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Night-time Detection of UAVs using Thermal Infrared Camera

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Abstract

With the proliferation of Unmanned Aerial Vehicles (UAVs), a series of safety and security challenges emerged. In recent years there have been numerous safety and security incidents with UAVs which prompted an increase in research of surveillance and interdiction methods tailored for UAVs. Detecting UAVs in flight can become very difficult in some circumstances such as during the night, in low visibility, or in urban environments. Thermal infrared cameras can detect small variations in heat on the level of tens of mK. Electrically powered UAVs do not produce large amounts of heat compared to aircraft powered by fuel combustion. This is because the electric motors are more efficient than combustion engines and because the air around the UAV is rapidly circulated. In this paper we have tested the applicability of a low-cost long-wave infrared sensor for detection of various UAVs in flight.

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Keywords: UAV; thermal infrared; surveillance; detection

1. Introduction

For the past few years there has been a rapid growth in number of registered UAVs on a global market. According to Federal Aviation Administration (FAA) Aerospace Forecast for fiscal years 2017-2037 there are currently over 1.1 million registered UAVs in the United States (US). It is estimated that by the year 2021 number of registered UAVs in the United States (US) will reach 6 million, 75% of which would be model aircraft and hobbyist UAVs which weight more than 250 grams and less than 25 kilograms.

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To cope with expanding traffic and to uphold required level of safety, governments implement regulations to operations of UAVs. In 2012 US government regulated operation of UAVs by publishing *Public Law 112-95 - FAA Modernization and Reform Act of 2012*. Operation of UAVs in Europe has been regulated by the act of European Comission in 2008 with *Regulation (EC) No 216/2008* for UAVs heavier than 150 kilograms, and with national regulations for UAVs lighter than 150 kilograms.

Even though government regulates operations of UAVs, increased number of operations results in higher probability of incidents. Gettinger and Holland, 2015 analyzed sighting reports published by FAA dating from December 17, 2013 to September 12, 2015. In their work, FAA reports are organized in two categories: *Sightings*, incidents in which a pilot or an air traffic controller spotted an UAV flying within or near the flight paths of manned aircraft though not posing an immediate threat or collision, and *Close Encounters*, where a manned aircraft came close enough to an UAV that it met the FAA's definition of a "near mid-air collision" or close enough that there was a possible danger. They have analyzed 921 incident reports and deduced that 35.5% of recorded incidents were *Close Encounters* and that over 90% of all incidents occurred above allowed maximum altitude.

To uphold regulation it is required to develop methods to detect UAVs in predetermined areas. Conventional methods of UAV detection are via radar, visual detection, or acoustic sensors. Hoffman et al., 2016 and Moses et al., 2011 tested radar detection of UAVs based on differentiating Doppler signatures of various UAVs. Zsedrovits et al., 2011 proved visual detection method by analyzing images gained from camera using image processing algorithms. Shortcoming of visual detection is detection of birds as UAVs. Detection via acoustic sensors relies on sound emission of different units. Case et al., 2008 state that acoustic array, unlike radar detection and visual detection method, does not depend on the size of observed object for detection, but rather on the sound of the engine. Requirement for this kind of detection method is a comprehensive database of UAV sounds.

Beside conventional methods of detection Peacock and Johnstone, 2013 tested possibility of detecting UAVs controlled via wireless devices (such as *Parrot AR Drone*). They have successfully detected and gained control of targeted drone as third party users. Shortage of this detection method is requirement of wireless receiver installed on UAV.

Another unconventional method of UAV detection is thermal imaging. Even though electric motor has much smaller dimensions than turbine or piston engines it still emits traces of heat. By acquiring thermal signature via thermal camera it is possible to detect and, with sufficient database, even identify foreign UAV. Beside detecting the UAV for purpose of air traffic surveillance, thermal imaging can also be used for collision avoidance during night-time operations. To prove that UAV detection using thermal imaging can be used as a viable detection system, this paper presents analysis of thermal images obtained via FLIR Lepton micro thermal camera which was mounted on a Raspberry Pi processing unit. UAVs used for testing were *DJI Phantom 4*, *Parrot AR.drone 2*, and one custom made hexacopter.

