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A Review on the Effectiveness of the Wyss Institute's Autonomous Flying Robots for Pollination

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ABSTRACT

With the alarming global bee population decline threatening agricultural ecosystems and food production, innovative solutions like robotic bees have gained attention as potential pollination substitutes. This report assesses the effectiveness of robotic bees for pollination through a literature review. Robotic bees are bug-sized autonomous flying robots in development by the Wyss Institute which are claimed to have agricultural pollination applications. Research shows that these "robobees" will likely not be a viable solution to the pollination crisis as there are significant downsides including the technology's substantial costs and environmental risks. Recommendations for addressing these challenges include the use of a computer-vision algorithm to help with navigation and a geo-fencing system to prevent unwanted wandering. Alternatives such as habitat restoration, simple artificial pollination, and conventional beekeeping, although not without their flaws, may serve as better solutions to the crisis. Despite this, engineers have been improving these micro-robots by enhancing their flight and processing capabilities and they may have species-specific pollination applications in the future.

Introduction

In recent decades, an alarming decline in bee populations around the world has emerged. In the United States, there has been a 61% reduction in the honey-producing bee colony population from its peak in 1947 to 2008. In Europe, the hive population decreased from 21 million in 1970 to only around 15.5 million in 2007 [1]. The threat of bee extinction is growing more and more likely, which could have severe negative effects on biodiversity and agriculture [2]. Various solutions have been proposed to tackle this crisis, one of which is the use of robotic bees or ”robobees”. These bug-sized autonomous robots aim to simulate the behavior of natural bees and potentially serve as a sustainable alternative for crop pollination [3]. The idea of utilizing robotic bees to compensate for the decline in natural pollinators is undoubtedly ambitious and raises numerous scientific and practical concerns. The primary objective of this research report is to assess the effectiveness and potential of robotic bees in pollination through a literature review. The report will dive into the various aspects of this emerging technology, examining its potential and limitations as a solution to the pollination crisis.

Background

Bees play a vital role in pollination, supporting the reproduction of 80% of all flowering plants and contributing to the life of approximately 150 species of fruit and vegetables [4]. However, factors such as habitat loss, pesticide use, climate change, and parasites have severely impacted bee populations, resulting in a phenomenon known as Colony Collapse Disorder (CCD) [5]. To combat the impending threat to agricultural ecosystems and food security, innovative solutions have been created to address the challenges posed by the decline of natural pollinators.

The extinction of bees would significantly impact global food production and ecosystem stability. Without bees, the reproduction of many crops would be severely impaired. This loss would lead to reduced yields, higher food prices, and potential food shortages [6]. This could affect billions of people around the world. Moreover, our biodiverse ecosystems would also suffer, resulting in the collapse of many animal and plant populations. In response to the urgent need for innovative solutions, many have been exploring the development of robotic bees as a potential substitute for natural pollinators. These tiny machines attempt to mimic the behavior of natural bees while providing a sustainable solution to the pollination crisis. Robobees are very controversial, because while some argue they could replace existing bees, preventing disaster and famine, others claim they could also be a waste of resources that only make the problem worse [7].

Scientific Development

Robobees were first introduced by the Wyss Institute at Harvard University in 2010. Initially developed for surveillance, scientists began to explore their use in pollination.

The prototypes were tiny devices that could fly and hover mid-air, powered by thin, piezoelectric actuators: strips of ceramic that expand and contract when an electric field is 2 applied. By using a high frequency of wing flaps, these robobees could mimic the aerodynamics of natural flying insects [8].

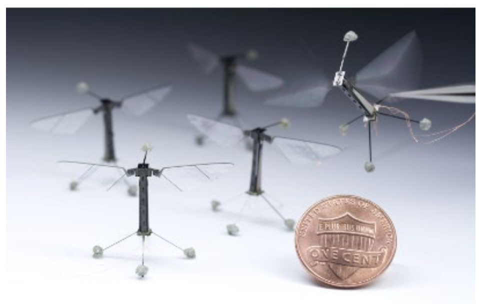

Figure 1. As seen in Figure 1, robobees developed at the Wyss Institute are incredibly small. Image reproduced from [9].

Robobees weigh less than one-tenth of a gram and are about the size of a paperclip. To achieve this incredibly small size, pop-up microelectromechanical technologies (MEMs) were used. This is a technique in the construction of micro-robots which consists of layers of laser-cut materials that can ”pop up” to form complicated 3-dimensional mechanisms. This method allows for the construction of complicated yet efficient technologies which can also contain circuitry and piezoelectric actuators.

