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OVERVIEW OF THE POSSIBILITY APPLICATION OF SOME NANO DRONE TECHNOLOGIES IN MODERN AGRICULTURE

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Abstract. The use of different types of drones in almost all sectors of the global economy is growing rapidly, but the use of drones in agriculture has suddenly increased. According to some data from the literature, the market for different types of drones in agriculture alone is expected to grow from USD 1.2 billion in 2019 to USD 5.5 billion in 2024.
A particularly interesting phenomenon is the significant increase in the use of drones (especially various nano-types) in the world and the possibility of some of them being used in agriculture in the Republic of Serbia.
The world of drone technology has taken a huge leap forward with the introduction of nano drones. For example, some modern nano drone solutions have dimensions of less than 2 x 2 cm.
Nano drones are ultra-small remote-controlled aircraft that can perform a variety of tasks. They are equipped with advanced sensors and functions such as obstacle avoidance and high-speed maneuverability. Some models are even capable of taking aerial photographs, staying in the air for long periods of time and flying autonomously. Nano drones are now more affordable than ever before. Prices range from a few hundred dollars to several thousand, depending on the model and features. Nowadays, nano drones are affordable for everyday users in various fields.
This paper introduces nano drone technology (e.g. the type of nano drones and equipment) as a new application for greenhouses: There are some stages that greenhouse growers can consider for the use of nano drones;
Safe inspection of the structural components of greenhouses; Pollination processes (e.g. the role of RobotBee); Application of shading composite glasshouses; Crop monitoring/inventory of greenhouses.

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Key words: *Nano drones, possibilities of application in green/glasshouses, production of vegetable crops, control.*

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INTRODUCTION

The population of planet Earth is constantly increasing. The global demand for food is following the same trend. Agriculture must not only produce more to meet the increasing food consumption, but also do so in a more sustainable way than before [1]. In recent years, precision agriculture has made many technological advances (e.g. GPS, GIS or various drones), providing farmers with an increasingly modern set of tools to increase crop production.

Today, unmanned aerial vehicles (UAVs) occupy a prominent position in the technical and technological equipment of participants in modern agricultural production [1, 31, 33], [6, 26, 31], [32, 33], [36, 46]. Drones are used in many areas of agriculture, such as mapping, crop stress detection, estimation of biomass and nutrients in the field, chemical spraying, weed management, and finally geo-referencing in GIS [2].

Although the vast majority of agricultural applications take place outdoors, there are some attempts to use specialized drones in greenhouses. The authors [3] present a method for automatic detection and classification of pests using a Support Vector Machine using images captured by a drone and an IP camera. In addition, [4] proposed a ground and airborne robotic system to measure temperature, humidity, CO2 and brightness in the greenhouses of Almeria (Spain). A concept for plant pollination using nanocopter drones is presented by [6]; however, no technical details were given in the study.

In general, the lack of indoor applications (e.g. greenhouses) is mainly due to the limitations that exist in indoor environments such as greenhouses. To navigate a drone outdoors, for example, the exact position can easily be determined using GPS and GIS. For indoor applications, however, GPS is not an option

Therefore, different approaches for indoor localization have been proposed, in some cases involving more sophisticated sensors such as lidars and cameras. It is known that these sensors generate large amounts of data and the processing of the data is very computationally intensive. To reduce the onboard processing workload, these calculations are usually transferred to the ground controller or even to a remote computing cloud service. However, this requires a reliable connection (e.g. wireless or radio).

A stable connection (e.g. wireless or radio) between the drone and the control unit is an important aspect of indoor navigation. On the one hand, the drone should be able to receive navigation commands, and on the other hand, it should send its current status or position back to the control unit. The real-time data from the built-in sensors should therefore be transmitted reliably.

Since drones operate with high-frequency signals, indoor farms are complex systems in which phenomena such as reflection, absorption, diffraction, scattering and interference can lead to attenuation or signal loss. As a result, the connection may become unreliable.

The propagation of RF signals is also influenced by environmental conditions, material properties and angles of incidence. In addition, as the use of technology in agriculture becomes more popular, other wireless devices can transmit in the same spectrum, causing signal interference.

This is especially true for UAVs that use Wi-Fi for their communications. As different technologies can share the same Wi-Fi spectrum, interference is not unlikely. For example, [7] studied the effects of adjacent channel interference in IEEE 802.11 WLANs and [8] studied the interference between Wi-Fi and ZigBee networks.

In the past, some researchers have attempted to study RF signal propagation in different building materials. In [9], a list of materials was analysed over a wide frequency range. Similarly, in [10], propagation losses were investigated, but this time the specific frequency bands of 2.4 GHz and 5 GHz were chosen as part of the IEEE 802.11 standard for Wi-Fi applications. Although these studies show the behaviour of RF signals on different construction materials, these data cannot be directly translated into solid conclusions for entire constructions.

Another area that other studies have focused on is Wi-Fi assessment in different buildings. In [11], the relationship between the RSS and the throughput of an IEEE 802.11g network in an office building was analyzed, and the results showed that the throughput was not proportionally affected when the RSS was changed. The authors of [12] conducted an experimental propagation comparison between Wi-Fi and Super Wi-Fi networks indoors and proved that Super Wi-Fi can improve network performance due to better signal propagation indoors. In [13], the propagation topology of a house at 2.4 GHz was investigated by comparing experimental measurements with indoor propagation modeling. Finally, the authors of [14,15] proposed Wi-Fi heat mapping methods to evaluate Wi-Fi networks.