In section two of this paper we describe the methods and apparatus used for this test. In section three we show and interpret results of the test, and in the final sectionwe draw conclusions and suggest ideas for future work.

2. Method and Apparatus

2.1. Test track

In order to test the ability of low-cost thermal infrared sensor to detect small airborne UAVs, we flew three UAVs of different sizes and configurations over a 100 m long test track (Figure 1). The goal was to determine at what distance the UAVs could be detected without trying to identify them. UAVs were flown at approximately 10 m above ground level and at a steady velocity of around 2 m/s. The test was performed on a relatively warm summer night (26 °C) against a clear sky and with no wind. The terrain of the polygon was grassy, without significant thermal sources and without any sources of light. The test was performed more than 2 hours after nautical twilight.

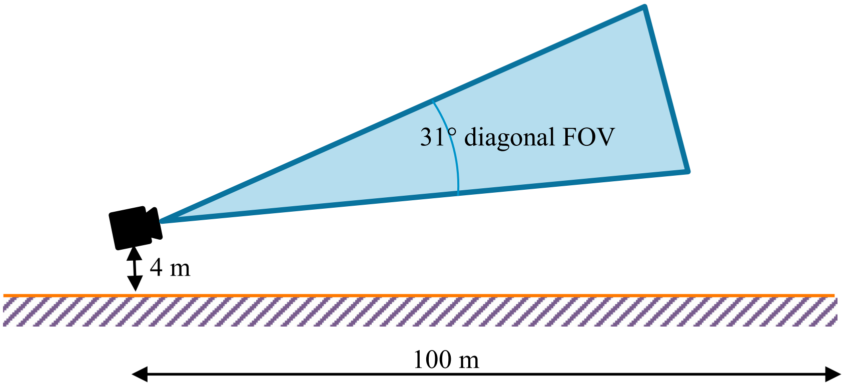

Fig. 1. Test Track

2.2. Thermal sensor

For this test we used a low-cost longwave infrared sensor produced by FLIR, called Lepton. The Lepton is produced in several versions with different field-of-view angles and with optional integral mechanical shutter. The version used in this test had a horizontal FOV of 25°, as opposed to the other version with FOV of 50°. Detailed specifications can be found in Table 1. Since the Lepton was designed for integration with mobile devices, it is very compact with maximum of 11.7 mm in length and weight of only 0.55 g (Table 1).

Table 1. Key FLIR Lepton Specifications (FLIR Lepton Engineering Datasheet, 2016)

Specification	**Description**
Function	Passive thermal imaging module for mobile equipment
Sensor technology	Uncooled VOx microbolometer
Spectral range	Longwave infrared, 8 µm to 14 µm
Array format	80 × 60, progressive scan
Pixel size	17 µm
Effective frame rate	8.6 Hz (exportable)
Thermal sensitivity	<50 mK
Temperature compensation	Automatic. Output image independent of camera temperature
Non-uniformity corrections	Automatic
FOV - horizontal	25°
FOV - diagonal	31°
Depth of field	10 cm to infinity
Lens type	f/1.1 silicon doublet
Solar protection	Integral
Electrical	

Video data interface	Video over SPI
Control port	CCI (I2C-like), CMOS IO Voltage Levels
Input supply voltage (nominal)	2.8 V, 1.2 V, 2.8 V to 3.1 V IO
Power dissipation	Nominally 150 mW at room temperature (operating), 4 mW (standby)
Mechanical	
Package dimensions – socket version	8.5 × 11.7 × 5.6 mm (*w* × *l* × *h*)
Weight	0.55 grams

Fig. 2. FLIR Lepton

Lepton's spectral range is from 8 μm to 14 μm with the best spectral response from 9.5 μm to 12.5 μm (Figure 3). With sensor array consisting of only 80×60 elements, the spatial resolution is very low, with each sensor element covering 0.3125° horizontally. Therefore, at the distance of 100 m, each pixel represented approximately 0.55 m of horizontal distance which is more than the length of some of the UAVs we tested.

