МЕТОДИ І СИСТЕМИ ОПТИЧНО-ЕЛЕКТРОННОЇ ТА ЦИФРОВОЇ ОБРОБКИ СИГНАЛІВ

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DRONE POSITIONING SYSTEMS THAT USE DIGITAL CAMERAS

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Unmanned aerial vehicles are very important in everyday life. Their number is increasing every day, as well as the scope of their use. Therefore, it becomes necessary to automate their flight from departure to kindergarten. During automatic flight, drones have certain problems during takeoff, landing and positioning. The problem is that when landing and taking off, it is necessary to ensure high positioning accuracy, which is impossible when using GPS, as it can provide accuracy of only a few meters, which is not enough, and the use of operators is accurate, but this method requires the use of quality cameras with stabilization. These stabilization cameras are very heavy, so the payload of drones is reduced, and they are very expensive (usually more expensive than the drone itself). Also, the use of operators during landing and departure can lead to a catastrophe due to human factors. The task of this article is to create a classification table, analyze landing methods, assess their advantages and disadvantages, give recommendations for the use of the most effective positioning system, as well as the development of new positioning methods.

In the course of work modern, and also the most widespread methods of positioning were considered, the critical analysis of robots is made. As a result, it was proposed to classify drone positioning systems that provide reliable takeoff, landing and delivery of goods using digital cameras. This classification includes all combinations of digital cameras and radiation sources that can be located both on the drone and on the landing or cargo delivery area. Examples are given for each combination proposed in the classification. A thorough analysis of the advantages and disadvantages of each configuration of digital cameras and radiation sources is given. Recommendations for choosing the best drone positioning system are provided. The main disadvantages of these systems are the complexity of algorithms, which makes systems more expensive, as well as complicates the creation of the system, which does not preclude the possibility of making a mistake when creating a system. And this can lead to an accident. All DPSs can be classified on group depending on the number of digital cameras, number and shape of reference light sources, locations of digital cameras and location of the light sources. From the point of reliability and economy the best DPS should include one camera on a drone and a minimal set of reference light sources on the ground. The authors suppose that three reference light sources that specify a triangle is the best choice because it makes possible estimation of the distance and angular coordinates of the landing pad.

Key words: *drone positioning system; digital camera; radiation source; digital image processing; coordinate calculation.*

Introduction

The number of commercially used drones including multi-copters is estimated approximately as several millions. Now they are considered as the perspective transport for goods delivery [1, 2]. The principal advantages of such transport are the following ones: low cost of goods delivery in comparison with any man driving transport, high mobility due to small size and wide range of possible de-signs and carrying capacity [1, 2]. It is known that drone or multi-copter take-off is quite easily procedure – it turns on the motors and flies up to necessary altitude. But drone landing still remains one of the most dangerous stages of flight. That is why many drone manufacturers have been designing the automatic landing systems (ALSs) and drone positioning systems (DPSs). Despite the large number of known ALS and DPS designs, the search for the new principles of drone coordinate measurements remains actual. In many cases, drone landing or drone goods delivery are performed under human control via digital cameras or using Global Positioning System (GPS), a digital compass and an altitude sensor [1, 2]. This human control increases the price of goods delivery and decreases its reliability due to human mistakes. On the other side, GPS has also the limitations: its signal can disappear or can be distorted in some places and some conditions. The drone market has grown since the start of COVID19, for example sales of drones used for agricultural spraying rose by a whopping 135 % [2]. The number of drone deliveries for 2020 and 2021 has also increased. For instance, in 2021, Zipline delivered about 100,000 parcels in just half a year, which is 30 % of the parcels delivered by them [3]. These facts make DPSs very important. That is why investigation of DPSs become actual and interesting. The goal of this paper is the attempt to propose the classification that could help to identify the most perspective DPSs.

Drone positioning systems based on drone camera

We propose the following DPS classification: all DPSs are divided on 2 groups – DPS based on drone cameras and DPS based on ground cameras (Fig. 1). DPS with drone cameras may uses one or several reference light sources, non-illuminated markers or symbol markers (Fig. 2). DPS with ground camera may be more complicated – they can use one or several digital cameras, one or several reference light sources on a drone or a drone without these light sources.

At the beginning we consider the DPS without reference light sources. The most common case – a drone is controlled by human operator during taking off, landing or goods delivery (Fig. 2, a).

