CEAS-GNC-2022-078

CEAS EuroGNC 2022
"Conference on Guidance, Navigation and Control"
3-5 May 2022 @ Technische Universität Berlin, Germany

Autonomous Solar-Powered Docking Station for the Unmanned Quadrotors

Robert Głębocki	WUT Professor, Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, 00-665, Warsaw, Poland. robert.glebocki@pw.edu.pl
Antoni Kopyt	Research and Teaching Assistant Professor, Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, 00-665, Warsaw, Poland. antoni.kopyt@pw.edu.pl
Mariusz Jacewicz	Research and Teaching Assistant, Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, 00-665, Warsaw, Poland. mariusz.jacewicz@pw.edu.pl
Dawid Florczak	Technical assistant, Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, 00-665, Warsaw, Poland. dawid.florczak@pw.edu.pl

ABSTRACT

Renewable energy resources could be used to increase the unmanned quadrotors mission durability. In this paper, the research of the autonomous docking station powered by solar energy is presented. The configuration of the system prototype is described. The station is capable to operate continuously by months without human intervention. Experiments take place to investigate the energy harvesting process for two solar panels configuration: stationary and with dual-axis solar tracker. It was found that to maximize the amount of energy required for the system operation photo-voltaic modules combined with solar tracker should be used instead of fixed solar panels.

Keywords: Quadrotor; Solar Energy; Docking Station

1 Introduction

Quadrotors could be used for a wide area of applications. e.g. surveillance, aerial imaging, agricultural, delivery, and search & rescue. Low cost, small size, vertical take-off/landing capability, and high maneuverability make them very attractive mobile platforms. The important drawback of quadrotors is the limited energy available onboard and high power consumption by the four rotors which results in the short time of mission duration and reduced range. Most often they are equipped with Lithium-Ion rechargeable batteries. A typical battery of the quadrotor must be manually replaced or recharged after several minutes of flight (from 30 min to 50 min) which limits practical applications of such drones. Often there is the necessity of observation of the selected area and data collection for a long time (e.g. several weeks). The manually operated drone makes the realization of such tasks extremely costly and inefficient.

Additionally, in the last years, one of the most important requirements is the autonomous operation capability of the system. The battery swapping or charging process should take place without human involvement. Up to this time, several solutions were proposed to eliminate the abovementioned difficulties. Three groups of solutions were stated by Al-Obaidi et al. [1] and Jawad et al. [2].

First, a battery with a higher capacity might be used. To increase battery performance the size must be also increased. The main drawback of this method is the mass increment of the drone. In this way, the useful payload is also reduced and drone performance (e.g. maneuverability) might be degraded significantly. Also, the large battery requires a long charging time.

Second, the battery might be replaced automatically by the fully charged one. Barrett et al. [3] presented the autonomous battery replacement system based on the ground mobile platform. The replacement system could be mechanically complex. Often, using “cold” swapping methods, a complete shutdown of drone onboard subsystems is required during the replacing operation. “Hot” swapping techniques were proposed by Toksoz et al. [4] and then the drone might be powered all the time. Park et al. [5] discussed the battery management system concerning drone delivery applications.

Third, the battery might be recharged automatically. The same battery remains in the drone during consecutive flights but the energy is delivered from some external sources. The charging process might be realized by wires or using wireless technologies. Various wireless techniques that allow increase mission duration were discussed by Lu et al. [6]. Also Junaid et al. proposed a wireless charging system [7]. Smart contact arrays were discussed by Fetisov et al. in [8]. Rohan et al. in [9] presented experimental tests of charging system which is based on wireless power transmission. Campi et al. [10] presented a system based on coils. Wireless drone charging was discussed by Choi et al. in [11]. A hybrid battery charging strategy was proposed by Kim in [12]. The basic difficulty connected with the battery charging approach is quite a long charging time.

Furthermore, the drone onboard resources are too low to store and process the data collected from several missions. To solve the problems the drone might be integrated with the ground-based docking facility [13]. Such stations are not a common solution. Mourgelas et al. in [14] presented a survey of autonomous charging stations. The charging stations could be grouped into two categories: stationary or mobile [15]. A discussion of mobile charging stations was presented by Zhang et al. in [16]. Rameshbhai [17] suggested that to achieve mobility the charging station might be easily integrated with the delivery truck which makes the system very practical.