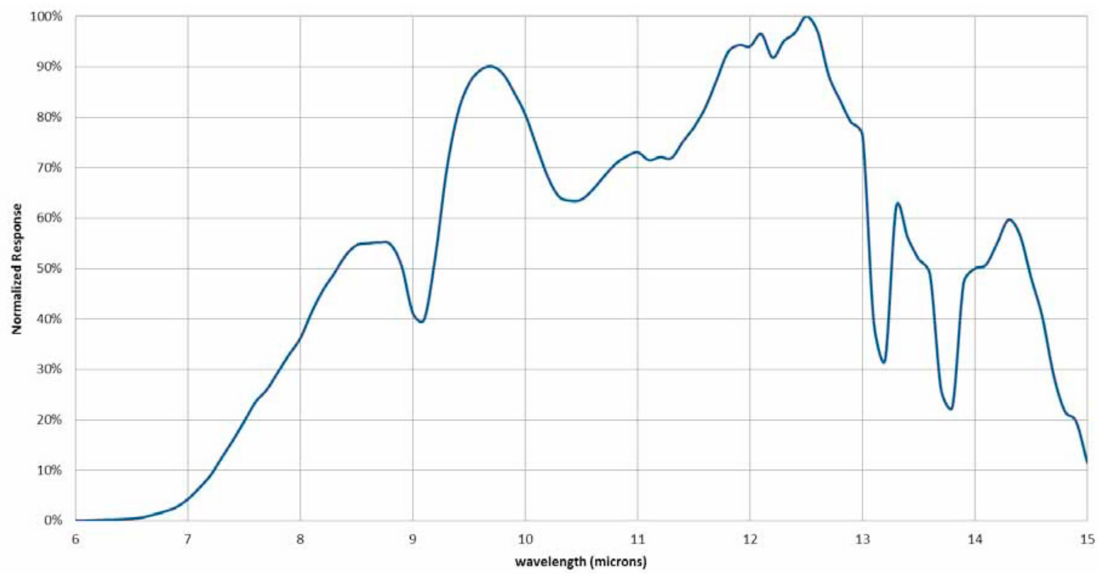

Fig. 3. Lepton Spectral Response (FLIR Lepton Engineering Datasheet, 2016)

The sensor was attached to the breakout board designed to facilitate easier connection of the sensor to the computer. The whole breakout board was then enclosed in a protective case and connected to the Raspberry PI 3 via GPIO pins (Figure 4).

Figure 4. Connection of Lepton to Raspberry Pi 3

2.3. UAVs

Three UAVs were used in this test: *Parrot AR.drone 2*, *DJI Phantom 4*, and a custom built hexacopter. These were selected to represent low-to-medium sized UAV types popular with consumers and professionals, which are sold in hundreds of thousands of units per year, as estimated by Glaser, 2017. All of UAVs tested were of multirotor kind, with 4 (*Parrot* and *Phantom*) or 6 motors (custom built hexacopter). Their specifications are available in Table 2. The *Parrot AR.drone 2* has a detachable protective soft polystyrene hull which was removed during the test because it is intended for indoor use. The Phantom 4 was flown without the gimbal and camera which are part of the standard equipment.

