LogForum

> Scientific Journal of Logistics <

2022, 18 (3), 275-284

http://doi.org/10.17270/J.LOG.2022.754

http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X

ORIGINAL PAPER

THE USE OF DRONES IN MOUNTAIN SEARCH AND RESCUE (GOPR) IN POLAND – POSSIBILITIES AND LIMITATIONS

Roman Domański

Poznan University of Technology, Faculty of Engineering Management, Poznań, **Poland**

ABSTRACT. Background: Distribution using drones is treated as a developmental and promising form of transport in the future – an innovative way of moving about. The literature review showed a lack of a comprehensive and holistic assessment of the phenomenon of the use of drones in mountain search and rescue in Poland, a research gap. The aim of the article is to perform a quantitative and qualitative assessment of this issue, acquiring new knowledge about the basics of phenomena and observable facts (cognitive aspect).
Methods: The subject of the study are drones. The scope of the study covers only the mountain search and rescue in Poland. The entities under study are central branches of Mountain Volunteer Search and Rescue (GOPR). The study used the method of an in-depth direct interview carried out with mountain rescuers – drone pilots in GOPR.
Results: The result of the analysis of the material from interviews is an assessment of the use of drones in search and rescue in Polish mountains: what drones are already used, in which mountain groups, how many are, how often they are used, what rescue tasks they perform, how many drone pilots there are, what competences they have, what opportunities and problems are associated with the operation of drones in mountainous terrain.
Conclusions: Drones are already used in mountain search and rescue by GOPR – mainly for searching for people and monitoring avalanches. At the moment, the scale of the phenomenon is not very impressive. However, drones are treated as a developmental issue in GOPR. In addition to plans to increase the number of drones, GOPR is also considering the introduction of drones into other categories of rescue tasks as well as providing the current fleet with new additional equipment. The main barriers to further proliferation of drones in GOPR are legal, insurance, financial, and behavioral issues.

Keywords: drones, unmanned aerial vehicle (UAV), rescue, mountains, Poland, Mountain Volunteer Search and Rescue (GOPR)

INTRODUCTION

Observing the spectacular use of drones in high mountains (the Himalayas, the Alps), it is only a matter of time before mountain rescuers are equipped with such devices in lower mountains, including the Polish Sudety and Karpaty Mountains. Increasingly better technical parameters of drones coupled with increasingly lower costs of their production and operation are favourable conditions for their further development and proliferation, even in such an extreme environment as mountains. In situations where difficult mountain terrain poses threat to human life and health, drones feature key advantages such as their mobility in space (flexibility of movement) and objectification (possibility of even risking the destruction of a device to save a human being). As can be seen from the long history of mountain accidents, the abilities of mountain rescuers and equipment they use have their limitations. In certain situations, the risk of responding to emergencies is too high. This opens up an option to use drones.

Distribution with the use of drones is seen as a promising form of transport in the future and is part of economic development framework programmes where transport is one of the priorities. Supporting mountain rescuers with drones will contribute to shortening the time of providing help to people injured in the mountains. In some situations, when weather conditions temporarily prevent rescuers from reaching the site where an accident happened, it

Citation: *Domański R., 2022. The use of drones in mountain search and rescue (GOPR) in Poland – possibilities and limitations. LogForum 18 (3), 275-284,* http://doi.org/10.17270/J.LOG.2021.754
Received: 26.08.2022, Accepted: 06.09.2022, on-line: 30.09.2022

may be the only option to provide search and rescue services (transport of medicines, video monitoring of a casualty).

The current introduction of drones in mountain search and rescue in Poland (Internet sources search) takes the form of local pilot programs implemented by individual groups of Mountain Volunteer Search and Rescue (GOPR). According to the author of this article, so far no systematic and thorough scientific research has been carried out on the functioning of rescue drones in the Polish mountains - a research gap. Therefore, the aim of the article is to perform a quantitative and qualitative assessment of this issue – acquiring new knowledge about the basics of phenomena and observable facts (cognitive aspect).

THEORETICAL BACKGROUND

A systematic literature review was carried out in September 2022 on the basis of the Scopus abstract and citation database. The analysis of the literature consisted in searching for selected characteristic words and phrases in three places: title, abstract, and keywords.