Some of the landing platforms are commercially available products [18], [19], [20], [21]. Unfortunately, often their usefulness is limited due to the necessity of station charging from the external power source. Ali et al. [22] addressed this problem and proposed the usage of a photo voltaic system with storage devices as a source of power for the mobile docking station. An autonomous charging system that adopts solar arrays is presented in [23]. Using solar energy to power the station was also proposed in Zhang et al. [24]. Often, the stations offer only charging capability without the protection of the drone from external factors. Such systems cannot be applied to missions when 24/7 operationality by long periods (weeks or months) is required.

The main contribution of this paper is the concept of an autonomous, weatherproof docking station powered by solar arrays. Such a system allows reducing the cost of exploitation of the drone. No human operator is required to realize the drone mission. A landing station could be placed in areas like forests, mountains, or deserts when there is no possibility to use external human-made power sources. Using renewable energy resources makes the system environmentally friendly and increases the level of autonomy.

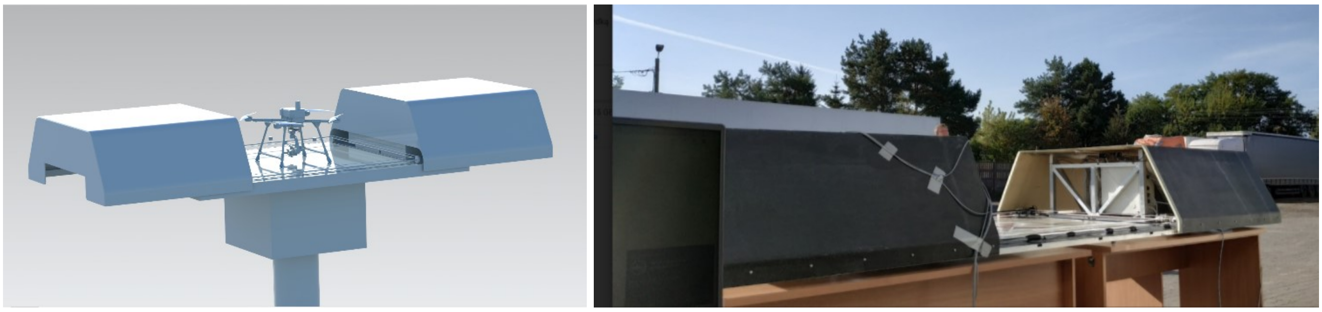
Moreover, the solar system configuration was experimentally tested to compare fixed panel and sola tracker performance. This problem was considered by Garcia et. all [25]. Also, Bazyari et. all [28] discussed the effectiveness of power plants with and without a tracker. Deekshith et. all [27] presented the comparison for two panels configurations but not in the context of drone docking stations.

This manuscript is organized as follows. In section 2 the autonomous docking system is described in detail. System functions and components are shown. In section 3 the results of experiments and obtained results are presented. The paper ends with a summary of the main findings. Finally, further research directions are suggested.

2 Autonomous docking station

2.1 System functionality and components

The system is composed of several subsystems: landing deck, drone positioning mechanism, mounting frame, antennas, solar arrays, batteries, power adapter, and control computer. The landing deck of the docking station is presented in Fig. 1.