For example, the drones used in the paper Experimental connectivity analysis for drones in greenhouses [16] were the AR.Drone 2.0 and the Anafi, both developed by the French company Parrot [19, 20]. The AR.Drone 2.0 is a low-cost, Linux-based drone, while the Parrot Anafi is a professional platform with advanced features. Both drones are equipped with various sensors, including an inertial measurement unit (IMU), a magnetometer, an ultrasonic altimeter and a pressure sensor, and each has two cameras. In addition, both comply with the 802.11n standard for sending and receiving commands and data to the control unit.

An ASUS X510UNR laptop equipped with a built-in Wi-Fi adapter based on the Intel 8265 chipset was used as the control unit.

As a control unit, an ASUS X510UNR laptop, which is equipped with a built-in Wi-Fi adapter based on the Intel 8265 chipset was used.

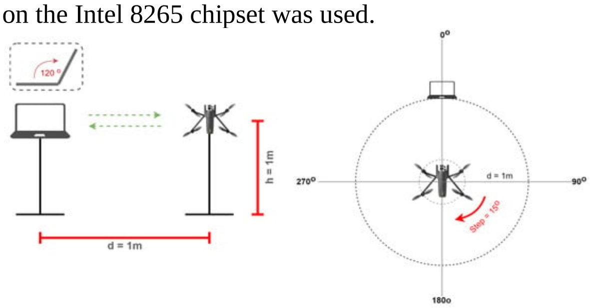

Fig. 1. Experimental radiation pattern configuration, [16].

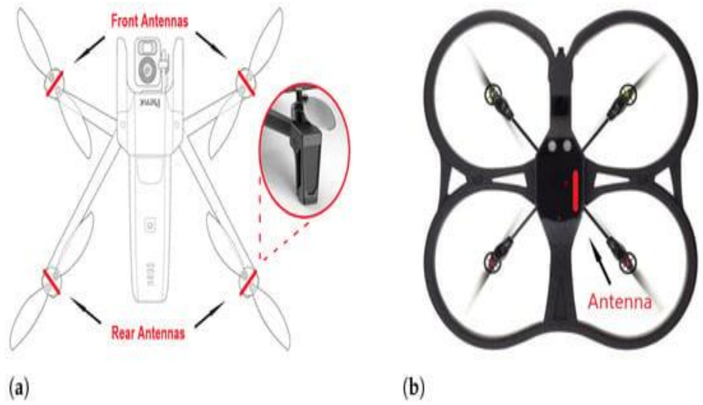

Fig. 2. Location of the antennas on two UAVs, [16].
(**a**) Parrot Anafi; (**b**) Parrot AR. Drone 2.0

The PC laptop (Fig. 1) in the experiment was configured to run Ubuntu 18.04 LTS. To ensure that the connection between a drone and a controller unit is reliable, the connection quality was evaluated. For this reason, three different experiments were conducted indoors and outdoors, measuring packet delay, throughput and signal strength. Data was collected using Python and the Linux integrated utilities ping and iwlist.

The outdoor experiments were conducted in an open field in Papendorp, (Netherlands), a location where there are few Wi-Fi networks. For the indoor test, the greenhouse facility on the campus of Wageningen College was used.

In real operation, the drones were able to navigate freely in space, and this is a dynamic process that can influence signal propagation. However, the greenhouse is a GPS-free environment, which means that significant errors occur during flights and it is difficult to maintain a constant position.

In this paper [16], we investigated the connectivity characteristics of two commercially available drones in the greenhouse specifically for video-based applications. Extensive measurements were performed under real-life conditions focusing on three main areas: the radiation pattern, the signal propagation within the greenhouse compartments and finally the maximum flight range that each drone can achieve without loss of video quality in the greenhouse corridor.

In this experiment [16], data was collected on signal strength, throughput and turnaround time for both drones in a greenhouse compartment. The drones were placed on the floor of the greenhouse at a distance of 2.5 m from each other and moved manually at each location. Measurements were taken at three different heights: 0.5 m, 1.5 m and 2.5 m. The data from each drone was collected in two different scenarios: first with the propellers switched on, with the throttle set to 100%, and then with the propellers switched off, with the throttle set to 0%.

During the measurements, not only were the position and orientation of the PC constant, but the drones also had a fixed orientation, as Fig. 3 shows. It is worth mentioning that no plants populated the greenhouse during the measurements.

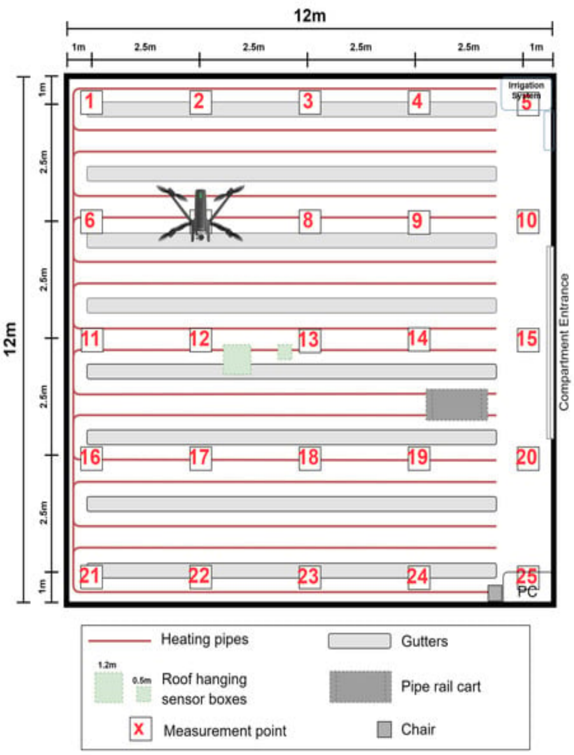

Fig. 3. Greenhouse compartment layout, [16].