These tiny robots have evolved over time, with each variation more adaptable than the prior [9]. In 2016, the robot could stick to walls and under leaves using static electricity [10]. A year later, scientists created a prototype that could swim and jump out of the water using a tiny combustible rocket made with oxyhydrogen [11]. In 2019, the bee’s energy was made self-sufficient using attached solar cells [12]. As Robobees evolved, researchers began to experiment with their uses in practical fields, and thus many questioned their ability to replace real bees in agriculture.

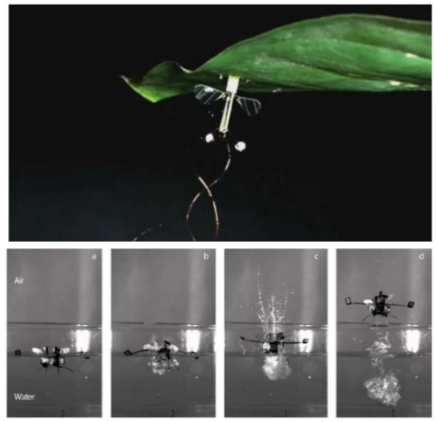

Figure 2. As seen in figure 2, robobees can stick to leaves and jump out of water. Reproduced from [10] and [11].

Robotic bees have been effective in pollination of certain plants in a controlled environment. In Japan, researchers used ionic liquid gels attached to horsehair on 4cm by 4cm drones to effectively pollinate Japanese lilies (Lilium japonicum). However, these drones were remote-controlled by humans and much bigger than the Wyss Institute's bees.

Challenges

Economic Challenges

There are more than 2 trillion bees in the world, each playing its part in the pollination of crops and flowers [13]. Replacing them with robots would be incredibly expensive. Even if they were only used for agricultural purposes, they could cost hundreds of billions of dollars[14]. There is currently little evidence showing the price of manufacturing individual robobees getting cheaper in the near future.

Technological Challenges

Unpredictable weather patterns could also affect these bees. Due to their small size, they may be susceptible to wind, rain, sandstorms, or snowstorms. Although terrain-adaptable micro-robots have been developed, they have been mainly ground-based[15]. Micro-robots such as the robobee may have their wings damaged by particles flying through the air. Unlike natural bees, which decompose and return to the ecosystem upon death, robobees will become electronic waste at the end of their operational life. This electronic waste is notoriously difficult to manage and can result in harmful substances leaching into the environment if not properly disposed of [16]. The production of Robobees could thereby contribute to the growing problem of electronic waste, with serious implications for both terrestrial and aquatic ecosystems. Thus, while the concept of robobees may seem like a novel solution to the decline of bee populations, the potential risks and harms they present must be carefully weighed.

Environmental Challenges

In addition to economic and technological considerations, the use of Robobees raises issues of potential hazards and waste. The material composition of Robobees could pose a risk to wildlife. If ingested by animals, these mechanical pollinators could become a toxic meal, causing harm [7]. Their introduction could disrupt the delicate interrelationships between plants, pollinators, and other organisms in the environment. The physical presence of Robobees could lead to competition for resources with natural pollinators, potentially altering the behaviors of these pollinators and other insects [7]. Furthermore, the energy required to produce millions of Robobees could contribute to increased carbon emissions.

Possible Improvements

However, Robobees could be improved through future technological advances, addressing concerns that scientists have for current bees. One of the changes that could be implemented is advanced sensors and AI for targeted pollination could enable Robobees to reliably distinguish intended crops from other plants. Onboard cameras and machine learning would allow Robobees to visually identify and 5 recognize target flowers. Neural networks would then analyze the sensor data to guide each Robobee to the right blossoms [17]. However, the bee's brain is very complex, and at the size of 2 cubic millimeters, it can memorize flower species and locations for pollen collection. Reverse engineering the bee's brain to fit a complex machine learning algorithm inside the size of a Robobee would be nearly impossible with today's technology [18]. However, due to the increasing capabilities of edge processing, fitting a neural network inside a small microcomputer on the robot bee's body may be increasingly likely. [19]. Alternatively, the robobees may be able to use the Internet of Things (IoT) to communicate with a central processing unit, thereby reducing the need for edge computing and machine learning. However, this would require a remote connection which, if broken, could lead to the loss of navigation ability for the bee.

