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FUNCTIONAL DESCRIPTION OF A TERRESTRIAL-AERIAL ROBOT TO DETECT AND MARK DANGEROUS AREAS

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There is an urgent need for a quick and effective survey of areas hit by accidents, that result in contamination with chemical, radioactive or explosive materials. Hence the need for mobile robots, which should be able to perform tasks in different environments for a long period of time, so that they can detect hazardous materials, identify their sources and create maps of their distribution. As a result, we can limit the spread of dangerous materials to other areas and reduce their harmful effects on the environment and the health of people. In this paper, we present a functional description of a robot capable of terrestrial-aerial movement in order to inspect areas and mark the contaminated parts. Here, we focus on the following topics: drone basic components, communications between the robot and the workstation, robot positioning, and detection of chemical contamination. During that we present a review of many important contributions in order to show the latest developments and try to explore future research directions.

Keywords: terrestrial-aerial robot, drone, communications, inner-outer loop control, GPS, chemical sensors.

Introduction

Undoubtedly, there are many areas which are at risk due to various human activities, such as landfills, industrial sites, gas companies, nuclear power plants, etc. These areas require constant inspection in order to detect unwanted hazardous emissions. The inspection can be performed by placing a set of appropriate sensors in fixed locations of the areas to be examined, but the use of mobile robots is more effective and economical.

The robot we aim to develop is a device capable of terrestrial-aerial movement in various environments and different weather conditions with the purpose of detecting dangerous materials and marking the high-risk parts of the area. In [1] we have described the various components of this robot and showed, through many diagrams, how these components are connected with each other, where the description is based on the patent in [2]. Through this paper, we aim to perform a functional description of some components of the robot to be developed, as the device can be functionally divided into several components based on the multiple partial functions it can perform.

The paper is organized as follows: In Section 2 we present a comparison between the different types of multirotors (multicopters), as well as a description of their working principle. In Section 3 we present a description of the wireless communication between the robot and the workstation. Then, in

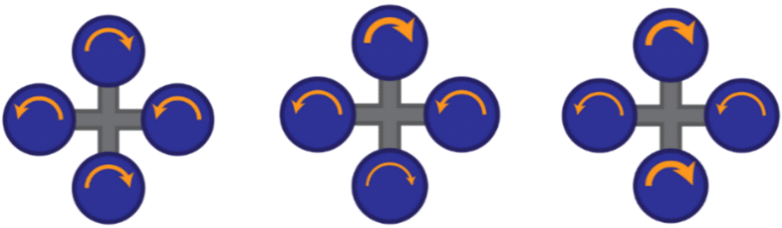
Section 4, we describe how robot positioning is done using global navigation satellite systems. After that, in Section 5, we conduct a review of the chemical sensor technology for aerial robots. Finally, we conclude in Section 6.

Description of the multirotor

The multirotor is an essential component of the robot to be described. It is responsible for providing the robot with the necessary thrust to move whether in the air or on the ground. The most common multirotors are: tricopter (3 rotors), quadcopter (4 rotors), hexacopter (6 rotors), and octocopter (8 rotors).

There are many factors that are taken into account when choosing the most suitable multirotor for an application. With the increase in the number of rotors, the vehicle's strength and ability to lift heavy loads increase, in addition to greater safety and stability. Furthermore, the multirotor's maximum speed and its ability to fly at higher altitudes also increase. The multirotor should be able to fly even when one of its motors breaks down. In this case, hexocopter and octocopter are more desirable [3]. With regard to the considered robot, we have previously shown in [1] that the use of a hexacopter offers many benefits compared to quadcopter. The use of an octocopter can also be a good option, but one must account for its high cost and energy consumption.

In a multirotor, half of the motors rotate clockwise, while the other half rotate counterclockwise. Flight control is based on the variations in the motors' angular velocities. When all the motors have the same speed, the drone can move up or down, or it can hover at the same altitude as shown in Figure (1.a).