In relation to the subject of drones, one selected:

- a total of 80,861 publications (entry "unmanned aerial vehicle" or "uav"),
- of which only 2,161 relate to rescue operations in general,
- including mountain rescue operations – only 52 positions,
- of which only 4 publications concern the territory of Poland.
- The results of the alternative selection are presented as follows:
- a total of 26,813 publications (entry "drone"),
- of which only 881 relate to rescue operations in general,
- including mountain services – only 26 positions,
- with no publication concerning the territory of Poland.

As part of the literature review, only the first result set was considered (higher number of sources, better selection accuracy). In the context of the Polish mountains, the first publication concerns a new method for detecting a person captured in aerial images acquired by an unmanned aerial vehicle (UAV). The UAV images were acquired during the field campaign carried out in the Izerskie Mountains (SW Poland). The method is used in a newly built system that supports search and rescue (SAR) activities [Niedzielski et al., 2017]. The second publication concerns the investigation of the role of clouds in the effectiveness of automated human detection in aerial imagery acquired by unmanned aerial vehicles (UAVs). Data were acquired during a field experiment carried out in the Izerskie Mountains (southwestern Poland). Sensitivity analysis, carried out on the basis of artificially blurred imagery, confirms that reduced image clarity may improve automated human detection [Niedzielski & Jurecka, 2018]. The third publication concerns the investigation of a potential impact of boosting saturation of aerial imagery on the performance of unsupervised human detection algorithms. The study is empirical since it is based on processing photographs taken during a full-year experiment in the Izerskie Mountains (southwestern Poland). We found that saturation boost is an image pre-processing method that may potentially improve the performance of human detection [Jurecka et al., 2019]. The fourth publication presents a report of a search and rescue mission carried out by the Bieszczady Mountain Rescue Service near the village of Cergowa in SE Poland, where a 65-year-old man (who suffered from Alzheimer's disease) was rescued after being detected using the use of SARUAV software. This software uses convolutional neural networks to automatically locate people in close-range nadir aerial images. The presented case study proves that the use of an UAV assisted by SARUAV software can accelerate the search mission [Niedzielski et al., 2021].

In conclusion, the subject of interest of all four publications is the search for lost individuals. The authors of these articles focus mainly on the issues of image processing, including the analysis of external (weather) conditions affecting it. Individual reports should be treated in the category of selective case studies from the area of the Izerskie Mountains and the Bieszczady Mountains – lack of a holistic publication synthesizing the state of facts

regarding the functioning of drones in search and rescue operations in the entire Polish mountains.

As part of the extended treatment of the analysis of the issue-related literature, it was decided to determine what subject matter is addressed in publications concerning mountain search and rescue operations outside Poland. Of the 52 publications, only articles from scientific journals were analyzed (maintaining consistency of source type) – 22 positions. Individual authors undertake the following research points:

- simulation environment for offline path planning of unmanned aerial vehicles on three-dimensional terrains – search and rescue assisting operations over mountains [Oz et al. 2013],
- novel work on autonomously identifying Safe Landing Zones (SLZs) which can be utilised upon occurrence of a safety critical event – mountain search-and-rescue [Patterson, 2014],
- design and verification of a Conflict Detection and Resolution (CD&R) system for manned/unmanned aerial vehicle (UAV) – useful to additional applications to mountain hikers for emergency search and rescue [Lin & Lai, 2015],
- evaluation of the concept and feasibility of using a Remotely Piloted Aircraft (RPA) system to support remote sensing in simulated major incident exercises - simulated exercise: mountain rescue [Abrahamsen, 2015],
- the flight path optimization algorithm, to search and locate lost persons in mountains [Xiang et al., 2018],
- using a drone to locate a mountaineer after he and his climbing partner were separated while summiting Broad Peak in the Karakoram Mountains – drones may become an invaluable tool in search and rescue operations, helping to reduce response time and maintain the safety of responders in many other types of difficult terrain [McRae et al., 2019],
- a novel approach to person detection in UAV aerial images for search and rescue tasks in Mediterranean and Sub-Mediterranean landscapes – better effectiveness than the system currently used by Croatian Mountain Search and Rescue Teams (IPSAR) [Božić-Štulić et al., 2019],
- a dynamic track planning algorithm for disaster detection UAVs – the model was constructed for different terrains in the environment, and the corresponding function model was designed for obstacles such as mountains and peaks [Qin et al., 2019],
- mission planning method of fire fighting and rescue of multi-UAV for multiple fires –
- by dropping fire extinguishing bombs by multiple UAVs [Zhang et al., 2020],
- the optimal allocation of drone base stations in a given geographical region – reducing the time span between sudden cardiac arrest (SCA) and early defibrillation by automated external defibrillators (AED) [Wankmüller et al., 2020],
- several image processing algorithms – important resource in search-and-rescue (SAR) missions - have been used by the Croatian Mountain Search and Rescue (CMRS) [Gotovac et al., 2020],
- the reliability of existing state-of-the-art detectors to simulate rescue scenes – proposing a model that can be used in SAR operations [Sambolek & Ivasic-Kos, 2021],
- the determinants that drive the behavioral intention of mountain rescuers to adopt drones in rescue missions – the relevance of personal and environmental factors for the acceptance of drones [Holzmann et al., 2021],
- evaluation of feasibility of using a rotor-wing unmanned aerial vehicle to support situation assessment in search and rescue operations in the mountains (avalanches) in the mountains of Setesdalen (Hovden) in Norway – a UAV is an effective tool carrier and saves time in rough terrain, it is a safe supplement to human resources in high-risk work environments, like an avalanche [Abrahamsen, 2021],
- a method of search and rescue location based on acoustic wave communication in the blind zone of communication – the search and rescue positioning system has been designed in detail [Yunfeng et al., 2021],