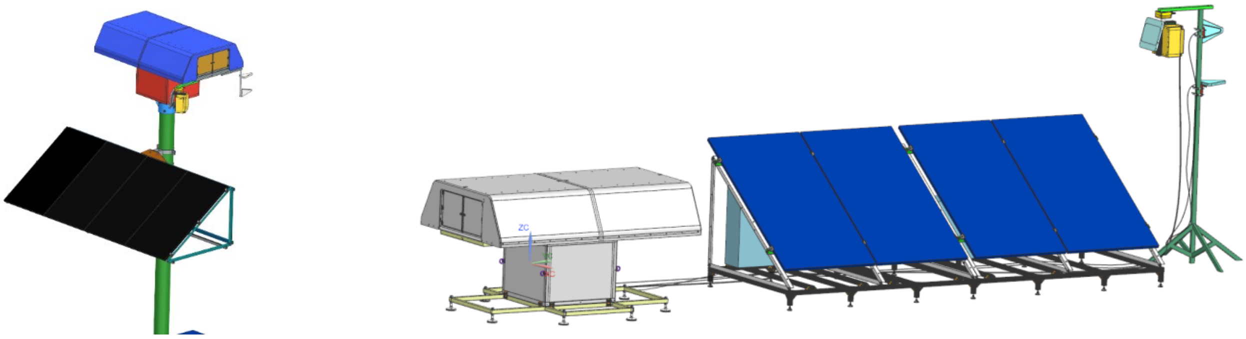


(a) (b)

Fig. 1 Docking station (a) CAD model (b) prototype of the system (configuration with cover opened)

The cover of the station is composed of two movable, glass fiber composite parts. The main function of the cover is to protect the drone during the charging process from environmental factors (e.g. rain, hail, dust, solar radiation) and prevent third-party interventions (e.g. thieves) into the system configuration. The cover is capable to resist a bird impact (equivalent hit energy is equal 100 J). Both parts of the cover are moved using electric actuators. The opening time is less than 20 s. The station could operate completely autonomously for several months in various weather conditions.

The system is developed in two configurations: the first configuration is stationary and the second is mobile. The landing pad and electronic modules in stationary configuration are mounted on the top of the vertical pole (Fig. 2a). The mobile version (Fig. 2b) could be easily deployed manually.



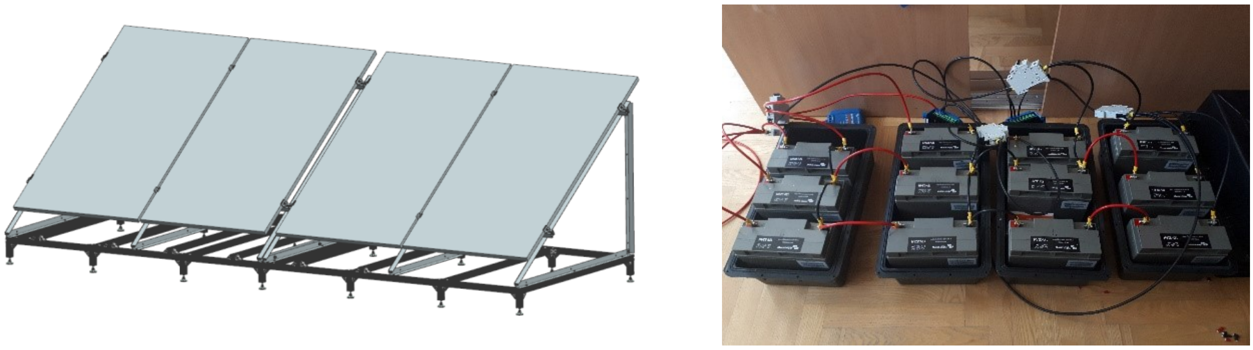
(a) (b)

Fig. 2 (a) Stationary version of the system (CAD model) (b) mobile version

For transportation purposes, the landing deck might be placed on mobile platforms (Fig. 3).

Fig. 3 Docking station mounted on the mobile platform (CAD model)

The system is powered by a set of four solar panels (Fig. 4a). The elevation of panels could be set manually in various seasons of the year. Each of the panels could generate 385 Wp. The harvested energy is stored in 12 batteries with a capacity of 22 Ah each (Fig. 4b) mounted below the landing deck. The voltage of the electric installation is 48 V.



(a) (b)

Fig. 4 (a) A set of solar panels (b) batteries used for energy storage

2.2 Quadrotors integrated with the system

Three commonly used quadrotors could be integrated with the system (Fig. 5): DJI Mavic 2 Pro [25], DJI Phantom 4 [26], and T-Motor 690A [27].

