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Bees in Space: ULmonitor, the beehive remote control tool for the Mars colonies, tested within Noah's Ark project in analog space base Lunares in Pila, Poland

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Abstract

The bees are one of the most intensively studied insect species in the history of humankind. Bringing the bees to the future extraterrestrial colonies could be beneficial in many ways, ranging from plant pollination through the production of the substances for food and medical purposes, to the psychological aspects of the astronaut-animal interactions. Considering the limitations of the future Mars colonies' artificial environment, especially in terms of the small area and the intensity of human labor, the whole process of beekeeping should be as little effort consuming and autonomous as possible. Every opening of the beehive for a simple check-up disturbs the delicate microclimate of the hive, excites the swarm, and may cause irreversible damage to the weakened families. Therefore, we decided to include the ULmonitor, the automatic check-up system invented for beekeepers, to the analog mission program carried out in the LUNARES Research Station, within the Noah's Ark project , dedicated to study and develop the self-sustainable micro-ecosystems for food and medicine production on board. This study focuses on the influence of Apis mellifera family isolation in artificial environment on the hive and swarm parameters, and the integration of the ULmonitor and HabOs systems for enabling the analog astronauts to control the hive remotely. The data on the swarm activity and behavior gathered with ULmonitor could have vast applications in the development of AI systems and the direct terrestrial, agricultural output.

Keywords: bees, Mars, Lunares, analogs, space agriculture

Acronyms/Abbreviations

RF - radio frequency

NFC - near-field communication

GSM - global system for mobile communications

1. Introduction

The honey bees (*Apis mellifera*) are eusocial flying insects, living in colonies, and known for their production and storage of honey. Because of their produce, they were one of the first animals to be domesticated by humans – the efforts to domesticate the bees are shown in Egyptian art around 4,500 years ago [1; 2], and the depictions of humans collecting honey from wild bees date to 15,000 years ago [2]. In nature, the bees build nests from the wax; domesticated bees are kept in man-made hives.

In addition to honey, the bees produce beeswax, bee bread, bee brood, propolis and royal jelly (which are used for food production, medicines/supplements, cosmetics, candles, etc). *Apis mellifera* is also used as a model in biology [3] and since it forms colonies, it can be also used for studying social behaviors.

Bee lifecycle. The life cycle of a bee, starts with laying of an egg by a queen (the only fertile female in the colony), the development through several moults of a legless larva, a pupation stage during which the insect undergoes complete metamorphosis, followed by the emergence of a winged adult [2]. The sex of a bee is determined by whether or not the egg is fertilised; after mating, a female stores the sperm, and determines which sex is required at the time each individual egg is laid, fertilised eggs producing female offspring and unfertilised eggs, males. The whole cycle l- from an egg to imago - lasts ca 24 days.

Navigation, communication and finding food. Honey bees can recognize a desired compass direction in three different ways: by the sun, by the polarization pattern of the blue sky, and by the earth's magnetic field. The sun is the preferred or main compass; the other mechanisms are used under cloudy skies or inside a dark beehive [4, 5]. Bees navigate using spatial memory with a "rich, map-like organization" [6].

Temperatures and their regulation in the beehive

In cold climates, honey bees stop flying when the temperature drops below about 10°C (50 F) and crowd into the central area of the hive to form a "winter cluster". The worker bees huddle around the queen bee at the center of the cluster, shivering to keep the center between 27 C (81 F) at the start of winter (during the broodless period) and 34°C (93 F) once the queen resumes laying (the temperature in the beehive allowing for laying eggs and hatching process circulates around 34.5-35°C and once kept, assures the right generations replacement). The worker bees rotate through the cluster from the outside to the inside so that no bee gets too cold. The outside edges of the cluster stay at about 8–9 C (46–48°F). The colder the weather is outside, the more compact the cluster becomes. During winter, they consume their stored honey to produce body heat. The amount of honey consumed during the winter is a function of winter length and severity, but ranges in temperate climates from 15 to 50 kilograms (33 to 110 lb) [2, 7]

ULmonitor is an "apiary on the screen", allowing the use of digital solutions to effectively manage an apiary, observe the bee colonies, supervise the situation in the beehive, as well as to conduct scientific panel research [8]. Using a chip placed in a beehive, it collects the measurements of temperature, air humidity and beehive's mass, , and transfers this data to a PC or computer using a wireless network(RF, NFC or GSM). The system can be controlled with a smartphone or a PC.