- investigation of the viability of using an aerial drone-repeater system configuration to restore and maintain radio communications between incident command (IC) and deployed rescuers in Southern Utah – this method of restoring radio communication among SAR personnel could drastically improve the ability to assist victims and help mitigate the risks faced by rescuers [McRae et al., 2021],
- the application using a solar powered unmanned aerial vehicle (UAV) to inspect mountain sites for the purpose of safety and rescue – with the maintenance of positive residual energy [Huang & Savkin, 2021],
- a new image segmentation algorithm using the RGB component difference clustering (RGBCDC) - the proposed algorithm shows a better potential for use in uncommon situations, especially for rapid emergency rescue after serious mountain hazards [Liu et al., 2021],
- an overview of the developing epidemiological situation related to the COVID-19 pandemic in mountainous areas - the use of technologies, such as drones, could contribute to an effective and timely emergency response in mountainous and remote settings [Van Veelen et al., 2021],
- widespread practical implementation of a drone still not taking place – rescuers benefit from drone usage, especially in urgent missions such as search and rescue and emergency items delivery, as the technology reduces response times while simultaneously minimizing risk exposure [Wankmüller et al., 2021],
- a convolutional neural network-based model for the detection of humans in aerial images of mountain landscapes acquired by unmanned aerial vehicles (UAVs) used in search and rescue operations – the detection of humans in aerial images based on the EfficientDET architecture and ensemble learning [Dousai & Lonearic, 2022],
- proposal of a three-dimensional path planning algorithm for multi-UAVs based on LSTM-DPPO (long short-term memory-distributed proximal policy optimization) framework – the proposed method can plan the optimal detection path with the minimum energy consumption [Zhang et al., 2022].

In summary, the thematic spectrum of the points is very diverse, although here also the topic of searching the terrain – mainly searching for people - prevails. Individual publications focus on narrow, detailed threads that can be divided into two clear categories: technical issues and organizational issues of working with drones. From the point of view of the complexity of the analysis of the phenomenon (similarity of the subject treatment to this article), two articles are worth noting: the experience of Croatian Mountain Search and Rescue Teams [Božić-Štulić et al., 2019] and the systemic design of the drone network [Wankmüller et al., 2020].

RESEARCH RESULTS

The subject of the study are drones, treated as an innovative way of distribution. The scope of the study covers only the realm of mountain search and rescue, limited only to the mountains in Poland. The entities under study are central branches of Mountain Volunteer Search and Rescue (GOPR). There are only 7 such branches: Karkonosze Group (Jelenia Góra), Sudety Group (Wałbrzych), Beskidy Group (Szczyrk), Podhale Group (Rabka Zdrój), Krynica Group (Krynica Zdrój), Jura Group (Podlesice), Bieszczady Group (Sanok). As part of the study, business trips (delegations) were made to each branch. The study was conducted in the form of an in-depth direct interview with mountain rescuers. The form of direct study was chosen as it primarily enables one to obtain very accurate and reliable information. The approach based on numbers and narratives was adopted: a synergistic co-relationship between quantitative components (hard statistical data) and qualitative components (soft verbal information).

