A drone detection with aircraft classification based on a camera array

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Abstract. In recent years, because of the rapid popularity of drones, many people have begun to operate drones, bringing a range of security issues to sensitive areas such as airports and military locus. It is one of the important ways to solve these problems by realizing fine-grained classification and providing the fast and accurate detection of different models of drone. The main challenges of fine-grained classification are that: (1) there are various types of drones, and the models are more complex and diverse. (2) the recognition test is fast and accurate, in addition, the existing methods are not efficient. In this paper, we propose a fine-grained drone detection system based on the high resolution camera array. The system can quickly and accurately recognize the detection of fine grained drone based on hd camera.

1. Introduction

In recent years, small civilian UAV such as quadcopter is developing rapidly. This brings various privacy and public security issues. Airspace monitoring equipment is demand in no-fly zones such as airports or private fields to detect unlawful flying drones in time.

However, the technologies and products for drone detection still need to be improved. Traditional military radar is limited in applicability, for the general civilian areas, visual or other passive detection method is more appropriate than active methods. Considering high market share of quadcopters (known as drones), these types of UAVs should be monitored carefully. There are some unique challenges for small drone detection:

- Consumer-grade drones typically operate at low altitudes, creating complex and variable backgrounds, while objects such as trees, houses occlude the drone very often.
- Regular aircraft such as aeroplane and helicopter may frequently fly over some place such as airport or hospital. Detection method should be able to distinguish different types of aircraft.
- Drones may appear in all directions, and monitoring equipment should be able to monitor multiple directions at the same time.

In this paper, we propose a camera array for drone detection. The equipment contains multiple cameras aiming various directions. Meanwhile, we propose a visual based drone detection method that applies deep learning.

- Hardware Design: We present a massively multiview capture system consisting of high-definition cameras and microphones. The system's capturing, transmission and processing components are all integrated.
Aircraft data set: Based on FGVC-Aircraft, we appended helicopter images and flying drone images. The new data set consists of three types of aircraft.

Drone detection algorithm: We have adopted a real-time drone detection algorithm that applied deep learning. According to our experimental results, this method is able to distinguish the differences between drone and other aircrafts.

The system described in this paper provides unprecedented resolution at a low cost with the promise of facilitating the civilian drone monitoring technology and regulate drone flight behavior.

2. Related Work
In recent years, the performance price ratio of small drones has greatly increased. This expands the application of the drone and exacerbates the privacy and security risks.[1,2,3]

A drone detection method could be based on radar, visual, audio and thermal image. Radar is a traditional active detection method. It has been utilized in military area for several decades.[4,5] However, radar is potentially invasive for the environment.

Among passive detection methods, audio-based detection method has some limitations in urban environment[6,7,8]. The principle of vision-based drone detection is similar to that of pedestrian detection or vehicle detection[9,10]. These methods use machine learning to detect the appearance or motion feature of the object. Visual detection method has good counter-jamming performance, but because of the complex feature of small drone, traditional visual-based detection method is less robust.[11,12,13] The thermal-based detection method is limited by the resolution of the device and can not effectively detect the small drone.

To locate the drone, it is usually necessary to cover the monitoring area with multiple detection devices. Radars often use scanning to achieve this coverage and target location. The camera array has many applications in human motion capture, 3D reconstruction, light field camera and so on. It meets the demands of drone detection after adjusting the layout of cameras.

3. System Framework
We present a camera array system consists of 30 cameras, which is designed to continuously monitor drone throughout the sky ball, as shown in Fig. 1. Our system uses thirty high-definition cameras and three microphones mounted on a hemispherical frame, providing complete coverage of the sky. Our detection algorithm fits such a high image resolution and frame rate.

3.1. Structure design
The physical structure of the system is a set of concentric discs placed in multiple layers. This physical structure is selected because it can take advantage of the space inside. The aluminium alloy frame has a total height of 483 mm and an external ball radius 500 mm. The height and size of each disc take into account a variety of factors, including the FOV and the camera perspective. 3ds Max was utilized to simulate the physical structure.

