Indoor Vision Based Guidance System for Autonomous Drone and Control Application

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***Abstract*—Drone is not the only high-tech toy anymore. It has been using an onboard range of applications from civilian to military, including indoor and outdoor operations. Outdoor drone relies on GPS signal to locate its position. It is different from the indoor drone. In this paper, the indoor drone is a review in many aspects also it is current one of must interested topic for researchers who have the main area in autonomous robotic and aerial technology.**

Keywords—Drone, UAV.

I. INTRODUCTION

The word "Drone" represents vehicle which does not require human to control it on board. Drones can be ground, aerial or naval vehicles. Human controls them from a far distance via various kind of control channels, for instance, radio, Wi-Fi, satellite. However, in this paper, we consider drone as Unmanned Aerial Vehicle or UAV, which is flying machine which is remotely controlled.

Nowadays, drones are not only high-tech toys anymore. They are used in a variety range of field from civilian to military. The example of drone for the army is Predator drone of US Army. Predator drone can perform in spy mission or even assassinate mission. For the civilian purpose, UAVs or drones are applied in many activities, such as news reporter, search, and rescue, delivery goods. The popularity and availability have been increasing over the time.

Drones can operate both outdoor and indoor environments. However, they have some different circumstances. The outdoor drones operate with GPS sensor to inform their location on earth, which receives a geo-location signal from GPS satellites. For indoor usage, the GPS signal is blocked from constructions or buildings. So the indoor drone cannot recognize location by GPS. Drones are interested not only in the commercial but also in academic research. Researchers around the world conduct experiments to improve and add more capabilities to drones.

The aim of this paper is to review indoor drones in many aspects namely basic components, controlling, indoor applications and also challenges. The indoor drones are used a lot in research.

This paper is organized as follows. Section II introduces the basic details of drone. Section III explain the current research of indoor drone in many aspects. Section IV gives the example of applications of indoor drones.

II. DRONE FUNDAMENTALS

The major characteristic of drones or UAV for indoor applications should be inexpensive, energy-efficient, and lightweight [1]. The most popular drone in research field is quadrotor drone. The quadrotor drone has 4 brushless motors to drive propellers.

A. Basic components of drone

The building blocks of a drone consists of: (i) frame, which is rigid structure to hold other components (ii) brushless motors, devices that drive propels of drone to lift the frame up from ground and a (iii) Electronic Speed Control (ESC) modules, electronic circuit to control speed of drone (iv) a control board, this unit acts as the brain of drone to monitor and connect other components together (v) an Inertial Navigation System (INS) or Inertial Measurement Unit (IMU) sensor values, this system monitor the navigation value of drone as well as value from attached sensors, such as, velocity, altitude, location, and (vi) a transmitter and receiver module, this module responsible for communication between drone and controller via communication signal [2].

B. Dynamic model of drone

[3] The quadrotor drone fly by the lifting force generated from its propellers, which drive by its motors. The dynamic model of drone respect to the Newton and Euler's laws. To determine the location and attitude of the quadrotor, the drone is considered under six degrees of freedom (6 DOF), which are location of x, y, z, roll, pitch, yaw. Figure 1 shown Euler angel of a drone.

The x, y, z coordinates are reference frame to determine the location of the drone relates to a reference point. The roll, pitch, and yaw are reference axis for flight movement of aircraft. Roll (ϕ) is the axes of rotation start from head to tail of aircraft. Pitch (θ) is the degree when aircraft lift its head up or lower its head down. The main purpose of pitch degree is use for an increase or decrease altitude of aircraft. Yaw (ψ) is the degree that aircraft change the direction of movement, which aircraft head to the left or right.

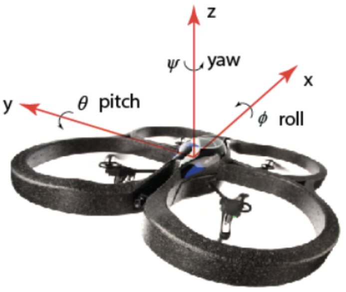

Fig. 1. Reference frame of a drone [4].

The value of 6 units are used to generate control signal to navigate the drone into the desired direction.

C. Classification of drone

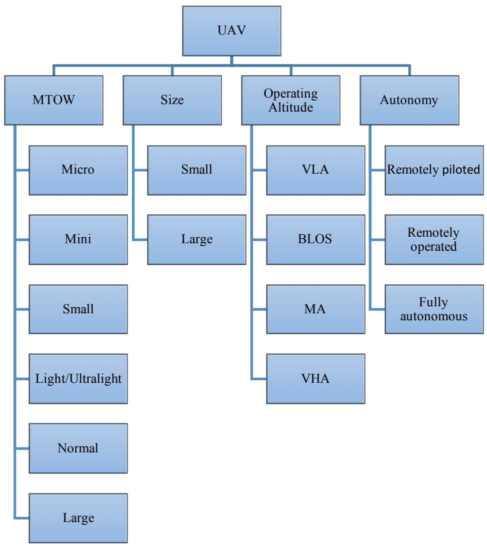

Fig. 2. Classification of UAV.