The results of the radiation patterns show that both UAVs have anisotropic radiation patterns and that signal equalization on the receiver side may therefore be necessary for RSS applications. In addition, the UAVs are more susceptible to signal and packet loss in certain orientations, which can lead to a drastic increase in RTT. The results also show that the construction design of the greenhouse does not have a significant impact on the communication characteristics. However, the measurements taken closer to the roof were more prone to connection problems. Although the Parrot Anafi had a higher RTT than the AR.Drone 2.0 in all cases, it outperformed the AR.Drone 2.0 as it achieved a higher signal strength and throughput in all cases.

The measurements in the greenhouse corridor prove that the Parrot Anafi is capable of flying up to a distance of 110 m without compromising the video quality. The minimum RSS value required to achieve this range was −62 dBm. The AR.Drone 2.0 was only able to reach a distance of up to 30 m from the ground station, while the minimum RSS required was −70 dBm. Between the two drones used in this study [16], it can be concluded that the Parrot Anafi outperforms the AR.Drone 2.0 in almost all cases and can therefore be considered a more suitable platform for use inside greenhouses.

2. HOW NANO DRONES HAVE CHANGED THE WAY WE INTERACT WITH TECHNOLOGY

In recent years, nano-drones have revolutionized the way we interact with various technologies. These tiny, very or sometimes ultra-light robots have opened up a world of possibilities, from search and rescue missions to surveillance, and now offer a new way of interacting with different technologies in everyday life [22].

Nano drones are small, maneuverable and can be operated remotely or autonomously. They are equipped with sensors, cameras and communication systems that enable them to collect data and send it back to the user. This data can be used to monitor or control a variety of functions, such as surveillance, mapping and search and rescue operations.

Nano drones can even be used to detect changes in environmental conditions to better understand the environment for humans.

In addition to their practical applications, nano drones have allowed us to discover new ways of interacting with the world. They can be used to create unique art installations and document events in an unprecedented way. Due to their small size and maneuverability, nano drones are also perfect for virtual reality experiences, allowing users to explore virtual worlds in unprecedented ways.

The potential of nano drones is huge and their various applications and technologies are still being explored.

2.1. The Impact of NANO Robotics on the Future of Autonomous Flight

The advent of miniature robotics is revolutionizing the future of autonomous flight. Miniature robots — also known as micro-aerial vehicles (MAVs) - are small, lightweight robots that can fly in confined spaces and navigate complex terrain [22, 23]. They are the size and shape of insects and are able to navigate and maneuver more precisely and agilely than larger fixed-wing aircraft.

These miniature robots (MAVs) provide the necessary different solutions to the challenges associated with traditional autonomous flight.

MAVs are able to reach previously inaccessible places and fly autonomously for longer periods of time and with greater maneuverability. They are therefore becoming increasingly popular for applications such as search and rescue missions, surveillance and environmental monitoring.

The use of miniature robots for autonomous flight has a number of advantages. For example, MAVs can carry out complex missions without a human pilot, which enables faster reactions and more efficient operations. In addition, MAVs can fly over greater distances and at higher altitudes than conventional aircraft, which increases the range and accuracy of data collection. Therefore, MAVs can be used to collect more detailed and timely information from hard-to-reach areas.

Miniature robotics are expected to have a major impact on the future of autonomous flight. MAVs are already being used in various industries, such as agriculture, construction, energy and transportation. As technology advances, MAVs are likely to become even more common, opening up new opportunities for autonomous flight.

The future of autonomous flight is an exciting prospect, and miniature robotics is helping to make this a reality. MAVs have the potential to revolutionize the way we interact with our environment and improve the safety and efficiency of operations. Miniature robotics has the potential to revolutionize the way we interact with our environment and its impact on the future of autonomous flight should not be overlooked.

2.2.Future Developments in Nano Drone Technology

The use of nano drones, also known as micro aerial vehicles, is becoming increasingly popular in both the commercial and military sectors. Nano drones are small, lightweight and relatively inexpensive, making them ideal for a variety of applications. As technology advances and nano-drones evolve, new possibilities are emerging that could revolutionize the way we use these devices, [33], [22].

One of the most exciting developments in the field of nano drone technology is the use of artificial intelligence. AI-controlled nano-drones can be programmed to perform certain tasks autonomously, such as inspecting dangerous environments or delivering goods. This could drastically reduce the need for human intervention in many situations, making the technology even more attractive to companies and other organizations.

Another area of development for nano drones is the use of 3D printing. By creating components from scratch, nano drones can be designed and built faster, cheaper and more efficiently than ever before. This could open up a world of possibilities for the customization of drones and make them even more useful for a variety of applications.

The use of sensors is also becoming increasingly important in nano-drone technology. With the help of sensors, nano-drones can collect data in real time, giving them valuable insights into their environment and helping them to better navigate their surroundings.

This could be particularly useful for applications such as navigation, surveillance and search and rescue missions.

Finally, augmented reality in nano-drone technology is expected to become mainstream in the near future. Augmented reality will allow nano-drones to display information such as maps, directions and weather conditions in real time. This could be invaluable for a variety of applications, from navigation to search and rescue.

The future of nano drone technology is bright and the possibilities seem endless. As the technology continues to advance, the applications for these tiny devices are sure to expand.