The readings of temperature, humidity and weight of the hive allow for the general analysis of the condition of the bee colony inside the hive without unnecessary interference. This is particularly important in winter, in unfavorable weather conditions, and also in the isolation conditions. It also allows to observe if the wintering passes without problems, identify the moment when the queen bee starts and finishes to lay eggs, and if there is sufficient ventilation in the hive.

Bee as a candidate for space travel

The history of bee research in the context of space flights dates back to NASA projects from 1982, when during the STS-3 mission a specially designed small container with various insects and their developmental forms (including 14 adult bees, 12 pupae flies, and 24 adult moths and 24 moth pupae) was taken on board. The project was partly implemented as part of the Student Shuttle Involvement Program (SSIP). As a result of the study, it was shown that the insects that hatched on board of the ferry were able to fly in microgravity without hitting obstacles or damaging their wings, in contrast to the ones that were taken onboard as adults, which showed significant impairment of flight and spatial orientation.

Once again, bees were put in space in 1984, during the Challenger space shuttle mission, where during the weekly mission STS-41C 3400 bees managed to build a classic honeycomb, and the queen laid 35 eggs, which, however, did not hatch. The bees were in a small hive adapted for flight - the Bee Enclosure Module.

Another experiment with (carpenter) bees in space was to be carried out during the STS-107 mission on the Columbia Space Shuttle in 2003, but it was not implemented due to the crash of the ferry.

Recently, a group of students has sent ISS on board as part of the "Go for Launch" project! Which was by far the only bee experiment on board the ISS and one of the longest bee experiments to date [9].

Lunares habitat in Pila, Poland

The habitat (Fig. 1) is a simulated space base and research laboratory, which consists of a living / working space connected to a 250 square meters hangar, which simulates the surface of the Moon or Mars [10].

Figure 1. Lunares Research Station in Pila, Poland.

One of the main scientific programs of the LUNARES Research Station is Noah's Ark, which focuses on organisms that could survive the harsh Lunar and Martian environments and provide substances useful for humans - like natural antibiotics, anti-clotting agents, food or sedatives. Currently, the main experiments within Noah's Ark include fly larval development in simulated micrograwity, the leeches' cocoons' development in simulated microgravity, the earthworms' survival in the meteorite soil and the beekeeping project. [11]

In research described here, we combined the advantages of the remote control of the apiary with the isolation studies conducted in the LUNARES Research Station in Pila, Poland, to investigate the influence of the isolation on the bees. The beehive was observed by a group of analog astronauts who simulated living in an extraterrestrial colony during the Endymion analog mission in LUNARES. Our observations may contribute to better understanding of the minimal conditions necessary for the bees survival in extraterrestrial locations, and provide further insight into the bees societal strategies of survival in isolation.

2. Material and methods

In each study, the honeybee family of approximately 45000 individuals was isolated in an artificially-lit, air-conditioned tent of ca 50 square meters (Figure 2). The tent was equipped in a source of water, a selection of the flowering plants, and a camera to observe the feeding, drinking and movement of the swarm. The lighting was set to 12h light /12 h dark cycle. The temperature in the tent was oscillating around 32C. The humidity in the tent was around 74-78%. .
The temperature, humidity and hive mass were recorded continuously and transferred to an online console using ULmonitor chip and application and the RF connection (Fig. 3, 4, 5). The sensors were placed in the nest, under the hive's internal roof and in the hive's bottom, and also in the water drinker holder to measure the outer temperature.