From [2], UAV can be classified by 4 criterions; mean takeoff weight (MTOW), size, operating altitude, and autonomy. The first criteria are mean takeoff weight. Mean takeoff weight is the maximum weight that UAV is allowed to lift the structure of UAV from ground. We can classify UAV into 6 categories as described in Table 1.

TABLE I.

Mean takeoff weight

Category	MTOW	Name
0	Less than 1 kg	Micro
1	Up to 1 kg	Mini
2	Up to 13.5 kg	Small
3	Up to 242 kg	Light/Ultralight
4	Up to 4332 kg	Large
5	Over to 4332 kg	Large

The second criterion is the physical size of UAV. This criterion is obviously categorized UAV to small and large. The third criterion is operating altitude, which is the height that UAV can fly. The UAV can be classified into 4 categories; Very Low Altitude (VLA), Beyond the Line Of Sight (BLOS), Medium Altitude (MA), and Very High Altitude (VHA).

TABLE II

Operating Altitude

Operating Altitude	Details
VLA	Less than 150 m and operator can see the drone
BLOS	Less than 150 m and operator may not see the drone
MA/VHA	Above 150 m

The final criterion is the level of UAV autonomy. In this criteria, UAV can be categorized into 3 groups; remotely pilot, remotely operated, and full-autonomous. Table III describes their details.

TABLE III

Autonomy

Autonomy	Details
Remotely pilot	Operator controls and monitors status of UAV.
Remotely operated (semiautonomous)	Operator assigns waypoints, objectives, etc., The UAV fly by itself, but the decisions are made by human.
Fully autonomous	Above 150 m

III. CHALLENGE FOR INDOOR DRONE

From criterions in the previous section, an indoor drone can be categorized as micro to small drone, depends on its MTOW. Also, it is very low altitude drone. Because it can operate under 150 m height.

For outdoor operation, the drones use GPS signal to recognize their location. But it is impossible for indoor operation. Because the GPS signal is blocked by the constructions or building such as thick walls, roofs. It is impossible for GPS signal to penetrate such kind of obstacles. We may consider this situation as GPS-denied environment. To control indoor drones, drones have to use another way to recognize their locations.

This section will explore the researches about indoor drone in many aspects.

A. Controlling and Navigation

Controlling is the process that drone receive signal from the controller to move or steer drone to the desired location. The drones receive the control signal via the carrier such as radio, Wi-Fi, or even satellites. We can separate controlling of drone into 2 modes; fully autonomous and non-autonomous (includes remoted piloted and semi-autonomous)

Fully autonomous controlling is drone ability to navigate and maneuver by a computer, without a human to control or interact under normal operation. Non-autonomous controlling is opposite to autonomous. Human has to issues control signal by him/herself. Sometimes, we can consider it as "manually control."

For autonomous control or navigation, drones have to know their location and navigation by themselves. There are various techniques to achieve autonomous mode. For indoor drone, drone can sense the environment by pure vision-based, and vision-based with additional sensors or devices. Drones use data received from their sensors as input to process and generate control signal.

There are 2 standard controller types used for sending the control signal to navigate drone, which is PD and PID. PD and PID controller are closed-loop feedback controller. The output is fed back to compare with the reference point or setting point to produce the error. This error signal is applied to the controller. Then controller drives actuator or plant to generate the output signal, which is the same signal that feedback to compare with the reference point. This process occurs repeatedly until the error is zero.

PD controller is used in [4][16][18]. PD controller consists of 2 control parameters; proportional, and derivative. The aim of using PD controller is to increase the stability of the system by improving control. It can predict the future error of the system response. PD controller has a smaller maximum overshoot due to the faster derivative (D) action compare with other controllers, which is the main advantage of PD controller.

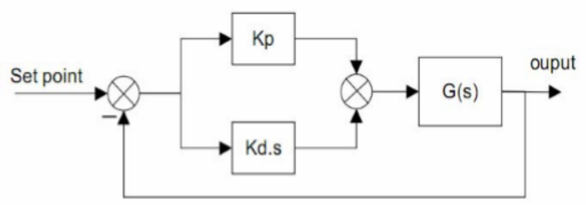

Fig. 3. Block diagram of PD controller

PID controller is used in [7][15]. This type of controller has additional control parameter which is the Integral parameter. PID controller is widely used in industrial control systems. It attempts to correct the error signal by calculating and then produce a corrective action that can adjust the process. A PID controller contains smaller maximum overshoot and no steady state error due to Integral (I) parameter.

The navigation of drone is driving from servo motors to control roll, pitch, and yaw level of drone. The control signal to each servo motors generated from mentioned controllers.

B. *Vision-based drone*

Vision-based autonomous controlling uses image processing techniques like eyes of human. Drones utilize image from built-in camera as input signal then processing it to generate control signal. Normally the image processing occurs on processing unit which is not on board. The pictures or videos captured from drone camera are used as input for localization, object tracking, also object avoidance.