3. SOME IMPORTANT TYPES OF NANO DRONES

3.1. PAV types of drones

In recent years, researchers have attempted to design and build unmanned aerial vehicles (Fig. 4) with the size and shape of insects [22-26], [31, 33, 36]. Therefore, a new class of drones called pico-aircraft or pico-air-vehicles (PAVs) has been defined [24]. Due to their small dimensions and low weight, there are currently only a few types of PAV aircraft. Quadrotor and mini aircraft are designs commonly used in the PAV class. Among the mentioned types, the single-rotor PAV has recently been performing with fewer advantages than the structures with rotating wings (quadrotor) because they mimic the movement of insects with wings that have incredible flight performances such as: hovering, sudden accelerations, and very fast turns [22]. Many researchers have worked on such constructions with micro-drones (Fig. 4). The Authors of [24] were pioneers in the field of controlled flights of microrobots. They proposed a concept for a microdrone with insect-like external parts and elastic joints (Fig. 4). The author [25] attempted to construct an insect-sized microdrone with a wingspan of about 25 mm and a weight of about 100 mg.

In order to research butterfly flight [22], a small and light butterfly-like drone was developed that weighs 40 mg, has a wingspan of 140 mm and a wing frequency of 10 Hz. The "RoboBee" project was initiated by the Author [23] to design and produce butterfly wings (Fig. 4.) as parts for PAV drones.

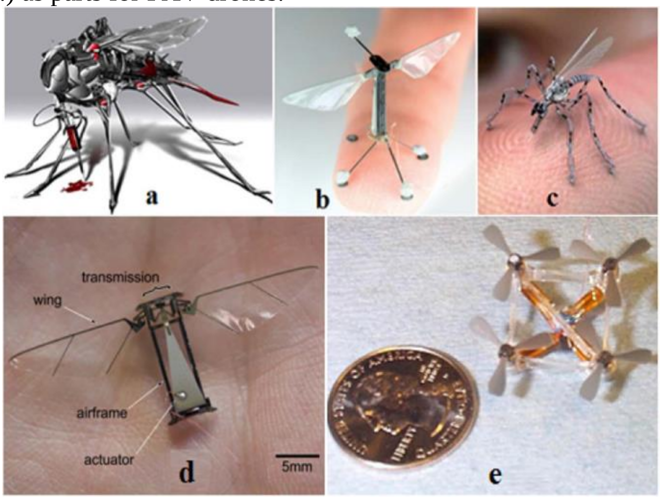

Fig. 4. Some important types PAV drones: (a, b, c, d) flapping wing, (e) quadrotor, [33].

3.2. Wasp III (UAV)

AeroVironment Wasp III developed the Nano Air Vehicle (NAV) under a DARPA (USA) funded research contract to develop a new class of air vehicle systems that can be used both indoors and outdoors.
This unconventional air vehicle, which mimics biological processes on an extremely small scale, could one day provide new reconnaissance and surveillance capabilities in urban environments.

The Wasp Micro Air Vehicle (MAV) is based on the technology of the former DARPA Black Widow MAV program. With a wingspan of 41 cm and a weight of 275 grams, the Wasp is AeroVironment’s smallest UAS. Wasp can be manually controlled or programmed for GPS-based autonomous navigation.
To ensure system interoperability, Wasp uses the same advanced technology as AeroVironment's other UAS. The drone features: a high-resolution EO and IR camera in a compact, aerodynamic, modular payload; Range: 5 km line-of-sight; Endurance: 50 minutes; Speed: 20 knots in cruise flight; Operating altitude: 152 m (500 ft), Landing method: Low-level landing in a confined area.

3.3. PD-100 Black Hornet Nono Unmanned Air Vehicle

The Black Hornet Nano is a military unmanned aerial micro-vehicle (MUAV) that was developed in 2013 by the Norwegian company Prox Dynamics AS and is used by the armed forces of many countries [47]. Today, the PD-100 Black Hornet complete system consists of two UAVs and a base station. The drone has a length of around 100 mm and a rotor span of 120 mm. It weighs 16 g, including the surveillance camera. The entire system weighs less than 1 kg without the display. The small drone is easy to fly and takes less than a minute to take off. Black Hornet is equipped with a steerable electro-optical (EO) camera that captures both still images and live video and can be zoomed and displayed on a handheld device for a clearer picture.

The drone can either be controlled directly or programmed to fly a predefined path using the built-in GPS system. The digital data link allows the operator to control the drone within a visual range of 1,000 meters.

The Black Hornet micro drone is powered by a very small, rechargeable electrical battery. The battery allows a flight time of about 25 minutes (or a maximum distance of 2000 meters) before it needs to be recharged.

The Black Hornet nano is controlled by an operator from the ground using a joystick-like device. The Black Hornet base station provides planning, execution and analysis services to the system operator.

3.4. A biologically inspired, flapping-wing, hybrid aerial-aquatic microrobot

From millimeter-sized insects to meter-sized vertebrates, several animal species exhibit multimodal locomotion capabilities in air and water [35]. The development of robots that can move in both air and water requires versatile propulsion strategies that reconcile the different physical conditions in air and water. The transition between air and water environments is a major challenge at the scale of microrobots, as the surface tension at the surface can be significant in relation to the weight and forces generated by the animal/robot. Study [35] on the design and operation of an insect-sized robot that can fly, swim and switch between air and water. This 175 milligram robot uses a multimodal wing flapping strategy to move efficiently in both fluids.