Figure 2. The beehive placed inside of the tent in the course of the Habeetat study.

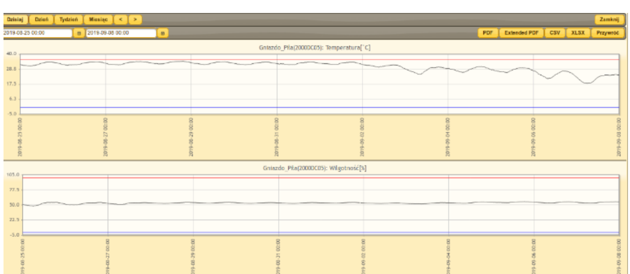

Figure 3. The view of the Ulmonitor console.

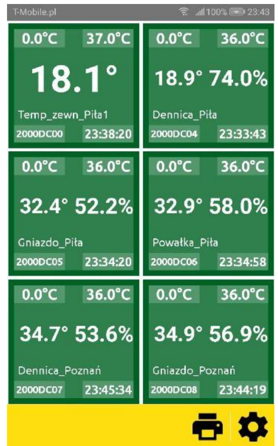

Figure 4. The phone application for monitoring temperature and humidity of the beehive.

Figure 5. The UlMonitor chip.

The data from the sensors was sent wirelessly to the concentrator, and then via the Internet to the user's console, and they were archived on the console server. The parameters collected from the hives were available online after logging in to the ULmonitor console and were observed in real time on charts or downloaded in pdf or csv files. The data was accessible both from the PC (Fig. 3) and the telephone (Fig. 4).
We conducted two 2-weeks observations of 2 bee families in isolation. As a control, we used a corresponding, not isolated bee family, placed in a 120 km away Poznan apiary.

3. Results and discussion

ULmonitor delivered multiple data on overall condition of the isolated hive. The nest became cooler, with the drop in the bees' reproduction process, resulting in further cooling of the nest center. The average temperatures of the inner swarm were around 34.5 deg. Celsius at the beginning to the 18-20 deg. Celsius at the end of the research. Outer temperatures in the isolation tent did not vary much due to the active air-conditioning.

During the isolation we observed 2 kg weight loss in the mass of the hive (about 160g per day), while the control hive in the non-isolated apiary gained 4 kg in the same time span. The decrease in the hive mass reflected both a decreased number of the bees and the use of stored food. However, the average mortality rate was similar to the one observed for the non-isolated apiary: around 1000-1200 bees every 4 days. Yet, we did not observe any freshly laid eggs.

According to the diurnal hive weight changes, only small number of bees had been leaving the hive every day.

Behavior observation

The numbers of bees leaving the hive decreased with time of the experiment both in Habeetat-1 and Habeetat-2 study. In addition, during the second mission, held later in August and September, the bees were visible less active, which we attribute to their chronobiological setup together with lowered external temperatures, both connected to the upcoming autumn.

The photo trap pictures showed that the bees were not collecting spirulina powder provided as an equivalent of the pollen. The bees were moving towards the light sources and gathering around them, not showing typical flying patterns. During the two week isolation we observed that the bees rarely landed on the blooming plants prepared for them, but landed quite often on the watering pads to collect water (Fig.6)

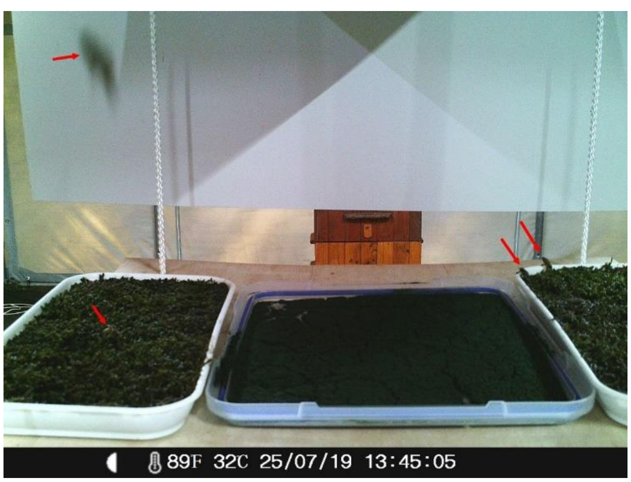

Figure 6. The watering and spirulina pads. The red arrows point at the bees.