Table 2. Specifications of tested UAVs

	Parrot AR.drone 2	**DJI Phantom 4**	**Hexacopter**
Size (w/o propellers)	36 × 27 × 10 cm	25 × 25 × 19.3 cm	75 × 75 × 37 cm
Weight	380 g	1380 g	4420 g
Number of motors	4	4	6
Motor power	14.5 W	40 W (calculated)	480 W
Motor type	Inrunner (geared)	Outrunner	Outrunner
Battery	LiPo, 3S, 1500 mAh	LiPo, 4S, 5350 mAh	LiPo, 6S, 5000 mAh
Propeller type	2-blade	2-blade	2-blade

3. Results and Discussion

We have determined that batteries are primary heat sources on, while motors and electronic speed controllers (ESC) generate much smaller thermal footprint. Though it was expected that the motors will be primary sources of heat due to the greatest energy consumption, their visibility in thermal spectrum was diminished because they were very well cooled by the rapid air circulation. Some inner components of the motor could reach particularly high temperature but that was not detectable from the outside. Additionally, their cross-section was very small when viewed from the distance. Batteries, on the other hand, are large, bulky, enclosed in the main body of the UAV, receiving only moderate air circulation, and are thusly easily discernible in thermal imaging. If the whole body of the UAV is enclosed, such as with *Parrot AR.drone 2* and *Phantom 4*, the temperature increases even more (Figure 5).

Figure 5. Thermal Image of *DJI Phantom 4*

Each UAV was flown two times along the test track, starting from the sensor and ending at the limit of detection. Limit of detection was reached when human interpreter could not perceive the UAV anymore, which usually happened when the UAV occupied only one pixel in the image. For *Parrot AR.drone 2*, the limit of detection was on average 41 m, for *Phantom 4* 51 m, and for hexacopter it was beyond the 100 m line of the test track. These distances are shorter than the theoretical detection limit calculated from the sensor specifications which are 66 m, 53 m, and 137 m, respectively. One possible cause is the orientation of the UAVs in respect to sensor which was not ideal (longest axis of the UAV should be orthogonal to the direction of sensor axis). The other cause is probably cooling of the external parts of the UAV due to the rapid circulation of air.

Relying on a human interpreter yielded somewhat inconsistent results, however, it is doubtful whether an algorithm could have outperformed him in conditions as noisy as these (Figure 6). It is worth noting that the images in Figure 6 have been upscaled and resampled using the cubic convolution algorithm because they were originally only 80x60 pixels in size which was exceedingly difficult to observe on an HD monitor. The interpreter had favorable starting conditions with UAV being very close to the sensor. This ensured proper identification of the UAV and subsequent easier tracking.

One thing to be noticed is the increased graininess of the images on the right in Figure 6. This is because the sensor automatically adjusts the range of brightness in order to show image features with higher contrast. Because of this the lower part of the images on the right is shown as brighter than the same part of the images on the left. This brighter part does not depict the ground, as it might be interpreted, but a layer of a higher temperature air near the ground. Another parameter which also causes increase in noise when the total brightness range in the scene is very narrow is dynamic brightness range.