As part of the study, 3 business trips were made (for the sake of organization and time and cost reduction, nearby locations were combined): 1. Szczyrk, Krynica Zdrój and Rabka Zdrój (20-24 June 2022), 2. Sanok and Podlesice (11-15 July 2022), 3. Jelenia Góra and Wałbrzych (18-21 July 2022). A day was planned to be spent in each location to gather data.

13 mountain rescuers, drone pilots - were interviewed. From 1 to 3 mountain rescuers participated in an interview in a given branch, 2 per interview on average. These were only men aged 25 to 55 (average age 44.5 years, median 46 years, mode 50 years).

All GOPR Groups are equipped with drones. Table 1 presents basic quantitative and qualitative data related to drones.

Table 1. Drones in GOPR – basic data

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
number of drones	2	2	3	6	3	2	1
drone model	DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 Enterprise Advanced, Autel Evo II Pro	DJI Phantom 4, DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 (Zoom, Enterprise Dual, Enterprise Advanced) (3 units), DJI Matrice 300 RTK (2 units), Autel Evo II Pro (1 unit)	DJI Phantom 4, DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	DJI Mavic 2 Enterprise Dual, Autel Evo II Pro	Autel Evo II Pro
since when in the Group	2020, 2021	2020, 2021	2016, 2019, 2021	2020, 2021, 2022	2019, 2020, 2021	2020, 2021	2021
area of the Group (km2)	2,160	2,000	4,200	3,800	2,615	3,020	2,400

Source: Author's own compilation.

Based on Table 1, it can be concluded that drones in GOPR are a new and developing topic, tracing its beginning to 2019 (interesting fact: historically drones appeared in the Podhale Group already in 2016). GOPR possesses a total of 19 drones. On average, the majority of GOPR Groups have 2-3 drones at their disposal, with the highest number of drones being in the Bieszczady Group, and the lowest number in the Sudety Group. There are 4 drone models in GOPR: DJI Mavic (8 units), DJI Matrice (2 units), DJI Phantom (2 units), Autel Evo II Pro (the last one in each group, 7 units – the result of a sponsorship scheme in 2021). Most of the drones used by GOPR are light drones (weighing about 1 kilogram), which can reach a maximum service ceiling of about 1,000 meters (in practice, the drones in GOPR fly at heights of 50-100 meters). Under normal stable weather conditions, a GOPR drone flies 20-30 minutes on one charge, covering a distance of 2.5-3.5 kilometers (a need for direct "visibility" of the operator – drone). All GOPR drones are equipped with an ordinary camera and the vast majority of them also have a thermal imaging camera. Additional equipment that drones in GOPR feature (depending on the needs of a given Group) includes: a reflector, a loudspeaker, a strobe diode, and a drop kit. In addition (no longer directly on the drone), there are: spare batteries and software supporting image processing, e.g. SARUAV (https://www.saruav.pl/).

Table 2 presents the possibilities of using drones by GOPR.

Table 2. Drones in GOPR – possibilities of their use

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
kind of operation	searching for people	searching for people	searching for people	searching for people evaluation and monitoring of avalanches, delivery of cargo	searching for people records of dangerous places	searching for people avalanche danger monitoring	searching for people
frequency of use (per year)	6-10	1-5	6-10	10-15	30-40	6-10	1

Source: Author's own compilation.

Based on Table 2, it can be concluded that at the moment drones in GOPR are used primarily to search for people (in each group) - the task of searching the area. The second significant group of tasks comprises monitoring and searching through avalanches, as well as making records of dangerous places (only in certain Groups). Only the Bieszczady Group used drones to transport cargo. Drones were used the most frequently in the Jura and Bieszczady Groups, the least frequently in the Sudety Group. On average, in a given year, a given GOPR Group used drones in operations from 6 to 10 times. Unfortunately, it is impossible to determine the most frequent and least frequent places of use of drones by GOPR due to the fact that accidents are random, they can happen everywhere. Due to the specific character of drones, the preferred areas of their work are open and unforested areas.

Table 3 applies to pilots – mountain rescuers operating drones.

Based on Table 3, it can be concluded that in total in the structures of GOPR there are 58 drone pilots, who are mainly able to fly each drone in their group. The largest number of drone pilots can be found in the Karkonosze and Bieszczady Groups and the lowest in the Podhale and Sudety Groups. The number of pilots (Table 3) is greater than the number of drones (Table 1), indicating the possibility of their effective use at all times. To pilot a drone, one must have appropriate qualifications. It takes a few days (up to a week) to obtain them. It is a cost of PLN 5,000-6,000. However, as in the case of a driving licence, skills are further refined by each pilot in practice.