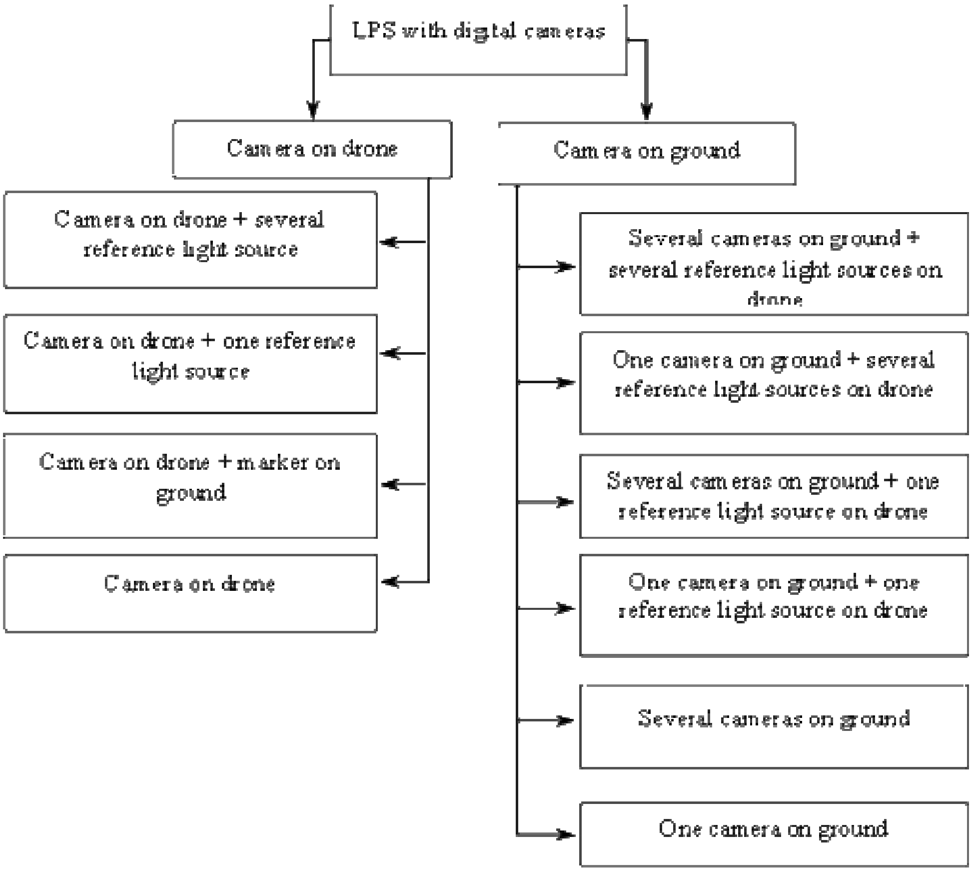

Fig. 1. Classification of drone positioning systems

A human operator see the drone landing pad via a digital camera and video transmitting unit. It helps him to evaluate the drone coordinates relatively the pad. Some digital image software allows automatic tracing a symbol, for example "H", on this pad. The advantage of this technique is high accuracy. The disadvantage is high risk of accidents due to human factors.

In general systems use machine learning to recognize objects. Such objects can be as a specially installed one or more light indicators on the ground, or a QR code, or objects that surround us (houses, trees, people, etc.).

There is a system that can automatically land a drone on a symbol on the ground [4]. Several cameras on the drone record the image of a letter or symbol on the ground, determine the presence of control points. Further, when landing, this is tracked, and the drone corrects the position. Such a system is accurate, but has disadvantages such as high price, does not have the ability to work at night and in bad weather conditions.

DPS FlytDock [5], Accurate Landing of Unmanned Aerial Vehicles [6], Precision Landing system [7], Autonomous Landing of a UAV [8] use camera on drone with QR marker on ground

(Fig. 2, b). These systems allow to land automatically on a platform with a visual marker. This marker can be printed even at home. By the size of the marker, you can find out the drone position relatively to the landing pod (height from which the UAV flies, etc.). The system does not use any addition-al sensors. Its software controller accurately brings the drone to the desired landing site using FlytAPI package and a local network or cloud. The advantages of this technique are high accuracy, doesn't depend on human factors. The disadvantages are does not work at dusk, at night, in bad weather conditions (rain, fog, snow).