This thesis in [35] analyzes the dynamics of flapping locomotion in an aquatic environment, identifies the challenges and benefits of surface tension effects in microrobots, and develops a series of new mesoscale devices culminating in a hybrid air- and water-bound microrobot.

Hybrid aerialand aquatic robots capable of traversing complex multiphase environments will have a wide range of applications, such as environmental exploration and search and rescue missions [35]. Due to their smaller size and lower weight, microrobots are advantageous for navigation in confined and cluttered environments. As the inertial forces decrease in the millimeter range, microrobots are more resistant to impact events such as a crash landing in water or a collision with obstacles.

Compared to conventional robots, microrobots can easily land on vertical surfaces or even perch on overhangs (by utilizing surface effects). Despite these functional advantages, hybrid air- and waterborne microrobots face unique manufacturing challenges and physical limitations [35].

According to [35], a hybrid air-water microrobot must solve two key problems: (i) multiphase actuation for air and water and (ii) overcoming surface tension for water ingress and egress. The large density difference between air and water leads to conflicting criteria for robot locomotion and design in these two environments. A number of robotic platforms such as fixed-wing, folding-wing and rotorcraft have been developed to explore multiphase locomotion. Although there are no fixed-wing or folding-wing designs that are fully operational in both air and water, a recent study adapted a rotorcraft for locomotion in water and demonstrated the transition from air to water and water to air. However, the design of a rotorcraft cannot easily be adopted by a microrobot, as it is difficult to manufacture and the surface tension can exceed the weight of the robot by more than ten times. In addition, the physics of scaling shows that conventional brushless motors are not feasible on the order of milligrams.

In this paper, the main challenges for hybrid locomotion in air and water in a subgram microrobot are identified and solved. In [35], the system dynamics of aquatic locomotion were investigated and it was found that an inherently unstable flapping-wing vehicle can be passively stabilized during swimming if it is operated at appropriate frequencies. He developed a 40-mg pulse device that uses electrolysis and combustion to achieve repeatable water-air transitions. This work [35] shows a bio-inspired hybrid air and water micro-robot with flapping wings. The robot has successfully demonstrated hovering in air, air-water transition, swimming, and take-off and landing on the water surface. This multifunctional microrobot is able to adapt to complex environments, and these locomotion capabilities will expand the functionalities and applications of future microrobots.

This robot could hover in the air, transition from air to water, swim, take off from the water surface and land (Fig. 5A). The robot hovered in the air and was inherently unstable without feedback. Using a motion tracking system with adaptive control, a stable hovering flight could be achieved (Fig. 5B). The control signals were calculated outside the airplane and sent to the robot via a cable band. When the robot touched down on the water surface, it broke the surface tension on impact and then sank into the water surface (Fig. 5C). To maintain its position or maneuver underwater, the robot flapped its wings at 9 Hz.

When the robot emerged from the water, it first swam to the surface (Fig. 5D). When it reached the water surface, two electrolyte plates in the robot body began to break down water into oxyhydrogen.

The gas was trapped in a chamber, and the increased buoyancy force gradually pushed the robot's wings out of the water (Fig. 5E). To completely detach from the water surface, we used an impulsive strategy:
An igniter ignited the oxyhydrogen mixture, and the robot jumped from the water surface (Fig. 5F). This combustion-based jump resulted in a typical jump velocity of 2.5 m/s and a typical jump height of 37 cm (Fig. 5F).
The robot took a ballistic trajectory in the air and landed on the ground about 0.55 s after take-off.

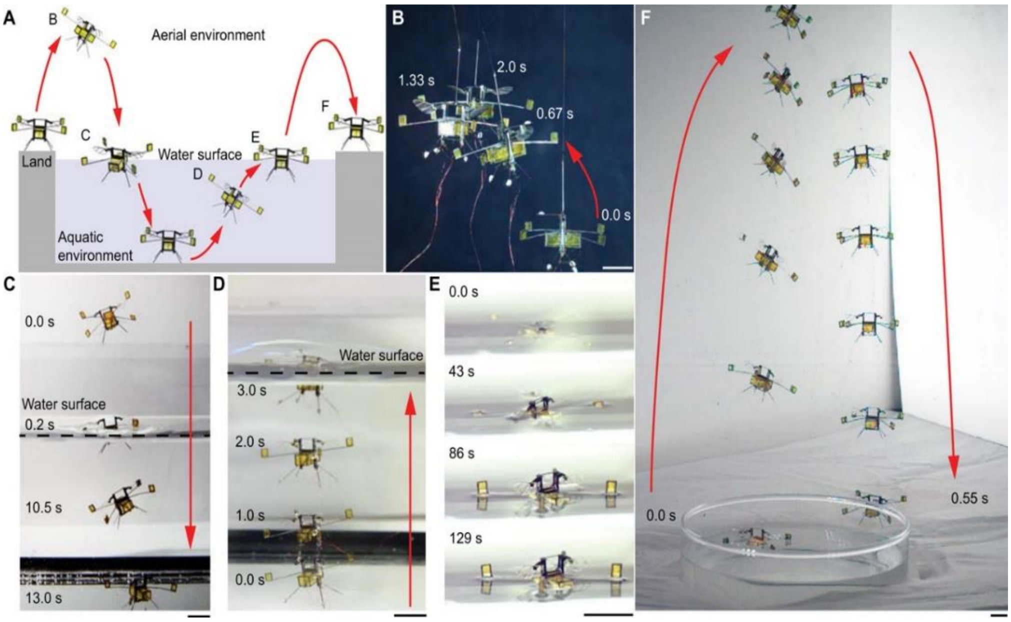

Fig. 5. Demonstration of aerial-aquatic locomotion and transition, [35].
(**A**) The robot is capable of aerial hovering, air-to-water transition, swimming, water-to-air transition, impulsive takeoff, and landing. (**B**) Composite image of a hovering robot. (**C**) Composite image of the robot transitioning from air to water. (**D**) Composite image of the robot swimming to the water surface. (**E**) Images of the robot gradually emerge from the water surface by capturing gas from electrolysis. (**F**) Composite image of robot take off and landing. Scale bars, 1 cm.

