanges and technical discussions among personnel from different research institutions are very important.

3. Intelligent Requirements for Bee Hives

In the era of intelligence, many interdisciplinary emerging technologies are used in the agricultural field, such as big data technology, sensor technology, computer vision technology, Internet of Things technology, artificial intelligence technology, etc. However, not all the latest technologies need to be incorporated into the beehive, it depends on the actual needs of beekeeping work. We have collected a lot of literature and information on beekeeping work, summarized the main intelligent requirements, and listed them in Table 2.

Table 2: Intelligent requirements for bee hives.

Intelligent Requirements	Functional purpose	Associated Sensors or Devices
Temperature and humidity data [12]	Monitoring the living environment of bee colonies, predicting the risk of bee infestation, diseases, and overwintering, and assisting in scientific beekeeping.	DHT11 / DHT22, SHT30 / SHT31 / SHT35 [13]
Beehive weight data [14]	Estimating honey production by subtracting the weight of the beehive from its initial state weight.	Thin half bridge weighing sensor or capacitive weighing sensor
Main control module	Processing and analysis of environmental data at the beehive end.	Arduino board, Raspberry Pi [15]
Bees entering and exiting the	Estimating the attendance and activity of bee	Dual infrared reflector tube,

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beehive	colonies.	Camera visual inspection [16]
Carbon dioxide concentration [17]	When the bee colony is restless, the concentration of carbon dioxide inside the box increases	SenseAir S12 / Sunrise, SCD30, SCD41 [18]
Detection of diseases such as bee mites [19]	Real time monitoring of the severity of bee colony diseases, timely prevention and control, to avoid bee colony decline, yield reduction, or even complete annihilation.	Camera and supporting deep learning model processing module, NVIDIA GPU
Acoustic data	Determine the presence of queen bees, identify restless bee colonies, and issue warnings for bee separation and mite diseases; Distinguish between normal buzzing and abnormal sounds, evaluate the health status of the bee colony	WT2003, SD card recording module、SPH0641, INMP441 [20]

In addition to the functional requirements and associated solutions described in Table 2, there are other features and applications worth exploring. Henry J. Svec et al. used cameras and YOLOv11 deep learning models to detect whether bees at the entrance of beehives were carrying pollen [21]. Through camera sensors and computer vision technology, more useful image-based information can be obtained. From practical applications, it can be found that the layout of cameras inside the beehive, on the display of the box, or in other external locations all have their specific needs and purposes.

4. Public Datasets Related to Bees

Data is the foundation for artificial intelligence systems to learn and train, serving as the core fuel and knowledge carrier, determining the intelligence limit, generalization ability, and practical value of the model. The data of bees themselves and various environmental parameters inside the beehive are very valuable. Table 3 lists well-known public datasets found through online resource searches, including bee images, sound data inside beehives, etc. In addition, the official website address and basic description of the publicly available dataset are provided. Relatively speaking, the most common type of data is images, because images are intuitive enough to reflect a lot of information. For some special research topics, data needs to be collected and processed by researchers themselves.

Table 3: Public datasets related to bees.

Datasets	Dataset URL Link	Description of These Datasets
Honey Bee Subspecies Classification	https://www.kaggle.com/code/gpreda/honey-bee-subspecies-classification	A dataset with adnotated images of bees from various locations of US, captured over several months during 2018, at different hours, from various bees subspecies, and with different health problems.
Bee or wasp	https://www.kaggle.com/datasets/jerzydziewierz/bee-vs-wasp	Hand-curated, close-up photos of bees, wasps, and other insects. The challenge is primarily to distinguish bees from wasps.
Asian Hornets, European Hornets and Wasps	https://www.kaggle.com/datasets/kawaiibaaaka/asian-hornets-european-hornets-and-wasps	The images have a high resolution of 3496×2356, with targets generally being very small. They are labeled in YOLO format using Label Studio. 14 Asian Hornets, 51 European Hornets, 103 Wasps.
Bee Dataset BUT-HS2	https://www.kaggle.com/datasets/masuel/bee-hyperspectral-dataset	The dataset consists of 647 photos and is divided into 2 main parts: Photos of dead bees and dead mites before treatment and after treatment with fumigation. Both parts have 3 categories: Bees, mites and bees with mites. Bee and mite samples were collected in November and during the dataset capture, they were approximately 2-3 weeks old.
Smart Bee Colony Monitor: Clips of Beehive Sounds	https://www.kaggle.com/datasets/annajyang/beehive-sounds	BeeAudio Dataset is an initiative to encourage computational means of addressing bee population decline, such as through creating machine learning algorithms to remotely and instantly detect the health status of the hive via sound data. This is the largest single dataset of bee audio, alongside multi-dimensional data, and it was all collected with a custom IoT device combining an ESP32 Wi-Fi module, INMP441 microphone module, and a BME280 temperature/humidity sensor.
Honeybee Segmentation and Tracking Datasets	https://www.oist.jp/research/research-units/bptu/honeybee_tracking_datasets	This dataset was created as a part of the study Towards dense object tracking in a 2D honeybee hive. It comprises frames and annotations of 2 video recordings of an observation bee hive. The recordings were done at 30 fps and 70 fps, in each of them 360 frames were annotated in a consecutive sequence at 2 fps.