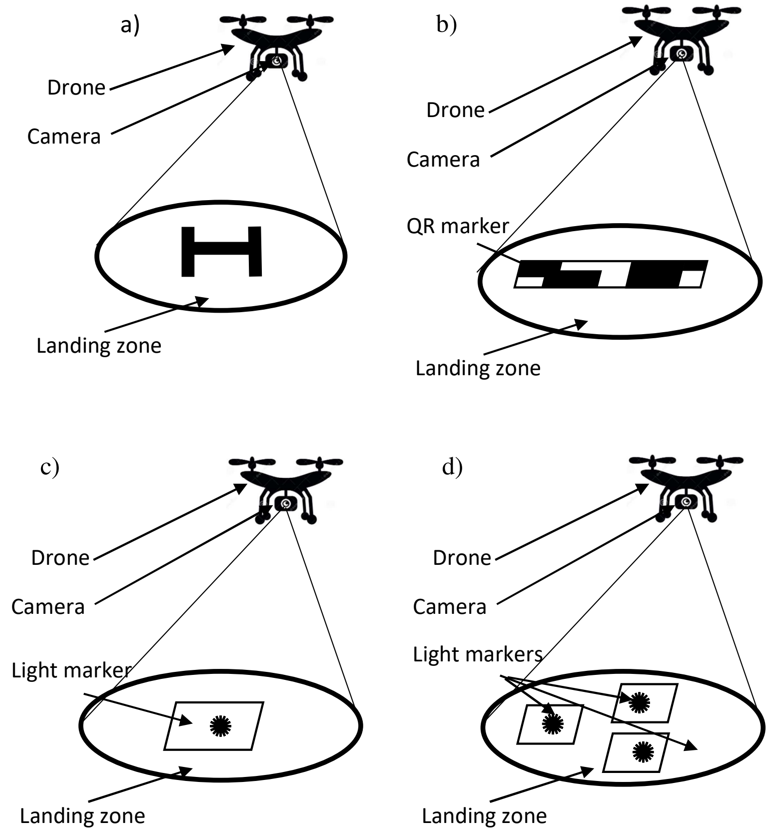

Fig. 2. Drone positioning systems: (a) manual DPS, (b) FlytDock, (c) IR Lock, (d) AAL

DPS IR Lock uses camera on drone with one reference light source. The landing accuracy is with-in 10 cm of the IR signal beacon, which moves less than 1 m/s [9]. The IR-LOCK sensor can be connected directly to the drone via an I2C interface [9]. The IRLOCK sensor must be mounted on the underside of a drone with the camera lens pointing straight down. The sensor board should be oriented so that the white button on the board is facing the front of the vehicle (or, to put it another way, the side closest to the camera lens should be facing the front of the vehicle) [9]. The advantages of this technique are high accuracy, doesn't depend on human factors, can work at dusk, at night. The disadvantages is does not work at bad weather conditions (rain, fog, snow).

The DPS named "High-Precision Landing System for Drones" is presented by FOXTECH company [10]. This system very similar to previous one. It uses camera on drone and one light marker on ground. The drone adjusts its position relative to the landing zone based on the position of the marker image received by the camera. A drone equipped with this system can perform autonomous take-off and landing at very short distances. Landing accuracy is controlled within 10cm. The advantages of this technique are high accuracy, doesn't depend on human factors, can work at dusk, at night. The disadvantages are does not work at bad weather conditions (rain, fog, snow), the system is only compatible with the DJI A3/N3 flight controller.

The simple autonomic drone landing system uses a LEDs pattern and visual markers recognition [11] (Fig. 2, d). A system consisting of three LEDs on the ground that forms an equilateral triangle and a camera on a drone is proposed. With this system, the drone can find out its position relative to the landing area and height. Knowing this information, the drone adjusts its position and lands. The advantages of this technique are very high accuracy, doesn't depend on human factors, can work at dusk, at night. The disadvantages are does not work at bad weather conditions (rain, fog, snow).

The system called "Automatic Aircraft Landing" (AAL) uses camera on drone with several reference light source (Fig. 2, d) [12]. It consists of three infrared laser reference light sources, which are located on the ground, and a digital camera on the drone. The laser light sources are recognized by the digital camera and the drone image processing software can monitor them, determine it's linear and angular coordinates relative to the runway and, based on the data obtained, send signals to the flight controller to adjust the drone trajectory. The advantages of this technique are very high accuracy, doesn't depend on human factors, can work at dusk, at night. The disadvantages are does not work at bad weather conditions (rain, fog, snow).