![Figure 1. The camera array structure.](image_url)
3.2. Devices
Fig. 2 shows the architecture of our system, which currently consists of 30 cameras, 3 microphones, 10 workstation nodes, and some network devices. All devices are integrated as a 1Gbps LAN. We upgraded graphics card to meet the requirement of detection algorithm. A single workstation’s processing performance is high up to 100FPS. So, each workstation controls 3 cameras and that meets requirement of real-time drone detection.

Figure 2. Device framework.

4. Drone Detection with aircraft classification
We adopt deep learning method to realize drone detection. In order to realize real-time identification and detection of multiple types of aircraft, we selected and optimized the basic network structure of YOLO v2[14,15,16]. Target classification is different from the Fast R-CNN and object coordinate, and other process, the processing of our system will realize point-to-point process, the target classification and target detection, and other process together. The process of the whole algorithm is shown in Fig. 3.

First, we split the image into cells, and each cell is responsible for identifying the target that the target center falls into. Each cell predicts that the box and the box contain the object's confidence score. Confidence score represents the confidence that box contains the target. Each box contains the central coordinates, and the width and height of box, and confidence, as well each cell predicts the probability of a class of target. Each box can be multiplied by the class probability and confidence to get the grade of the category, which will eventually effect the detection result.
To the data set, we approximately collected 30,000 images. The dataset contains images of aeroplane, helicopter and drone. All images are resized to fit the network. The dataset is manually labelled. Meanwhile, we optimized the original network structure and parameters to meet the requirements of real-time drone detection. Currently, we only distinguish three different types of aircraft. In the future, the identification algorithm can be further optimized to achieve fine-grained classification.

5. Result

5.1. Dataset
As mentioned above, we built a dataset containing multiple types of aircraft, as show in Fig. 4. The data set includes fixed-wing aircraft, helicopters and consumer drones. The image of the aeroplane comes from the FGVC-aircraft data set, which contains 10,000 images of 100 different aeroplane models. The helicopter images are all collected manually from the Internet. Part of the consumer drone's image comes from Internet's, while the rest images were extracted from the captured video.

5.2. Drone identification
In our experiment, the images from dataset were randomly divided into training set and test set. The test set for each experiment included 300 images of drones, 100 helicopter images and 100 images of fixed-wing aircraft, the rest of which were used as training sets. The results of repeated experiments are shown in Table 1. The detection result of the target object in the image is shown in Fig. 5.

In the results, the drone detection accuracy is low. We suspect that the accuracy of the identification is affected by the large difference in the image used in the drone data set. However, the accuracy rate of all aircraft recognition has reached a high level, which is not easy to lead to false detection, and is sufficient to achieve the target detection in the large number of image sequences generated in the camera array.

6. Conclusion
We have found that deep learning can be used to detect drones quickly and accurately. Therefore, we have developed the system of fine-grained detection drone based on camera array, which can quickly and accurately realize the fine-grained classification of drone. At the same time, we propose to use the deep network structure model to identify the drone in the detection scene in real time. In our experiment, the accuracy rate of this method is very high. In addition, we also collected 30,000 data sets of three models.
In the future work, we will improve the system from two aspects. First, we will expand the variety and quantity of data sets to realize the identification and detection of more models. Secondly, we will realize the steady tracking of drone.

**Table 1.** The result of three types of aircraft detection

| Aircraft       | Accuracy | Precision |
|----------------|----------|-----------|
| Drone          | 0.5213   | 1         |
| Helicopter     | 0.9047   | 0.9894    |
| Aeroplane      | 0.9603   | 1         |

From table 1, we found that the drone of the accuracy of only 0.5213, this is because the drone test set from under the background of more complex scenarios, and our scene is more of a training set to clear the background of the hospital, airport, forces and other special places. However, because of our system can recognize the image sequence, so only about 0.5 accuracy can be achieved drone recognition detection, does not violate our results, also can achieve good detection result.
Figure 5. Drone detection with aircraft classification

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