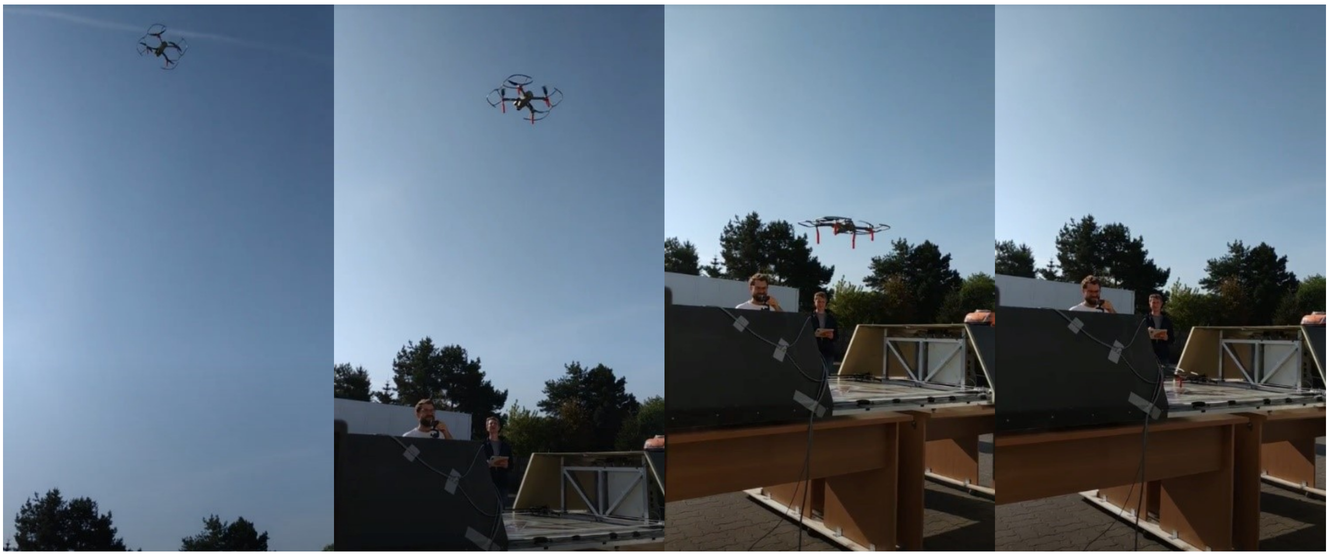
(a) (b) (c)

Fig. 5 Quadrotors that could be integrated with the system: (a) DJI Mavic 2 Pro (b) DJI Phantom 4 (c) T-Motor 690A

Each drone was modified to cooperate with the system interfaces. Electrodes were mounted in the legs of each drone. Quadrotors are equipped with a set of onboard sensors (e.g. Inertial Navigation Units, GPS receivers, magnetometers, cameras). Using various drones allows realizing a variety of tasks. Only one drone could be docked at the same time in the station. During the mission the drone could fly the distance 14.5 km.

2.3 Typical mission overview

The typical mission looks as follows. At first, the mission scenario is programmed remotely by the Internet from the system command center. Next, the cover is opened and the drone with a fully charged onboard battery starts autonomously. Then a data collection process takes place during the flight. Typically, a set of hundreds of high-resolution images are taken by the camera drone during a single flight and stored on the onboard memory card. The size of the set of photos from single flight is most often 7 GB. Then the quadrotor returns to the station. In the last stage of the flight, the drone lands on the landing pad (Fig. 6).



(a) (b) (c) (d)

Fig. 6 Autonomous landing of the drone during flight tests

The charging process requires precision landing functionality (required error smaller than 0.25 m in horizontal plane). Precision drone positioning is difficult with pure Inertial Navigation System (INS) or Global Navigation System (GPS) receiver. High landing accuracy could be achieved using vision systems. After touchdown, the quadrotor is aligned mechanically to ensure the proper contact between drone legs and electrodes mounted in the charging pads (Fig. 7). Such an approach is widely used in drone charging stations [28].

In the middle of the landing pad, there is a marker that is used by the quadrotor optical guidance system in the landing phase. After landing, data collected by the drone are sent to a computer mounted on the station. Then the data (images and flight logs) are sent to the cloud online service (e.g. Google Drive or One Drive) by the data link. The images are processed offline and an orthophoto map of the terrain is created. Simultaneously, the onboard battery charging is realized to prepare the drone for the next mission. The energy is transferred from the stationary batteries to the onboard drone battery. The system could realize up to 4 missions per 10 hours (it was assumed that the data are typically collected during daytime). This means that the maximum charging time should be shorter than 2 h.