The presentation of a hybrid air-water microrobot with flapping wings [35] and Fig. 5 includes position (i) a detailed analysis of observations on the passive, upright swimming stability of the robot in water, (ii) the challenges and advantages that the surface tension of water brings to millimeter-scale robots, (iii) a discussion of meso-scale device design, and (iv) an impulsive method for water-to-air transition. The observation that a flapping-wing vehicle can be passively stabilized in water can be applied to larger, conventional robots. Flapping-wing locomotion in air and water is not subject to size and weight limitations. The flapping wing design has a number of advantages over conventional fixed-wing and rotorcraft.

3.5. Robobees from Harvard University

The idea behind the development of RoboBee (Fig. 6) was to develop autonomous micro aerial vehicles that are capable of flying independently and under their own control and achieving coordinated behavior in large groups. To this end, the development of RoboBee is roughly divided into three main components: Body, Brain and Colony. Body development is about constructing robotic insects that can fly autonomously using a compact and seamlessly integrated power source; brain development is about "smart" sensors and control electronics that mimic a bee's eyes and antennae and can dynamically sense and respond to the environment; colony development is about coordinating the behavior of many independent robots so that they act as an effective unit.

Robobees would displace wild and managed insect pollinators, many of which have highly specialized interactions with native flowering plants, further driving their decline and increasing human dependence on alternative pollination methods for food production.

Robobees would not pollinate wildflowers – from a grower's perspective, that would be a waste of resources, and from an engineer's perspective, that would mean they would need to be extremely diverse and subtle in their abilities to deal with flowers.

Fig 6. RoboBees, Wyss Institute at Harvard University, [36].

Inspired by the biology of bees, researchers at Harvard College's Wyss Institute [36] are developing RoboBees (Fig. 6, Fig. 7), man-made systems that could perform countless tasks in agriculture or disaster relief. A RoboBee is about half the size of a paper clip, weighs less than a tenth of a gram and flies with "artificial muscles" made of materials that contract when a voltage is applied. Additional modifications allow some RoboBee models to go from swimming underwater to flying and "settling" on surfaces using static electricity.

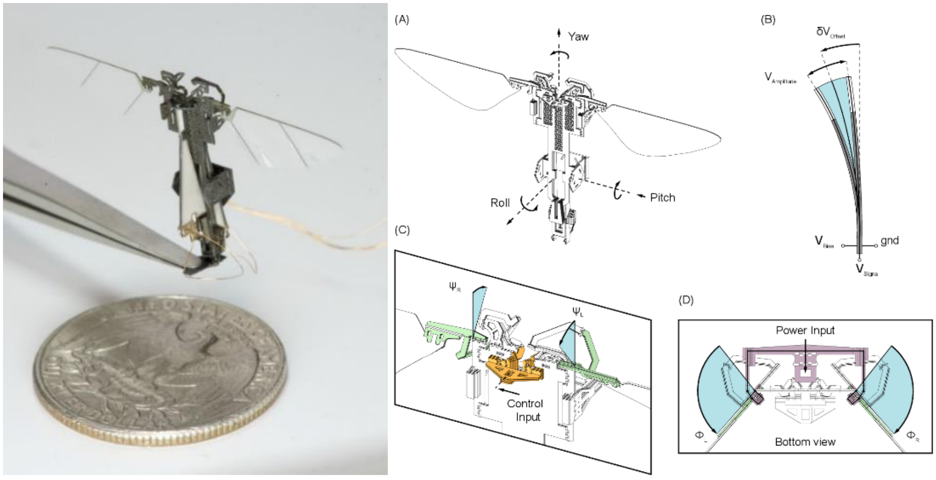

Fig.7. Flying 80-milligram, insect-scale, flapping-wing robot modeled on the morphology of flies, [36].

Robo-bees [34], or mechanical bees (Fig. 8) are machines that take over the work of real bees, e.g. pollinating plants and monitoring the health of beehives. They are used to increase productivity in agriculture, especially as bee populations are dwindling worldwide.
Robotic bees, also known as mechanical bees, are machines designed to imitate the work of real bees. They are mainly used for pollination, but can also be used to monitor hive health [34].
Bees play an important role in agriculture: according to the US Department of Agriculture, they pollinate around 35 percent of the world's food crops. And honey bees pollinate more than 90 commercially grown crops in the U.S. alone, including apples, broccoli and almonds. Most bees are kept like farm animals and transported from one place to another to pollinate the plants that ultimately provide the fruits and vegetables we all eat.

Fig.8. Robot bees or mechanical bees,

Although there is no threat of a global food shortage due to mass bee mortality, as is widely reported, honey bees still face major challenges [34].
Robotic bees represent a possible solution to this problem. Robotic bees, also known as mechanical bees, could be the future. How are robotic bees used?

Researchers and engineers from around the world have been experimenting with ways robots can do the work of real bees. Their creations come in a variety of shapes and sizes. Some fly around with propellers and use ionic liquid gel-coated horse hair bristles to collect and transfer pollen from one plant to another. Others have flexible wings powered by "artificial muscles" and use an electrostatic patch to perch on just about anything.