At the time of isolation, the bees kept the brood, while the eggs and larvae were probably eaten. After the isolation ended, we found that there were nearly none sealed brood (Fig. 7). Normally, the bees seal the larvae after about 9 days. Since there was no brood after 14 days, we suppose that the brood was eaten by the workers, as the new larvae and eggs were absent. We interpret this behavior as a sign of stress and protection against diseases such as rot. The bees, having no access to the protein from the outside and being under stress, did not raise a new generation. If (in the egg-laying season) such a situation would last longer than two weeks, the family would die of hunger, cold and lack of proper care after two months, due to the absence of newly born bees.

Figure 7. The empty wells in the comb after 2 weeks of bees isolation.

The development of an effective method of breeding bees in isolation on relatively small areas with no access to daylight is a challenge in the context of the future colonization of other planets but also on Earth, given the increasing climate changes, economic challenges and the ongoing decrease in the number of bees.

In gardening applications in greenhouse plantations, the insect-pollinated plants are currently pollinated by the bumblebees, a species showing high pollination efficiency and resistance to isolation conditions. A disadvantage of the bumblebee as a species that could be taken on a space mission is its relatively unilateral specialization, which means that its inclusion in the biological cycles of the habitat would not be a cornerstone for other cycles. The multitasking of bees - pollination, production of honey, freckles, pollen, propolis and a wide range of self-regulation of hive well-being predispose this species to be a pollinator of choice on board of the future space stations. However, taking into account that in case of the weakening or death of the bee colony we would risk a simultaneous interruption of many processes and cycles of which the bees would be a part, a multispecies approach seems safer. Therefore, for the future interplanetary missions applications, the continuation of bee isolation research should be complemented with other pollinator and social insect species research.

During our study, we received similar results on the bees reproduction to the previous tests conducted during NASA missions in weightlessness: the queen stopped laying eggs, the balance of insects hatched against dying was negative [STS- 41C mission]. Therefore, is seems possible that isolation in a small area and limited access to daylight are sufficient stressors for a bee family to cause its dysfunction, and the lack of gravity or microgravity can be an additional factor.

We observed a decrease in reproductive capacity of the swarm studied in the Habeetat-2 mission. Many species show similar phenomenon in the harsh environmental conditions, as a result of stress, or to save energy reserves. Some comparisons can be drawn even between the bees' and human behaviors in isolation, for example, limitation of leaving the hive (analogy to the problem of EVA or cocooning relations), using stocks with limited possibilities / attempts to replenish them, and focusing on resources that cannot be generated on board - the bees collected water in the ISRU mechanism, but did not use a source of vegetable protein - spirulina, which was an analog of pollen, or naturally available pollen on plants introduced into isolation.

In addition, the hive interior temperature records indicated a decreasing activity of the bees. Probably, the lack of brood resulted in a lesser demand for the energy-consuming process of maintaining constant nest temperature. It could also be a reflection of a switch to a “consumer mode”, which resulted in a debilitating and permanent process of deterioration of the colony's condition, having the natural mortality rate of insects sustained. At the same time, despite decreasing food stores overall bee number the colony, no disease was observed.

One of the far-fetched but interesting analyses originating from the Habeetat study could be the analogies of aspects of the swarm behavior in isolation to human isolated colonies, in space or on Earth. The development of algorithms comparing the bee with the human models would require further research and machine learning approaches on large datasets.

4. Conclusions

We have shown that the isolation of bees results in decreased outdoor activity, reproduction rate and a switch to using stored food rather than foraging for it. UlMonitor proved to be a useful tool, with which the analog astronauts could monitor the swarm.

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