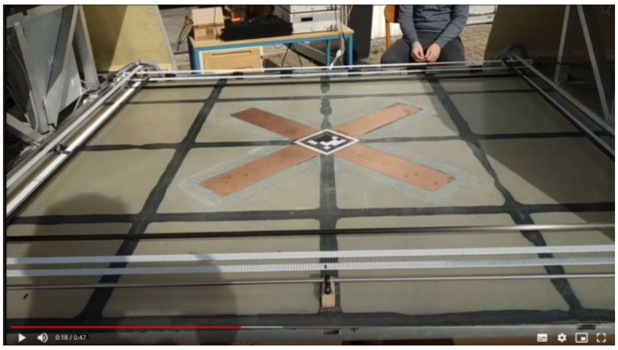


Fig. 7 Landing pad with electrodes

3 Experiments

One of the most important issues is the amount of energy required to operate the station successfully without blackouts. The amount of energy depends on the type of solar tracker, materials of the solar panel and the sunlight intensity [26]. Solar panels could create the necessary power only in sunny conditions. The power system should provide maximum energy at the lowest possible cost. To achieve this goal as much as possible solar radiation should be captured. Experiments were evaluated to investigate the energy harvesting process and optimize the configuration of solar arrays. Two independent configurations of the panels were used in the experiments. The first configuration (mi-2839) is composed of two monocrystalic, stationary solar panels mounted on vertical support (Fig. 8) and pointed directly on the south. The second configuration (mi-5431) is composed from two identical panels but is also equipped in the dual-axis solar tracker. In this way the solar tracker follows the sun path during the day, facing east direction early in the morning, south at noon and west in the late afternoon [29]. The angular panel motion is realized by an electric direct current brush motor and the range of tilt is 150°. Each of the panels is 1840 mm × 1030 mm in size and could generate 385 W of power. Effectiveness of the panel is approximately 20.3%. The goal of the experiments was to compare the energy gained by both configurations and choose the most suitable option. Trials take place in Przasnysz (geographical coordinates 53.00985 N, 20.92974 E, Poland) in October because of relatively short-day duration and low lighting intensity. Measurements were evaluated for several weeks. Hoymiles DTU-Pro WiFi module was used for system status monitoring. Data were acquired every 15 minutes. Then MATLAB R2020b was used for data processing.

Fig. 8 Solar panels used during the measurements

4 Results

The comparison of power for both panels for the selected time range is presented in Fig. 9.