The proposed system can provide measurement of six navigation parameters, as well as components of linear and angular velocities, which provide automated flight control during landing without the use of additional sensors [12, 13].

Drone positioning systems based on ground camera

Another LPSs when cameras based on ground. In this case we can use one or several cameras on ground and one or several light sources of light on drone (Fig. 3 (a, b, c, d)). Ground based camera receive light signal from drone. Then signal process by computer and send signals to drone for correct its position.

For instance, A Ground-Based Near Infrared Camera Array System [14] concentrated on the vision-based landing navigation. The system, which describe in this article, consist of 3 main parts: 1. An array of infrared cameras and a near infrared laser beam based on a cooperative far-field optical imaging module; 2. Module for calibrating a large-scale array of outdoor cameras; 3. Laser marker and 3D tracking module. (Fig. 3, c).

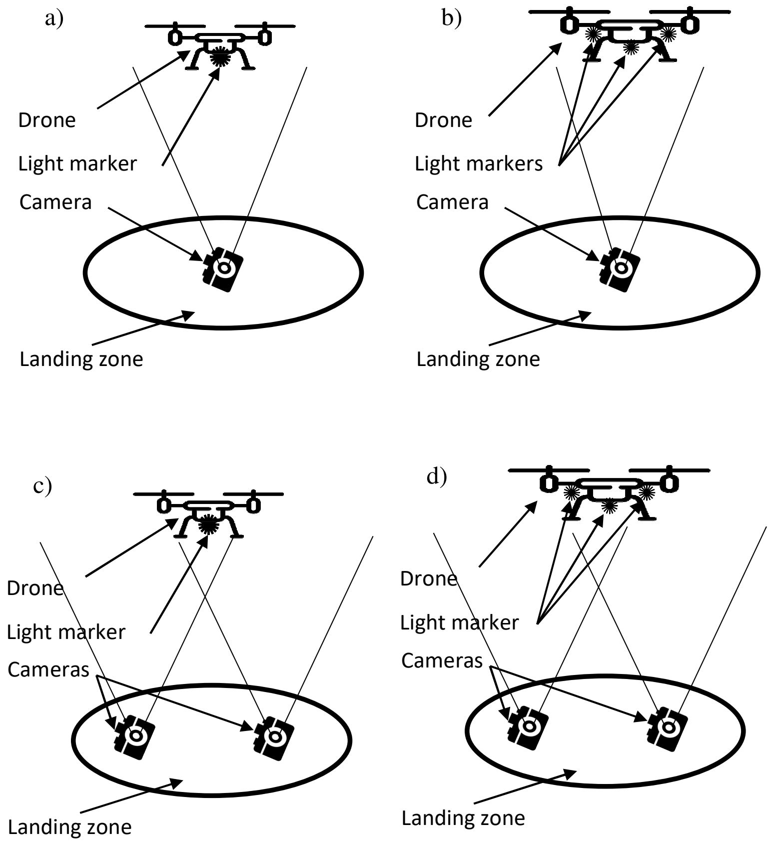

Fig. 3. Camera on ground: (a) one light source on drone, (b) several reference lights sources on drone; Several cameras on (c) one light source on drone, (d) several reference lights sources on drone

With the aim of increase the stability and toughness of the landing system, this system needs to be capable of take away the wrong targets well. Removing false goals is mostly revealed in three aspects [14]:

– Involved in multi-camera co-detection based on the epipolar limitation, false targets can be removed using a symmetric transmission error;
– Involved in localization of the stereo vision of several cameras, false targets can be re-moved due to the limitations of the trace of drone space motion;
– Involved in tracking a target, false targets can be removed by analyzing the directions of motion and speeds of possible targets.

Thus, the aim can be found rightly [14].

The problem of this method is to use cameras. It means that we have image processing. So, this method is slowly and energy consuming.

After analyzing the previous information, we came to the following: the best system, in our opinion, is the system "Automatic Aircraft Landing" [12]. Because it gives high accuracy, but the use of an additional marker complicates the algorithm of this system. We offer a system that uses three sources of radiation on the ground and a camera on the drone. This system will provide high accuracy, while the algorithm is very simple. Three LEDs form a triangle on the landing area. The camera on the drone forms an image of these LEDs. According to the position of the LEDs in the image, the drone evaluates its position relative to the landing area (what is the deviation from the center, height, angle of roll and pitch) and it simplifies coordinate estimation.