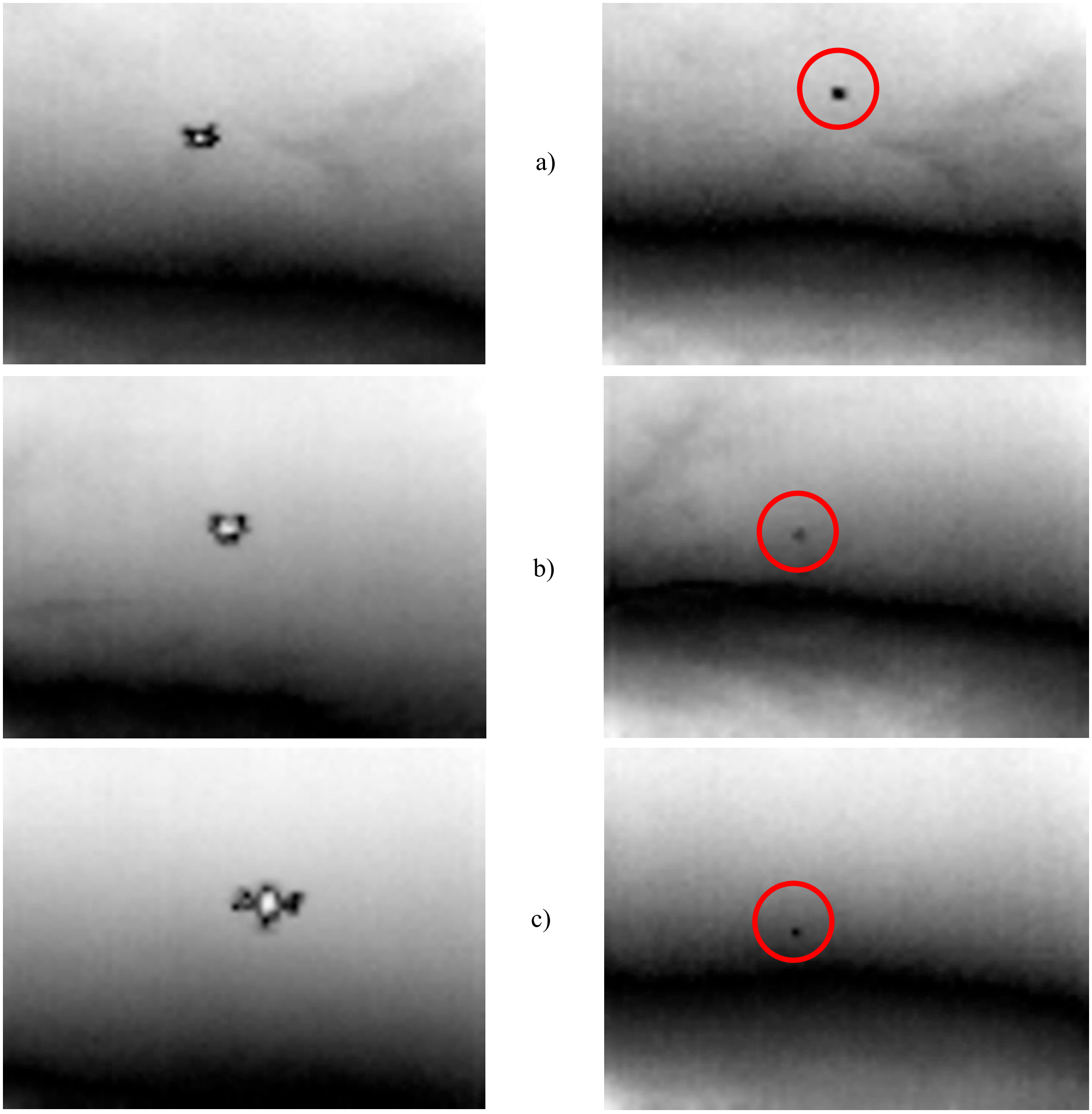

Fig. 6. Upscaled and Resampled Thermal Images of UAVs at 5 m (left) and at Limit of Detection (right) for: a) Parrot AR.drone 2, b) Phantom 4, c) hexacopter.

4. Conclusions

In summary, we performed a small-scale detectability test of commonly used and most prevalent UAV types. Our goal was to determine whether very low-cost and extremely mobile thermal sensor could be used to detect electrically powered multirotor UAVs for the purpose of air traffic surveillance or night-time collision avoidance. To achieve this, we have flown three different UAVs over a test track and recorded their movement with FLIR Lepton infrared long-wave sensor.

We concluded that:

- Small electrically powered multirotor UAVs can be detected with low-cost thermal sensor in some conditions.
- Due to noise, human interpreter was necessary for detection.
- Main source of heat are batteries, not motors.
- Maximum range of detection is shorter than calculations assume.

In future work we will test detectability of UAVs against more diverse backgrounds, including overcast sky and top-down perspective. A more rigorous test of detectability will be performed with UAV appearing from unknown directions. Finally, methods for reducing the heat signature of the UAV will be tested.

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