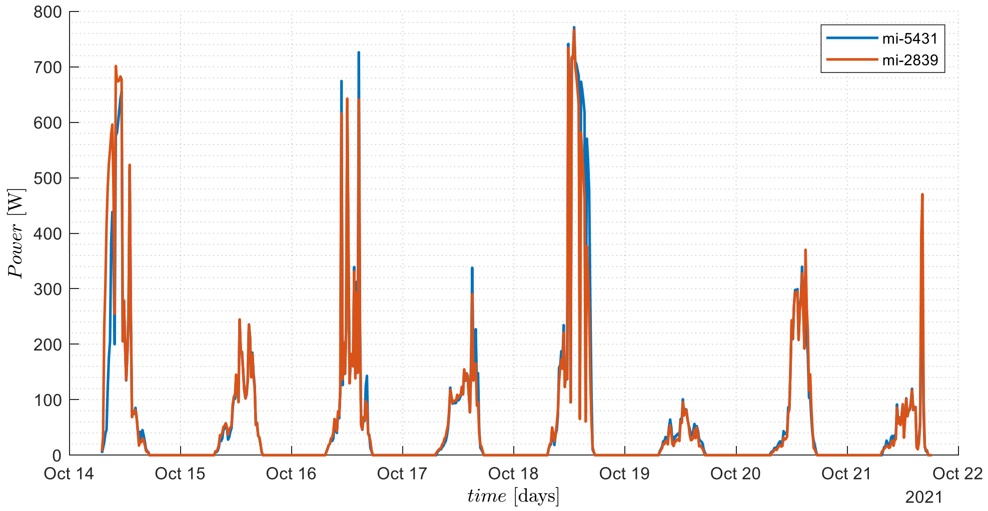


Fig. 9 Power generated by the two solar panels

The maximum amount of power generated by the single panel was 780 W. A strong difference in generated energy between sunny and cloudy days could be observed. Obviously, during nights the power level is 0 W due to lack of sun radiation. The total energy generated during the selected days by the stationary panel was 10887.5250 Wh and by rotating 11129.1125 Wh. Energy from both panels was 22016.6375 Wh. The rotating panel allows gaining more power but the difference was only 241.5875 Wh.

The history of total energy generation (by both panels) on consecutive days of the month was presented in Fig. 10.

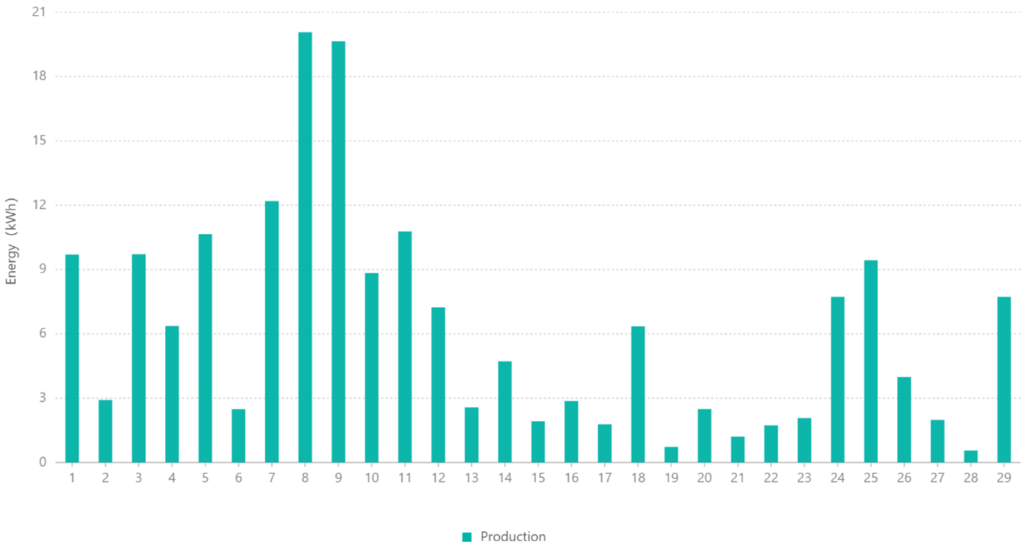


Fig. 10 Energy generation by both panels in October 2021

The maximum amount of energy (20.07 kWh) was generated on 8th October. The least energy was generated on 28th October (only 0.552 kWh) due to cloudy conditions. The relation of energy between the best- and the worst-case scenario is 36.35. It means that energy shortages might occur at some days. The necessary energy must be stored in batteries in previous days to ensure continuous system operability.

The total energy produced during 29 days was 180.46 kWh. From the obtained results it might be concluded that a more suitable option is to use solar trackers to power the docking station.

5 Conclusion

In this paper, a concept of using renewable energy sources in an autonomous ground-based docking system for unmanned quadrotors is presented. The prototype of the station was manufactured and tested. The system is powered by a set of solar arrays which allows operating for several months without human involvement. The docking station could cooperate with three different quadrotors that making the solution flexible.

The second part of contribution presented in this manuscript are tests of solar panels configurations. Experimental results show that using a dual-axis solar tracker is more effective than the stationary array.

Further research could concentrate on flight trials of the drones and measurements of energy consumption by the system in various weather conditions. Other drones might be also integrated with the system. The mechanical design of the structure might be also optimized to reduce the total mass.

Acknowledgments

This research was funded by the National Center of Research and Development (grant number 4/1.1.1/2020 „Renewable energy resources in transport").

The project was realized by the Warsaw University of Technology in Cooperation with GKP Aero Company.