Another technology that could help is geographic fencing using a Global Positioning System (GPS). This is already being used in large-sized drones, but its implementation has yet to be seen in robobees [20]. This provides an effective mechanism for controlling robobee movements. Virtual boundaries transmitted to Robobees from a central station would constrain flights within predefined access zones like farmer's fields. The central controller could track the swarm in real time and adjust geo-fences as needed. If a robobee flies near the boundary, it will redirect to avoid crossing. This creates a flexible boundary, keeping Robobees in permitted areas for targeted pollination. Geo-fencing allows for the regulation of Robobee ranges for safety and proper crop pollination. This prevents stray robotic bees which could get lost and wasted. This could also prevent them from going into places of biodiversity and interfering with other animals. However, researchers are already working towards implementing a GPS inside Robobees, making the possibility of geo-fencing likely and achievable [21].

Comparison to Alternative Solutions

Conservation and Restoration of Natural Habitats

The conservation and restoration of natural habitats for pollinators like bees, butterflies, and other insects is a primary solution. This involves planting more native plants, and restoring natural habitats [22]. Unlike robobees, this solution aims to tackle the root cause of the pollination crisis by creating a sustainable environment for natural pollinators. It is more holistic and beneficial for overall biodiversity, but it requires substantial time, effort, and policy changes. This tactic is already being used in many regions but is seeing little progress in overall bee population trends. Conservation tactics can sometimes only benefit half of the bees in studied cases [23]. As long as the dangers of pesticides, parasites, and warming still exist, CCD will still be a threat.

Robobees will be unaffected by pesticide, parasites, and global warming, making it a much more stable solution that can resist long-term environmental changes.

Other Forms of Artificial Pollination

This involves using handheld tools or sprayers to transfer pollen from one flower to another physically. It can be done by jets, humans, and large robots [24]. While this type of pollination may be effective for some plants, it may not work well for others. For example, pollinating almonds would be incredibly difficult without bees because they require cross-pollination between trees [25]. Another example would be the highbush blueberry, which requires bees to be pollinated because of its flower's bell-shaped structure [26].

Robobees have the potential to improve pollination efficiency for these plants in agriculture. Their smaller size allows them to more efficiently pollinate certain species of flowers. Many species of agricultural plants require bee pollination or other forms of entomophily due to their complex flower shapes which require small, precise mechanisms to extract pollen. This means that many macro-technological alternatives to bee pollination are limited as many species of flowers require insect-sized pollination.

Beekeeping and Managed Pollination

Beekeeping and the use of managed pollinators like honey bees are often used to help increase pollination[27]. This solution involves the human management of pollinators and their hives. Managed pollinators can perform more complex tasks than Robobees and contribute to honey production. However, they are affected by the same environmental threats as wild pollinators, and their populations are decreasing as pesticide use or climate change continues[28]. They also cannot be controlled by humans and often wander past cropland, harming wild bees and stealing resources. Viruses developed in managed colonies can even spread to wild bees, causing further harm [29].

Robobees, on the other hand, are less susceptible to diseases and environmental changes. They can also be managed more easily with the use of geo-fencing, preventing them from competing with wild bee species.

Conclusion

As the natural bee population continues to fall in many areas of the world, a solution is needed to quickly combat this crisis to prevent the loss of biodiversity and agriculture. The Wyss Institute's robobees are a new technology that is advancing rapidly. There is evidence that artificial pollination using small drones similar to robobees is possible.

However, the manufacturing and maintenance costs of robobees are substantial, and the replacement of a significant portion of the natural bee population with these technological substitutes would demand billions of dollars. Furthermore, the environmental impact of robobees, from their potential disruption of ecological balance to their contribution to e-waste, cannot be ignored. Additionally, their deployment would require sophisticated AI, advanced sensors, and geo-fencing technologies to ensure effective, targeted pollination without causing unwanted disruptions to the environment.

However, it is crucial to bear in mind that robobees are merely one potential solution in a much larger toolkit. Solutions such as the conservation and restoration of natural habitats, other simpler forms of artificial pollination, and the use of managed pollinators, while not as technologically advanced, are more developed and less expensive than current robobees. However, these current solutions all have their own problems. Conservation of existing bees, while morally the best option, has been shown to be ineffective with the existence of parasites, pesticides, and climate change. Simpler forms of artificial pollination aren't effective for many plants because of the shape of their flowers and cross-pollination requirements. Managed pollinators are most commonly used, but they could disrupt local wild bee species and be equally affected by colony collapse disorder.

In conclusion, the concept of robobees for pollination is still premature and needs more research and development. Their effectiveness in averting crises cannot be overlooked, but many changes still will need to be made before their implementation. More research needs to be done regarding production, their interactions with the environment, decomposition and more.

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