Following some major breakthroughs in the last several years, many of these projects are not far off from regular commercial use.

3.6. Pollinate Crops with Robot Bees

Some of the newer applications for drones in agriculture are still in the testing and development phase. One of the most publicized (and often invented) applications is the pollination drone. Researchers in the Netherlands and Japan are developing small drones that can pollinate plants without damaging them. The next step is to develop autonomous pollination drones that can work without constant instructions from operators and monitor the health of the plants.

Another drone technology under development also has to do with machine learning. Improving artificial intelligence (AI) in drones is important to make them more useful for smaller farmers in developing countries. Current drone technologies are more effective at monitoring known crops such as maize grown in large monoculture fields. Current drone monitoring programs struggle to detect areas with greater crop diversity, lesser known products and crops that look similar at all stages of growth and are therefore less effective at monitoring crop growth and health. More needs to be done to train AI systems to recognize less common crops and more diverse cropping patterns.

Drones have already transformed the agricultural industry and will continue to grow in the coming years. Although the use of drones is becoming increasingly useful for smallholder farmers, there is still a long way to go before they are part of every farmer's equipment, especially in developing countries. Regulations for the use of drones need to be enacted and revised in many countries, and more research needs to be done to investigate the effectiveness of drones in certain tasks such as pesticide application and spraying. There are many ways in which drones can be useful to farmers, but it is important to understand their limitations and functions before investing in expensive equipment.

3.7. Aerodynamically controlled pollination

The Polybee Company [36, 37] has developed a pollination method that works for strawberries, peppers, tomatoes and eggplants both indoors and in greenhouses (Fig. 8). Polybee Company [36, 37] has developed its own method, aerodynamically controlled pollination, in which self-fertile plants are pollinated without contact by using the downdraft of the drones to optimally vibrate the inflorescences (Fig. 8)

Fig 8. Polybee uses aerodynamically controlled pollination to dislodge the pollen, [36, 37].

These plants pollinate themselves and usually use bumblebees to transfer the pollen from the anthers to the stigma. While bumblebees pollinate the flowers by landing on the flower (recognizable by the small “blue spots" on the flowers), Polybee Co. use aerodynamically controlled pollination [17], [36, 37] to remove the pollen (Fig. 8)

“The idea is to transfer enough energy to the flower to detach the pollen grains from the anthers so that they fall onto the stigmas. Bees do this through vibration and contact, but can also take advantage of turbulent air currents.

The Polybee team investigated the fluid-structure interaction between the turbulent air and the flower and found that certain factors in the airflow are crucial for the release of pollen. According to Siddharth, these include turbulence, kinetic energy, air velocity, etc. With this knowledge, Polybee worked backwards to ensure that the drones create air conditions that trigger the release of pollen without ever touching the flower.

The company is promoting this autonomous pollination technology to both commercial farmers and seed breeders, the latter of which can benefit from precision pollination in pure breeding. Cross-pollination in the production of hybrid seeds is also on the company’s product roadmap, albeit at a later stage.

4. AGRICULTURE — NANO DRONES IN A GREENHOUSE?

Drone technology is finding new applications in the greenhouse [17]. There is no doubt that drones are an emerging technology, but do they have a place in greenhouses? The answer is clearly YES, but the applications we envision for outdoor agriculture may need to be adapted for greenhouses. “Like any other business, greenhouse operators are interested in the labor savings, operational efficiencies and business benefits that drones could offer.

4.1. Greenhouse Application

While it may seem like a crazy thought to consider flying small unmanned aircraft systems (sUAS) inside a greenhouse, there may be some useful applications that greenhouse growers should consider.

There are some applications that greenhouse growers might consider for UAS [17]: Safe inspection of components, sales and marketing, shading agent application, crop monitoring or crop inventory.

The first application is obvious - the safe inspection of components. How many greenhouses currently use one person to inspect gutters, covering materials, structural components and mechanical systems (e.g. cables, motors)?

The safe solution is to use a small drone equipped with live video to allow the operator to safely inspect these structural systems from the ground while a person acts as an observer. The observer helps the drone pilot to fly safely around the greenhouse.

One grower recounted how a worker fell out of a greenhouse with gutters during an inspection, and this event was the final motivation to purchase an $800 drone to accomplish the same task. This application alone should be a major reason to consider purchasing a UAS.

The next application is also an easy target. All agricultural and horticultural businesses should consider taking video or photos from the air to use at trade shows, on social media and on company websites for sales and marketing. How many TV commercials do you see today that use a short aerial video clip to promote a business? The perspective that images from these low altitudes offer is remarkable.

If you think your needs in this area are low, consider hiring an external drone company to collect your aerial images (photos or video) and then use their software to bring them into a final form.

When considering whether or not to do this in-house, you need to consider the cost of the aircraft, specialist insurance, camera/sensor, software and licensing. As with all other applications, it should be easy for you to find a local company that offers the imaging products you need.

The third application, the use of shading agents, may surprise you. Even in the U.S., there are many small (<55 pounds or <25 gr) UAS sprayers for sale that can be used to apply shading agents to greenhouse covers. While it is possible to find unmanned aerial sprayers that weigh more than 55 pounds (or 25 grams), from a regulatory standpoint, it is easier to fly aircraft that stay under that threshold. The 55-pound (or <25 gr) limit refers to the weight of the entire aircraft system (airframe, battery and payload) at takeoff.