(a) (b) (c)

Fig. 1. Performing different movements of a quadcopter: (a) hover: all the motors have the same speed, (b) pitch or roll: one motor has higher speed than the others, (c) yaw: two motors of the same direction have higher speed than the other two motors [20]

The vehicle mainly performs three other types of movements as shown in Figures (1.b) and (1.c), which are: 1) pitch, which means rotation around the side-to-side axis. 2) roll, which means rotation around the front-to-back axis. 3) yaw, which means rotation around the axis perpendicular to the plane of the drone.

Communication

A wireless connection is needed between the drone and the workstation. There are several technologies for implementing it. No technology is best suited for all applications, rather, it depends on the application requirements [4]. Wireless technologies can be divided into two main groups, licensed spectrum technologies and unlicensed spectrum technologies. Examples of licensed spectrum technologies are GPRS, EDGE, UMTS, WAVE, and LTE. Examples of unlicensed spectrum technologies are Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4), and WiFi (IEEE 802.11). Some technologies such as WiMAX (IEEE 802.16) may contain licensed spectrum standards and unlicensed spectrum standards [5]. According to the application requirements, the drone can be equipped with a licensed spectrum technology as in [6, 7], or an unlicensed spectrum technology such as WiFi [3, 4], it can also use cognitive radio (CR) technology [8].

As for the robot of detection and identification of hazardous areas, the channel must be fast enough to transmit data with large sizes such as video, i.e. at a speed higher than 2 Mbps [5]. The appropriate maximum range depends on the size of the area to be examined, which can span several kilometers.

Positioning using global navigation satellite systems

It is very important that the robot be provided with the necessary equipment that allows to determine its position accurately at every moment of time. To achieve this, global navigation satellite systems (GNSS) are often used. The most common system is the global positioning system (GPS), which is owned by the government of the United States. GPS consists of three main segments: space segment, control segment, and user segment.

The system works according to the following principle: The user device receives navigation messages that carry information about the exact location of the satellite and the transmission time of the message. Using the concept of time-difference-of-arrival, the receiver can locate the satellites that fall within its field of view. The receiver must be able to see at least four satellites in order to perform the necessary calculations for accurate positioning [9–11].

Another global navigation system is the Russian GLONASS system. Other systems include the Galileo system and the Beidou system. There are regional systems such as the Indian NavIC system and the Japanese Michibiki system.

User segments can be designed to receive signals sent by satellites of different systems such as GPS and GLONASS together. This allows for improved accuracy and faster position correction. However, global navigation systems suffer from many disadvantages as their signals are greatly affected by obstacles such as high buildings and mountains [12]. Also, these systems are susceptible to jamming as intentional interference can completely disrupt signal reception. Therefore, they are not sufficient on their own for accurate positioning [3].

Detection of chemical contamination

With regard to providing drones with chemical sensors, research works focus on detecting the presence of specific gases in the area to be examined, determining their concentration, distribution and sources. In [13] a review of developments in the field of chemical sensing using airborne robots was conducted for the time period from the beginning of the 1990s to the mid-2000s. Also in [14] a review of developments in gas sensing technologies was conducted, and a classification of the methods used in this technology was made. After that, practical applications began to appear as chemical sensors became commercially available at reasonable prices and sizes that would allow them to be installed on drones [15–18]. In [18] the tunable diode laser absorption spectroscopy (TDLAS) chemical sensor was used, which can remotely measure the concentration of a specific gas. This sensor was installed on a hexacopter in [19]. Based on this reference study, it can be said that future work is directed towards obtaining chemical sensors with smaller size, lighter weight and less energy consumption, in addition to increasing the accuracy of gas distribution mapping and source localization.

Conclusion

In this work, we have described some of the functional components of a robot capable of terrestrial-aerial movement, whose task is to conduct an inspection of different areas, detect the presence of chemical and radioactive contamination, and mark high-risk parts. The focus in this work was on the following topics: the principle of operation of a multirotor, the communication between the drone and the workstation, robot positioning, and detection of chemical contamination. In our future work, we will continue to describe the remaining components of the device.