Conclusions

All DPSs can be classified on group depending on the number of digital cameras, number and shape of reference light sources, locations of digital cameras and location of the light sources. From the point of reliability and economy the best DPS should include one camera on a drone and a minimal set of reference light sources on the ground. The authors suppose that three reference light sources that specify a triangle is the best choice because it makes possible estimation of the distance and angular coordinates of the landing pad.

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СИСТЕМИ ПОЗИЦІОНУВАННЯ ДЛЯ ДРОНІВ, ЯКІ ВИКОРИСТОВУЮТЬ ЦИФРОВІ КАМЕРИ

Безпілотні летальні апарати дуже важливі в повсякденному житті. Їх кількість збільшується з кожним днем, як і сфери їх використання. Тому стає необхідним автоматизувати їх політ з моменту вильоту до посадки. При автоматичному польоті безпілотники мають певні проблеми при вильоті, посадці та позиціонуванні. Проблема полягає у тому, що при посадці та вильоті необхідно забезпечити високу точність позиціонування, що є неможливим при використанні GPS, оскільки він може забезпечити точність лише в декілька метрів, чого не достатньо, а використання операторів хоч і є точним, але цей метод потребує використання якісних камер зі стабілізацією. Ці камери зі стабілізацією дуже важкі, тому корисне навантаження дронів зменшується, а також вони дуже дорогі (зазвичай дорожче ніж сам дрон). Також, використання операторів при посадці та вильоті може призвести до катастрофи через людський фактор. Задача цієї статті полягає у створенні класифікаційної таблиці, аналізі методів посадки, оцінці їх переваг і недоліків, створенні рекомендацій до використання найбільш ефективної системи позиціонування, а також розробці нових методів позиціонування. В процесі роботи було розглянуто сучасні, а також найбільш розповсюджені методи позиціонування, здійснено критичний аналіз робіт, запропоновано класифікацію систем позиціювання дронів, які забезпечують надійний зліт, посадку та доставку вантажів із застосуванням цифрових камер. Ця класифікація містить усі комбінації цифрових камер та джерел випромінювання, які можуть бути розташовані і на дроні, і на посадковому майданчику чи майданчику для доставки вантажу. Наведено приклади по кожній запропонованій в класифікації комбінації. Наводиться ґрунтовний аналіз переваг та недоліків кожної конфігурації цифрових камер та джерел випромінювання. Надано рекомендації щодо вибору найкращої системи позиціювання дронів. Основними недоліками розглянутих систем є складність алгоритмів, що робить системи дорожчими, а також ускладнює створення системи, що не виключає можливості зробити помилку при створенні системи. А це може призвести до аварії. Автори запропонували та обґрунтували систему, яка застосовує три еталонних джерела випромінювання, які задають трикутник, оскільки це дає можливість оцінити відстань та кутові координати посадкової площадки.

Ключові слова: система позиціонування дрону; цифрова камера; джерело випромінювання; цифрова обробка зображень; обчислення координат.

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АВТОМАТИЗОВАНИЙ РОЗРАХУНОК ОПТИЧНОЇ СИСТЕМИ ПАНКРАТИЧНОГО ПРИЦІЛУ

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Запропоновано здійснювати автоматизований розрахунок багатолінзової оптичної системи панкратичного прицілу за допомогою одного із сучасних алгоритмів глобальної оптимізації, а саме адаптивного методу диференціяльної еволюції Коші. Оптична система, що розглядається, забезпечує видиме збільшення від $4^{\times}$ до $16^{\times}$ та кутове поле зору в просторі параметрів від 5,15° до 1,32°. Вона має діаметр вхідної зіниці 42 мм, віддалення вихідної зіниці в діапазоні 85...90 мм та максимальну довжину системи – 325 мм. Приціл містить 14 лінз в 9-ти компонентах, виготовлених зі скла каталогу CDGM. У всіх станах панкратичної оптичної системи віньєтування променів повністю відсутнє. Для досягнення високої якості зображення, параметричний синтез прицілу здійснювався одночасно для п'яти проміжних станів, що відповідають видимому збільшенню 16^{x}, 13^{x}, 10^{x}, 7^{x} і 4^{x}. Завдяки розробленому спеціалізованому програмному забезпеченню виконано експериментальну перевірку дієздатності такого підходу на прикладі