The cost of purchasing one drone with basic equipment is in the order of PLN 10,000-15,000 (recently there has been a significant increase in the cost of these devices in connection with the war in Ukraine). Additional optional equipment is an expense of PLN 100,000-150,000 thousand (the better the equipment parameters, the higher the price). The main operating costs of a drone include: charging a battery and replacing propellers (low, several hundred zlotys a year) and insurance – both of a drone and pilot (significant, several thousand zlotys per year for one package of a drone plus a pilot).

Table 3. Drones in GOPR – drone pilots and their qualifications

	Beskidy	Krynica	Podhale	Bieszczady	Jura	Karkonosze	Sudety
number of drone pilots	8	5	3	16	5	18	3
substitutability (ability to pilot each drone in a Group)	full	full	full	full	full	partial	partial
number of mountain rescuers in a Group (total)	350	100	200	200	130	160	120
number of professional rescuers in a Group (in the above-mentioned total)	22	15	22	20	15	19	16

Source: Author's own compilation.

The further development (chances) of drone exploration in GOPR rescue operations in the Polish mountains will depend on the following:

- creating an internal systemic program of drone operation as a dedicated section within the framework of GOPR,
- the possibility of obtaining rights for internal certification of drone pilots within the framework of GOPR (a pilot's qualifications should be updated periodically – it is quite expensive), which would allow one to reduce the costs of a license,
- simplifying legal regulations and preferential insurance regulations dedicated to mountain search and rescue (GOPR) using drones,
- spending more time training drone skills as part of the search and rescue service in GOPR,
- the number of accidents in the mountains related, on the one hand, to an increase in the number of tourists, on the other hand, to a variety of activities undertaken (hiking, skiing, cycling, paragliding) – a strong upward trend in recent years,
- technological development of drones with regard to greater speed and accuracy as well as extending the time of using devices (power supply issue),
- changes in the attitude of rescuers and those rescued toward the issue of drones – statistics show that this solution works, so it should be trusted,
- providing financing for the development (new purchases) and maintenance (additional equipment) of the drone fleet in the structures of GOPR.

In rescuers' opinion, in a mountain operation with the use of a drone, the most difficult problematic aspects (limitations) include the following:

- adverse weather conditions (strong wind, high precipitation, dense fog/cloudiness, low temperatures – risk of drone icing),
- inacquaintance with the terrain in which an accident occurred,

- the planning stage of a rescue mission and then its implementation stage (drone and pilot logistics),
- the issue of electric power backing – the need to replace and charge a battery during a rescue operation,
- an element of time pressure and focus – working under stress (pilot's concentration, risk of drone failure),
- aviation law provisions that GOPR must comply with (risk of flight delays pending approval by air traffic controllers),
- exchange of information and data (different standards) between GOPR and other services, e.g., the police if they also participate in a rescue operation.

CONCLUSION, LIMITATIONS AND FURTHER RESEARCH

The study result is a comprehensive and exhaustive quantitative and qualitative assessment of the fleet of rescue drones in the Polish mountains in a geographical cross section (individual mountain groups): what drones are already used, in which mountain groups, how many there are, how often they are used, for what rescue operations, what tasks they perform, how many drone pilots there are, what competences they have, what opportunities and problems are associated with the operation of drones in the mountainous terrain. The results of the study allow identification of similarities and differences between individual GOPR groups. The study results should be treated as pilot categories.

Drones are already used in mountain search and rescue operations by all GOPR Groups, mainly for searching for people and monitoring avalanches. At the moment, the scale of the phenomenon is not very impressive: frequency: most often several times a year. Within a given GOPR Group, there are definitely more drone pilots than devices (flexibility of work), and in most cases, each pilot can operate any drone (mutual substitutability). The issue of drones is treated as a development issue in GOPR. In addition to plans to increase the number of drones, GOPR is also considering the introduction of drones into other categories of rescue tasks as well as providing the current fleet with new additional equipment.

Knowledge about drones in mountain search and rescue operations is much broader than presented in this article – limited only to the Scopus base. From the point of view of up-to-date information, popular science articles in the press and on the Internet are at the forefront. It is planned to review other sources of knowledge in the future in order to obtain a more complete theoretical picture of the phenomenon. In the future, in a few years, it would be advisable to conduct an identical empirical study again to compare the scale of the changes. The entity under study was only GOPR. In the future, it is planned to also extend the research to the Tatra Volunteer Search and Rescue (TOPR), which provides assistance in the highest mountains in Poland.