References

1. Msallam M., Syryamkin V.I. Improving a device for identifying and marking parts of territory with chemical and radio-active contamination // Journal of Physics: Conference Series. 2021. Vol. 1843(1). doi: 10.1088/1742-6596/1843/1/012013.
2. Gutsul V.I., Syryamkin V.I., Ilyichev V.N. et al. Patent for invention of the Russian Federation No. 2661295, 2018. [in Russian]
3. Fogelberg J. Navigation and autonomous control of a hexacopter in indoor environments // LUP Student Papers. 2013. URL http://lup.lub.lu.se/student-papers/record/4359940.
4. Drone networks: communications, coordination, and sensing / Yanmaz E., Yahyanejad S., Rinner B., et al // Ad Hoc Networks. 2017. Vol. 68. doi: 10.1016/j.adhoc.2017.09.001.

5. Hayat S., Yanmaz E., Muzaffar R. Survey on unmanned aerial vehicle networks for civil applications: a communications viewpoint // IEEE Communications Surveys & Tutorials. 2016. Vol. 18(4). P. 2624–2661. doi: 10.1109/COMST.2016.2560343.
6. Gas-drone: portable gas sensing system on UAVs for gas leakage localization / Rossi M., Brunelli D., Adami A. et al. // Sensors. 2014. IEEE. Valencia. Spain. P. 1431-1434. doi: 10.1109/ICSENS.2014.6985282.
7. Gallego V., Rossi M., Brunelli D. Unmanned aerial gas leakage localization and mapping using microdrones // 2015 IEEE Sensors Applications Symposium (SAS). Zadar, Croatia. 2015. P. 1–6. doi: 10.1109/SAS.2015.7133629.
8. A survey of game theory in unmanned aerial vehicles communications / Mkiramweni M.E., Yang C., Li J. et al. // IEEE Communications Surveys & Tutorials. 2019. Vol. 21(4). – P. 3386–3416. doi: 10.1109/COMST.2019.2919613.
9. Jules G.M. The Global Positioning System // IEEE Transactions on Microwave Theory and Techniques. 2002. Vol. 50(3). doi: 0018-9480/02$17.00.
10. Dziadczyk E., Zabierowski W., Napieralski A. Satellite navigation system GPS // CADSM'2007, Polyana, Ukraine. 2007.
11. Global positioning system wide area augmentation system (WAAS) performance standard. 2008. URL: https://www.gps.gov/technical/ps/2008-WAAS-performance-standard.pdf.
12. Indoor drone application with acoustic localization / Demircali A.A., Balban E., Yilmaz A. et al. // 6th International Symposium on Electrical and Electronics Engineering (ISEEE). Galati, Romania. 2019. P. 1–5. doi: 10.1109/ISEEE48094.2019.9136143.
13. Lilienthal A.J., Loutfi A., Duckett T. Airborne chemical sensing with mobile robots // Sensors (Basel). 2006. Vol. 6(11). – P. 1616–1678.
14. A survey on gas sensing technology / Liu X., Cheng S., Liu H. et al. // Sensors (Basel). 2012. Vol. 12(7). P. 9635–9665. doi: 10.3390/s120709635.
15. Ishida H., Wada Y., Matsukura H. Chemical sensing in robotic applications: a review // IEEE Sensors J. 2012. Vol. 12(11). P. 3163–3173. doi: 10.1109/JSEN.2012.2208740.
16. Autonomous gas-sensitive microdrone: wind vector estimation and gas distribution mapping / Neumann P.P., Asadi S., Lilienthal A.J. et al. // IEEE Robotics & Automation Magazine. 2012. Vol. 19(1). P. 50–61. doi: 10.1109/MRA.2012.2184671.
17. Neumann P., Bennetts V., Bartholmai M. Adaptive gas source localization strategies and gas distribution mapping using a gas-sensitive micro-drone. 2012. doi: 10.5162/sensoren2012/P5.4.
18. Towards real-world gas distribution mapping and leak localization using a mobile robot with 3D and remote gas sensing capabilities / Bennetts V., Lilienthal A., Khaliq A. et al. // IEEE International Conference on Robotics and Automation : proceedings. 2013. doi: 10.1109/ICRA.2013.6630893.
19. Bringing mobile robot olfaction to the next dimension – UAV-based remote sensing of gas clouds and source localization / Neumann P.P., Kohlhoff H., Hüllmann D. et al. // IEEE International Conference on Robotics and Automation (ICRA). Singapore. 2017. P. 3910-3916. doi: 10.1109/ICRA.2017.7989450.