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5. Academic Research Journals Related to Bees

Bees researchers in universities or research institutes usually need to publish and share their research results, and academic journals are one of the most influential channels. Table 4 lists well-known academic journals related to bee research, and there are also many journals that are not directly related to bees, but have published papers on bee research.

Table 4: Academic journals related to bees.

Journal Name	Organizer	Aims and scope
Apidologie	French National Institute for Agriculture, Food and Environment (INRAE) and Deutscher Imkerbund E.V. (D.I.B.)	The main topics include: behavior, ecology, pollination, genetics, physiology, toxicology and pathology. Systematic research concerning the Anthophila clade, as well as studies on the rearing, exploitation and practical use of bees and their products
Journal of Apicultural Science	Research Institute of Pomology and Floriculture	The main subject areas include bee biology, bee genetics, bee breeding, pathology and toxicology, pollination and bee botany, bee products, management, technologies, and economy, solitary bees and bumblebees
Frontiers in Bee Science	Frontiers Media S.A.	Topics are bee protection & health, including pathogens, parasites, poisons, and aspects of breeding & selection of managed and wild bees; bee physiology, including thermoregulation, neurobiology, behavior, cognition & biochemistry; bees in pollination, including pollination in ecosystems from wilderness to highly managed agricultural & urban settings; bee genetics, including research with a genetic foundation concerning all global bee species.
Bee World	The International Bee Research Association	All aspects of beekeeping and all species of bees worldwide
Smart Agriculture	Institute of Agricultural Information, Chinese Academy of Agricultural Sciences	Mainly publishing important theoretical innovations and method application results in the fields of agricultural sensors, agricultural information management systems, intelligent agricultural machinery and equipment, agricultural Internet of Things, agricultural cloud computing, agricultural block-chain, agricultural spatial information technology, agricultural data intelligent analysis and mining, agricultural artificial intelligence, and animal and plant phenomics.
Chinese Journal of Applied Entomology	Institute of Zoology, Chinese Academy of Sciences; Chinese Entomological Society	The main content includes review and progress, research papers, research briefs, technology and methods, application foundations, etc. Some of the content involves research related to bees and beehives.
Apiculture of China	Institute of Bees, Chinese Academy of Agricultural Sciences; Chinese Beekeeping Society	Including bee industry research, bee industry technology, bee industry economy, products and health, etc.
Journal of Bee	Yunnan Academy of Agricultural Sciences	The main contents include experimental research reports, bee feeding and management, disease and pest control, Chinese honey bees, honey sources and pollination, bee product development, bee machinery, bee culture, etc.

Another form of public disclosure for research results is patent application, which has legal protection benefits [22-24].

6. Famous Smart Beehive Products

Table 5 lists some of the world's well-known smart beehive companies.

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Table 5: Famous Smart Beehive Products.

Well-known Company	Main Business	Websites of Official Institutions
Beewise, Israel	Getting healthy hives and superior pollination with AI + Robotics.	https://beewise.ag/home
Beehero, USA/Israel	With BeeHero's data-driven, managed pollination solutions for commercial crop growers. Helping beekeepers build, maintain and deploy the strongest, healthiest hives.	https://www.beehero.io/
ToBe, Israel	Precision beekeeping platform.	https://tobe.green/
Arnia Perfetta, UK	Monitoring system and anti-theft system for beekeeping.	https://www.arniaperfetta.it/en/
BroodMinder, USA	Fostering bee survival by nurturing the worldwide community of beekeepers and scientists with essential bee health information captured through remote hive monitoring	https://broodminder.com/
Intelligent Hives, Poland	Predictive beekeeping with AI and IoT. Monitor, analyze and act across unlimited apiaries.	https://intelligenthives.eu/
Huiyangfeng, China	Construction of smart bee farms, research and development of smart beehives, big data in the bee industry, and knowledge services.	https://www.caasbee.com/
Jiangxi Fengfujia Technology Co., Ltd., China	Products such as honey, bee tools, and smart beehives	https://www.zgffjkj.com/

7. Conclusion and Futrre Work

This article provides a brief but comprehensive overview of research related to intelligent beehives, aiming to provide an introductory understanding for non biological students or researchers. Although not comprehensive enough, the listed content is representative.

In recent years, some technology institutions and enterprises have launched some intelligent beehives, but due to their high prices, they are difficult to be accepted by beekeepers. One solution that comes to mind easily is to reduce the cost of intelligent software and hardware for beehives. Another way to reduce the cost of smart beehives is to place only one smart beehive in a certain local area, while continuing to use ordinary beehives for the rest. The data collected by one smart beehive can be representative of the local area. For some traditional beehives, it is not feasible to directly replace them with smart beehives. Therefore, researchers can consider developing a detachable intelligent model that can be easily placed into traditional beehives for use. This would be a promising direction for development.

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