The author hopes that these study results contribute to the development of science, originality and novelty. The advantages of this article are the following: it relates to developmental, future distribution technology (drone transport), it is considered in the context of a specific, niche research area (mountain search and rescue), it is a socially important topic from the point of view of protecting human health and life (alternative ways of providing help).

ACKNOWLEDGMENTS

This research was funded by the National Science Centre – NCN Poland, under the program MINIATURA 4, grant number: 2020/04/X/HS4/00336.

REFERENCES

Abrahamsen, H.B., 2021, Use of an unmanned aerial vehicle to support situation assessment and decision-making in search and rescue operations in the mountains, Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine, 22 (1), 1-1, https://doi.org/10.1186/1757-7241-22-S1-P16

Abrahamsen, H.B., 2015, A remotely piloted aircraft system in major incident management: Concept and pilot, feasibility study, BMC Emergency Medicine, 15 (1), art. no. 12, 1-12, https://doi.org/10.1186/s12873-015-0036-3

Božić-Štulić, D., Marušić, Ž., Gotovac, S., 2019, Deep Learning Approach in Aerial Imagery for Supporting Land Search and Rescue Missions, International Journal of Computer Vision, 127 (9), 1256-1278, https://doi.org/10.1007/s11263-019-01177-1

Dousai, N.M.K., Lonearic, S., 2022, Detecting Humans in Search and Rescue Operations Based on Ensemble Learning, IEEE Access, 10, 26481-26492, https://doi.org/10.1109/ACCESS.2022.3156903

Gotovac, S., Zelenika, D., Marušić, Ž., Božić-štulić, D., 2020, Visual-based person detection for search-and-rescue with uas: Humans vs. machine learning algorithm, Remote Sensing, 12 (20), art. no. 3295, 1-25, https://doi.org/10.3390/rs12203295

Holzmann, P., Wankmüller, C., Globocnik, D., Schwarz, E.J., 2021, Drones to the rescue? Exploring rescue workers' behavioral intention to adopt drones in mountain rescue missions, International Journal of Physical Distribution and Logistics Management, 51 (4), 381-402, https://doi.org/10.1108/IJPDLM-01-2020-0025

Huang, H., Savkin, A.V., 2021, Path planning for a solar-powered UAV inspecting mountain sites for safety and rescue, Energies, 14 (7), art. no. 1968, 1-19, https://doi.org/10.3390/en14071968

Jurecka, M., Miziński, B., Niedzielski, T., 2019, Impact of boosting saturation on automatic human detection in imagery acquired by unmanned aerial vehicles, Journal of Applied Remote Sensing, 13 (4), art. no. 044525, https://doi.org/10.1117/1.JRS.13.044525

Lin, C.E., Lai, Y.-H., 2015, Quasi-ADS-B based UAV conflict detection and resolution to manned aircraft, Journal of Electrical and Computer Engineering, 2015, art. no. 297859, 1-12, https://doi.org/10.1155/2015/297859

Liu, Y., Liu, S., Xu, J., Wang, Y., Tan, G., Li, D., Fan, B., 2021, A New Clustering Algorithm Toward Building Segmentation From Aerial Images by Utilizing RGB-Component Differences, Earth and Space Science, 8 (8), art. no. e2020EA001571, 1-15, https://doi.org/10.1029/2020EA001571

McRae, J.N., Nielsen, B.M., Gay, C.J., Hunt, A.P., Nigh, A.D., 2021, Utilizing Drones to Restore and Maintain Radio Communication During Search and Rescue Operations, Wilderness and Environmental Medicine, 32 (1), 41-46, https://doi.org/10.1016/j.wem.2020.11.002

McRae, J.N., Gay, C.J., Nielsen, B.M., Hunt, A.P., 2019, Using an Unmanned Aircraft System (Drone) to Conduct a Complex High Altitude Search and Rescue Operation: A Case Study, Wilderness and Environmental Medicine, 30 (3), 287-290, https://doi.org/10.1016/j.wem.2019.03.004