One limitation with these sUAS is the density of water (i.e., 8.3 pounds/gallon or 3.75 kg/4.5lit). For this reason, most sUAS spray aircraft have tanks that hold less than 3 gallons, which limits the range in a single flight. This is a major advantage over manual and less safe application of shading agents.

The fourth application, scouting or crop monitoring, may be a little further in the future. The challenge with scouting/monitoring of ornamental plants is the diversity of crops produced. For monocultures such as corn, rice, turf and cotton, we are more likely to be able to link a specific plant problem (e.g. nutrient deficiency, insect infestation, water stress, disease) to the output of a sensor (e.g. thermal, multispectral) than for diverse greenhouse crops. In the near future, the mere fact that sUAS alert a farmer that something is wrong could be enough to justify the use of this technology in a greenhouse.

The last suggestion for sUAS use is inventorying. Many researchers, including us, have been working for years on automated ways to obtain inventory information using sUAS. As you can imagine, the most difficult scenario is when plant covers overlap. There are already companies (e.g. Drone Deploy and Agremo) whose products can help growers in row crops to count plants.
Whether the same software can count a variety of greenhouse plants at different stages of production is unclear. Inevitably, we will be able to use sUAS to perform automatic counts of greenhouse crops.
There are certainly other applications (e.g. pollination) and more you can think of, but this list should at least get you started in the right direction.

4.2. Robotic Bees Support Vertical Farms

In vertical farms [43], [52], plants (Fig. 9), are made to grow densely stacked on high shelves rather than in a field with the help of artificial light and artificial intelligence, without human intervention.
Under these conditions (vertical farms), robotic "bees"," such as the new technology, are a very good solution.

Fig 9. Vertical farms and future nano robotic [43], [52].

The modern concept of vertical farming was proposed in 1999 by Dickson Despommier, a professor at Columbia College [43]. It is the design of a kind of skyscraper farm (vertical farm) that could feed 50,000 people.

Vertical farming today faces technological and economic challenges with high start-up costs compared to traditional farms. Vertical farms also have high energy requirements because they use additional light such as LEDs. The world's first commercial vertical farm opened in Singapore in 2012. Robotic bees are not new to vertical farms.
Since the mid-20th century, researchers have been looking for ways to automate agriculture, such as tractors with automatic steering. In the 1980s and 1990s, engineers began tinkering with task-specific devices, such as a robotic melon harvester and tomato-picking robots.
Today, companies are developing autonomous bee robots for various tasks, and some devices can also perform additional tasks such as weeding, spraying pesticides and monitoring diseases.

CONCLUSIONS

Nano drone technology includes ultra-small remote-controlled aircraft that can perform a manz variety of tasks.
They are equipped with advanced sensors and functions such as obstacle avoidance and high-speed maneuverability. Various nano models are capable of taking precise aerial photographs, staying in the air for long periods of time and flying autonomously.
The world of drone technology has taken a huge leap forward with the introduction of nano drones, as some advanced technical solutions, such as nano drones, have a footprint of just 2 x 2 cm.
The technology of these drones is constantly improving, with new features such as face recognition, obstacle avoidance and flight stability being introduced.
These advances have been made possible by the miniaturization of components and the improved efficiency of special electric micromotors and batteries.
One of the safe applications of nano-drones today is the use of greenhouses for operations: safe inspection of greenhouse components; processes of pollination (e.g. the role of RobotBee); application of glass shading agents; crop monitoring/inventory of greenhouses.
Research on the application of nano-drones (especially the RobotBee like insect type) in some areas of agriculture should be continued.

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PREGLED MOGUĆNOSTI PRIMENE NEKIH TEHNOLOGIJA NANO DRONOVA U SAVREMENOJ POLJOPRIVREDI✧

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Abstract. Upotreba različitih tipova dronova u skoro svim sektorima svetske privrede brzo raste, ali upotreba dronova u poljoprivredi je naglo povećana. Prema nekim podacima iz literature, očekuje se porast tržište različitih poljoprivrednih dronova sa 1,2 milijarde dolara ($USD) u 2019. na 5,5 milijardi dolara ($USD) 2024. godine.

Posebno je interesantan fenomen značajno povećanje upotrebe različitih tipova i modela nano dronova u Svetu i mogućnost njihove upotrebe u poljoprivredi (objekti zaštićenog prostora).

Svet tehnologije dronova napravio je ogroman korak napred uvođenjem tenologije nano dronova, gde neka moderna rešenja imaju dimenzije manje od 2x2 cm.

Nano dronovi su ultra-male letelice sa daljinskim upravljanjem, koje su sposobne da obavljaju mnogo različitih zadataka. Opremljeni su ultra naprednim senzorima sa karakteristikama kao što su izbegavanje prepreka i manevrisanja pri velikim brzinama. Cene se kreću od nekoliko stotina do više hiljada US dolara u zavisnosti od modela, karakteristika opreme i specifičnosti namene.

Ovaj rad predstavlja pregled tehnologije primene nekih tipova nano dronova i njihove neophodne opreme i nove primene u staklenicima ili plastenicima (ili slični zatvoreni objekti) kao neke faze koje korisnici staklenika mogu razmotriti za upotrebu, kao što je:

Bezbedna inspekcija nekih strukturnih komponenti staklenika/plastenika; Procesi oprašivanja (npr. uloga RobotBee); Primena smeše za osenčenje stakla na svim stranicama staklenika; Monitoring stanja useva/inventar plastenika ili staklenika.

Ključne reči: *Nano dronovi, mogućnosti primene u plastenicima/staklenicima, proizvodnja povrtarskih kultura, kontrola.*

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