References

[1] M. R. Al-Obaidi, W. Z. Wan Hasan, M. A. Mustafa and A. Norhafiz. Charging Platform of Chess-Pad Configuration for Unmanned Aerial Vehicle (UAV). *Applied Sciences,* vol. 10(23), no. 8365, pp. 1–13, 2020.

[2] A. M. Jawad, H. M. Jawad, R. Nordin, S. K. Gharghan, N. F. Abdullah and M. J. Abu-Alshaeer. Wireless Power Transfer With Magnetic Resonator Coupling and Sleep/Active Strategy for a Drone Charging Station in Smart Agriculture. *IEEE Access,* vol. 7, pp. 139839–139851, 2019.

[3] É. Barrett, M. Reiling, S. Mirhassani, R. Meijering, J. Jager, N. Mimmo, F. Callegati, L. Marconi, R. Carloni and S. Stramigioli. Autonomous Battery Exchange of UAVs with a Mobile Ground Base. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*, Brisbane, QLD, Australia, 21–25 May 2018.

[4] T. Toksoz, J. Redding, M. Michini, B. Michini, J. P. How, M. A. Vavrina and J. Vian. Automated Battery Swap and Recharge to Enable Persistent UAV Missions. In *Infotech@Aerospace 2011*, St. Louis, Missouri, USA, 29–31 March 2011.

[5] S. Park, L. Zhang and S. Chakraborty. Battery Assignment and Scheduling for Drone Delivery Businesses. In *2017 IEEE/ACM International Symposium on Low Power Electronics and Design (ISLPED)*, Taipei, Taiwan, 24–26 July 2017.

[6] M. Lu, M. Bagheri, A. P. James and T. Phung. Wireless Charging Techniques for UAVs: A Review, Reconceptualization, and Extension. *IEEE Access,* vol. 6, pp. 29865–29884, 2018.

[7] A. B. Junaid, A. Konoiko, Y. Zweiri, M. N. Sahinkaya and L. Seneviratne. Autonomous Wireless Self-Charging for Multi-Rotor Unmanned Aerial Vehicles. *Energies,* vol. 10(6), no. 803, pp. 1–14, 2017.

[8] V. Fetisov, O. Dmitriyev, L. Neugodnikova, S. Bersenyov and I. Sakayev. Continuous monitoring of terrestrial objects by means of duty group of multicopters. In *XX IMEKO World Congress Metrology for Green Growth*, Busan, Republic of Korea, 9–14 September 2012.

[9] A. Rohan, M. Rabah, M. Talha and S.-H. Kim. Development of Intelligent Drone Battery Charging System Based on Wireless Power Transmission Using Hill Climbing Algorithm. *Applied System Innovation,* vol. 1(4), no. 44, pp. 1–19, 2018.

[10] T. Campi, S. Cruciani, M. Feliziani and F. Maradei. High efficiency and lightweight wireless charging system for drone batteries. In *2017 AEIT International Annual Conference*, Cagliari, Italy, 20–22 September 2017.

[11] C. H. Choi, H. J. Jang, S. G. Lim, H. C. Lim, S. H. Cho and I. Gaponov. Automatic Wireless Drone Charging Station Creating Essential Environment for Continuous Drone Operation. In *2016 International Conference on Control, Automation and Information Sciences (ICCAIS)*, Ansan, Korea (South), 27–29 October 2016.

[12] S. J. Kim and G. J. Lim. A Hybrid Battery Charging Approach for Drone-Aided Border Surveillance Scheduling. *Drones,* vol. 2(4), no. 38, pp. 1–11, 2018.

[13] J. L. Fendji Kedieng Ebongue, I. Bayaola, C. Thron and A. Förster. Charging Stations placement in Drone Path planning for large space surveillance. In *CARI 2020 - African Conference on Research in Computer Science and Applied Mathematics*, Thies, Senegal, 4–17 October 2020.

[14] C. Mourgelas, S. Kokkinos, A. Milidonis and I. Voyiatzis. Autonomous drone charging stations: A survey. In *PCI 2020: 24th Pan-Hellenic Conference on Informatics*, Athens, Greece, 20–22 November 2020.