Niedzielski, T., Jurecka, M., Miziński, B., Pawul, W., Motyl, T., 2021, First successful rescue of a lost person using the human detection system: A case study from Beskid Niski (SE Poland), Remote Sensing, 13 (23), art. no. 4903, 1-18, https://doi.org/10.3390/rs13234903

Niedzielski, T., Jurecka, M., 2018, Can Clouds Improve the Performance of Automated Human Detection in Aerial Images?, Pure and Applied Geophysics, 175 (9), 3343-3355, https://doi.org/10.1007/s00024-018-1931-9

Niedzielski, T., Jurecka, M., Stec, M., Wieczorek, M., Miziński, B., 2017, The nested k-means method: A new approach for detecting lost persons in aerial images acquired by unmanned aerial vehicles, Journal of Field Robotics, 34 (8), 1395-1406, https://doi.org/10.1002/rob.21720

Oz, I., Topcuoglu, H.R., Ermis, M., 2013, A meta-heuristic based three-dimensional path planning environment for unmanned aerial vehicles, SIMULATION, 89 (8), 903-920, https://doi.org/10.1177/0037549712456419

Patterson, T., McClean, S., Morrow, P., Parr, G., Luo, C., 2014, Timely autonomous identification of UAV safe landing zones, Image and Vision Computing, 32 (9), 568-578, https://doi.org/10.1016/j.imavis.2014.06.006

Qin, Y., Chen, Y., Qiao, H., Che, Z., Zhang, G., 2019, Design of dynamic track planning algorithm for disaster detection UAV, Hongwai yu Jiguang Gongcheng / Infrared and Laser Engineering, 48 (10), art. no. 1026003, 1-6, https://doi.org/10.3788/IRLA201948.1026003

Sambolek, S., Ivasic-Kos, M., 2021, Automatic person detection in search and rescue operations using deep CNN detectors, IEEE Access, 9, 37905-37922, https://doi.org/10.1109/ACCESS.2021.3063681

Van Veelen, M.J., Voegele, A., Rauch, S., Kaufmann, M., Brugger, H., Strapazzon, G., 2021, Covid-19 pandemic in mountainous areas: Impact, mitigation strategies, and new technologies in search and rescue operations, High Altitude Medicine and Biology, 22 (3), 335-341, https://doi.org/10.1089/ham.2020.0216

Wankmüller, C., Kunovjanek, M., Mayrgündter, S., 2021, Drones in emergency response – evidence from cross-border, multi-disciplinary usability tests, International Journal of Disaster Risk Reduction, 65, art. no. 102567, https://doi.org/10.1016/j.ijdrr.2021.102567

Wankmüller, C., Truden, C., Korzen, C., Hungerländer, P., Kolesnik, E., Reiner, G., 2020, Optimal allocation of defibrillator drones in mountainous regions, OR Spectrum, 42 (3), 785-814, https://doi.org/10.1007/s00291-020-00575-z

Xiang, J., Qing-Yi, H., An-Wen, W., Jun-Song, T., Chun-Yu, L., Chen, F., Ding-Yi, F., 2018, 2-OptACO: An Improvement of Ant Colony Optimization for UAV Path in Disaster Rescue, Journal of Information Science and Engineering, 34 (4), 1063-1077, https://doi.org/10.1109/NaNA.2017.16

Yunfeng, Z., Yang, Y., Yimin, D., Dailiang, Y., Zhoubo, W., 2021, UAV search and rescue positioning method based on sound wave communication, International Journal of Wireless and Mobile Computing, 21 (3), 265-273, https://doi.org/10.1504/IJWMC.2021.120909

Zhang, S., Zhang, M., Shao, J., Pu, J., 2022, Multi-UAVs 3D Path Planning Method Based on Random Strategy Search, Xitong Fangzhen Xuebao / Journal of System Simulation, 34 (6), 1286-1295, https://doi.org/10.16182/j.issn1004731x.joss.21-0112

Zhang, X., Hu, Y., Li, W., Pang, Q., Yuan, G., 2020, Multi-UAV fire fighting mission planning based on improved artificial bee colony algorithm, Zhongguo Guanxing Jishu Xuebao / Journal of Chinese Inertial Technology, 28 (4), 528-536, https://doi.org/10.13695/j.cnki.12-1222/o3.2020.04.018

Roman Domański ORCID ID: https://orcid.org/0000-0001-5861-4978
Poznan University of Technology,
Faculty of Engineering Management,
Institute of Logistics, Poznań, **Poland**
e-mail: roman.domanski@put.poznan.pl