Localization refers to the correctness or exact location of an object, person or other entities using sensory data [12]. As we mentioned earlier, indoor environment cannot use GPS signal. The drones have to use other data to identify their location. The sensory data can be the various forms such as electric, magnetic wave, image, sound, or even light. In term of localization, we can categorize vision-based localization into 2 groups; marker, and non-marker recognition.

Marker recognition technique uses defined symbol pattern for the drone to recognize its location. In [5] use marker recognition technique to keep the distance between drone and human. The drone estimates the distance between marker and drone by calculating the area of recognized marker image. The drone recognition rate is right at the distance of 3 m. [13] adjust marker on grid. Each marker contains detail of location. When drone fly above the marker, drone read the marker as AR (Augmented Reality) code. Then the location is interpreted form AR code.

Non-marker technique use image processing method to create the virtual position from image information. [6] didn't use marker to navigate autonomously. The researcher uses image processing technique, which is MLESAC to create vanishing point. This point is used as reference point that drone have to reach. Also, Canny edge detection algorithm and a Hough Line transform algorithm are applied to estimate an approaching intersection frame. Then the intersection is use as location to turn drone left or right.

Marker technique is easier to implement than non-marker technique. However, non-marker is more flexible. Moreover, additional techniques can be used to improve localization. [7] set the flight path for drone before take-off. The predefined path is generated from metaheuristic algorithm call simulated annealing. The researcher divides the map into grid then calculate the free path without obstacles. Motion capture system is also used to enhance the accuracy of flight control. [8] use Vicon system to improve correctness of drone flight path to follow the predefine path. Surprisingly, the sound is used as navigation input as well. [9] proposed Doppler effect, acoustic sensing method for a drone's direction on any observer. It is frequency shift from the different velocity of acoustic source and observer. [12] applied the idea of RFID to control drone. The high-resolution Impulse Radio-based Ultra-Wide Band is used. The drones attached with tag. The data from the tag is the 4th additional location data besides x, y, z locations. The real-time video and flight path of the drone can be used with additional sensors to scan indoor areas.

Sometimes, the autonomous controlling is not required. Non-autonomous controlling can be implemented in many ways besides basic controlling. Basic controlling is human use controller such as, rc (radio controller) with joystick, or emulated joypad on tablet.

[10] use 3 different kinds of input signals to control drone. They are gesture, marker, and sound. The researcher implement this control system on Aerostack which separate interface of the

application into Graphic User Interface and Natural User Interface to monitor drone behaviors.

Kinnect is used in research to control drone. Kinnect is motion sensing device developed by Microsoft. It originally used for game. However, it can be applied in many application. [4] [11] proposed Kinnect to control drone by using human gesture. In [4] use whole body to act signal to control drone. [11] combined Kinnect with Fuzzy logic controller.

Object tracking is the method of estimating the motion of an object in frame of video under the requirement that the interested object was recognized in the previous frames [15]. Then drones have to follow the object and keep the object stay within the frame. [15] proposed a computer-vision approach called tracking-learning-detection (TLD) to track any object which chosen by a user. The object appears in the video-stream capturing from the front camera of the drone. Location information of the tracked object is used to guide the drone using the proportional-integral-derivative (PID) controller. [16] proposed object tracking using image transformation. Image was changed from RGB to HSV, Hue, Saturation, Value. Then from HSV transform to binary image. The drone used binary image to locate the object and track it.

Obstacle avoidance is one major feature that autonomous drone should capable. Drones may avoid objects or structures that thwart the flight path to reach the destination safely. [17] proposed computation the distance among the UAV and the obstacles, which change their position dynamically, and then to choose the closest one. When a collision risk is discovered, the algorithm creates the escape points. This research use RGB-D camera as a additional sensor for drone. [18] [19] use technique called Potential Field Method to create predefined flight plane for a drone. This method calculates path of flight including avoidance path in complex environment.

C. Power

One advantage of indoor drone is not only light-weight also energy efficient. However, it is not efficient enough. There is a limitation which is the operation time of drone is short. For example, AR.Drone and Bebop Drone have the flight time around 8 – 11 minutes. One way is to invent new kind of battery. But some researcher creates platform to change battery automatically. [20] developed an automatic battery replacement mechanism that allows UAVs to fly continuously without manual battery replacement. [21] designed the drone with on-board solution, based on artificial vision. The developed system can autonomously take off, navigate and land, recharging its battery by using a dedicated landing platform.

IV. Indoor Drone Application

There is a lot of application of indoor drones. In this section, we will introduce some of the application of using the indoor drone.

The indoor drone can be used in search and rescue mission. After disaster occurs, there are some area that cannot reach by men including hazardous environment such as, dangerous chemical, high temperature. We can use drone in this kind of mission to search for survivors or even locate the source of problems [1].

We can apply drones for indoor entertainment. There is national competition for indoor racing drones in London. The modified drones can have speed more than 40 km/h [22]. In filming, drone can be used to capture cinematic scene by assign flight path corresponding to requirement of director [23].

V. Conclusion

Drones involve our life both directly and indirectly. In addition, drone will have impact to our society soon. This paper reviews the basic and current research about drones in many aspects. The example of indoor drones is presented. This could give idea for readers who interested in drones and continue their research in the future.

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