[15] K. Yu, A. K. Budhiraja and P. Tokekar. Algorithms for Routing of Unmanned Aerial Vehicles with Mobile Recharging Stations. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*, Brisbane, QLD, Australia, 21–25 May 2018.

[16] P. Zhang, S. Xu, W. Zhang and W. Dong. A Cooperative Aerial Inspection System with Continuable Charging Strategy. In *Proceeding of the IEEE International Conference on Robotics and Biomimetics*, Dali, China, 6–8 December 2019.

[17] P. R. Gabani, U. B. Gala, V. S. Narwane and R. D. Raut. A viability study using conceptual models for last mile drone logistics operations in populated urban cities of India. *IET Collaborative Intelligent Manufacturing,* vol. 3, no. 3, pp. 262–272, 2021.

[18] [Online]. Available: https://www.heishatech.com/dnest-hardware-for-drone-in-a-box-solution/. [Accessed 28 October 2021].

[19] [Online]. Available: https://www.airscort.me/. [Accessed 28 October 2021].

[20] [Online]. Available: https://bssholland.com/products/atlasnest-atlaspro-docking-station/. [Accessed 28 October 2021].

[21] [Online]. Available: http://www.edronic.com/. [Accessed 28 October 2021].

[22] E. Ali, M. Fanni and A. M. Mohamed. Design and task management of a mobile solar station for charging flying drones. In *2020 11th International Conference on Environmental Science and Development (ICESD 2020)*, Barcelona, Spain, 10–12 February 2020.

[23] M. Khonji, M. Alshehhi, C.-M. Tseng and C.-K. Chau. Autonomous Inductive Charging System for Battery-operated Electric Drones. In *Proceedings of the Eighth International Conference on Future Energy Systems*, Shatin Hong Kong, China, 16–19 May 2017.

[24] Y. H. Zhang, L. F. Shi, X. Ruan, Y. J. Yang and Z. Jiang. UAV Autonomous Charging System based on Multi-Information Cooperative Positioning. In *Proceedings of the 2018 7th International Conference on Energy, Environment and Sustainable Development (ICEESD 2018)*, Shenzhen, China, 30–31 March 2018.

[25] Y. Garcia, O. Diaz and C. Agudelo. Performance of a solar PV tracking system on tropic regions. *Energy and Sustainability,* vol. 195, pp. 197–207, 2015.

[26] S. Bazyari, R. Keypour, S. Farhangi, A. Ghaedi and K. Bazyari. A Study on the Effects of Solar Tracking Systems on the Performance of Photovoltaic Power Plants. *Journal of Power and Energy Engineering,* vol. 2, pp. 718–728, 2014.

[27] D. K, D. Aravind, N. H and B. Reddy. Solar tracking system. *International Journal of Scientific & Engineering Research,* vol. 6, no. 9, pp. 994–999, 2015.

[28] "https://www.dji.com/pl/mavic-2/info," [Online]. [Accessed 13 July 2021].

[29] [Online]. Available: https://store.dji.com/pl/shop/phantom-series?from=menu_icon. [Accessed 2021 October 2021].

[30] "T-motor," [Online]. Available: https://store-en.tmotor.com/goods.php?id=831. [Accessed 11 marca 2021].

[31] M. Galimov, R. Fedorenko and A. Klimchik. UAV Positioning Mechanisms in Landing Stations: Classification and Engineering Design Review. *Sensors,* vol. 20(13), no. 3648, 2020.

[32] B. Gupta, N. Sonkar, B. S. Bhalavi and P. J. Edla. Design, Construction and Effectiveness Analysis of Hybrid Automatic Solar Tracking System for Amorphous and Crystalline Solar Cells. *American Journal of Engineering Research (AJER),* vol. 02, no. 10, pp. 221–228, 2013.

[33] A. Edward, T. Dewi and Rusdianasari. The effectiveness of Solar Tracker Use on Solar Panels to The Output of The Generated Electricity Power. In *IOP Conf. Series: Earth and Environmental Science. 6th International Conference on Sustainable Agriculture, Food and Energy*, Manila, The Philippines, 18–21 October 2018.