Intruder Drone Localization Based on 2D Image and Area Expansion Principle for Supporting Military Defence System

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***Abstract*— Improper usage of UAV or drone allows people to conduct strikes on vital properties, such as a military base. The critical capabilities of drone are its movement flexibility and its relatively small size. These abilities make standard radar systems hard to detect drone position. Thus, the counter-attack maneuver towards drone attacks becomes difficult. We propose a framework to establish a radar-like information system that can track the location of any intruder drone attacking a prohibited area. It works by using a UAV tracker equipped with a calibrated 2D camera and GPS sensor. This tracker uses a camera to detect the existence of an intruder, then follow the intruder while sending the intruder's coordinate to a specific server by estimating the intruders' location using both sensors. We describe the mathematical model to estimate the relative position of an intruder drone from our UAV tracker by using a 2D camera, then combine the obtained information with GPS sensor data to pinpoint the coordinate of any intruder. We adopt the Area Expansion Principle as the mathematical model. As a result, we reduce the cost of intruder drone detector system that is useful for defending an area.**

Keywords—UAV, drone, radar-like system, vision-based detection and tracking, distance estimation, area expansion principle.

I. Introduction

The advanced progress of Unmanned Aerial Vehicle (UAV) or drone technology has brought both many good opportunities and risks for humanity. For the good opportunity, UAV technology can help people to observe dangerous areas without risking human life. For daily activities, a UAV can also be used as a package courier or capturing any aerial photographic panorama. Unfortunately, the rapid development of UAV technology has its own potential risks.

The low-cost characteristic of any UAV makes it easy to be possessed by public society. Many people can buy UAV because They are sold legally for commercial use without violating any government regulation. However, the possession of this technology might bring a various impact to society. With cruel intention, the UAV technology could be used as an equipment to conduct surveillance towards private or restricted area[1]. Moreover, it could also be used to carry weapon into an area.

To minimize potential risks resulted from improper use of UAV technology, an anti-UAV attack technology should be developed. There various research that developed these anti-UAV attack systems [2] [3]. One key aspect in the anti-UAV attack that is widely being researched is the technology to detect the incoming intruder drone on a restricted area [4]. Detecting the location of incoming intruder drone is still an open topic, due to the relatively small size of UAVs and its maneuverability. Therefore, it is hard to develop a UAV detector on a wide area. In addition, the UAV can fly on low altitude or even hide behind an object making it difficult for UAV detector to locate their position.

Because of these capabilities, an approach to detect UAV using a single radar-like system that can only detect large size objects such as a commercial plane are not suitable to sense incoming UAV in an area [5]. A single big radar tends to miss the existence of a UAV in its range because UAV can camouflage its appearance and movement by hiding on its surroundings. Because detecting an intruder drone in an area is the first and the most important step on developing a good anti-UAV system, developing the proper framework for this functionality is worth to be done.

This paper is systematized as follows. Part II discuss the problem formulation. In Section III, the proposed framework will be explained with detail steps. Section IV depicts our result and analysis especially on the target positioning method. Finally, section V present our conclusion statement.

II. Problem formulation

To solve the afore mentioned open problem, this paper proposes a new framework to detect the intruder drone in an area using a UAV. This paper tries to fill the gap between current anti-UAV attack system and the capabilities of possible commercial UAV attack maneuver. This paper proposes the concept of UAV as agents to track and follow any intruder drone before sending its location to the command center. The key feature of the proposed framework is it only requires non-sophisticated sensors, which are a calibrated 2D camera and a Global Positioning System (GPS). For the sake of clear naming, this paper calls the UAV agents to detect intruder drone position as *the tracker.*

The proposed method uses a 2D camera to capture the view in front of the tracker containing an intruder drone. By using a developed algorithm that will be explained later, the proposed method can recognize the intruder in an image and estimate the intruder drone's relative-position from a tracker. The proposed method only measures the UAV's position from the center of the image and the UAV pixel size in the image. By using only these two parameters, the proposed method could estimate the real world relative-position of an intruder from a tracker.

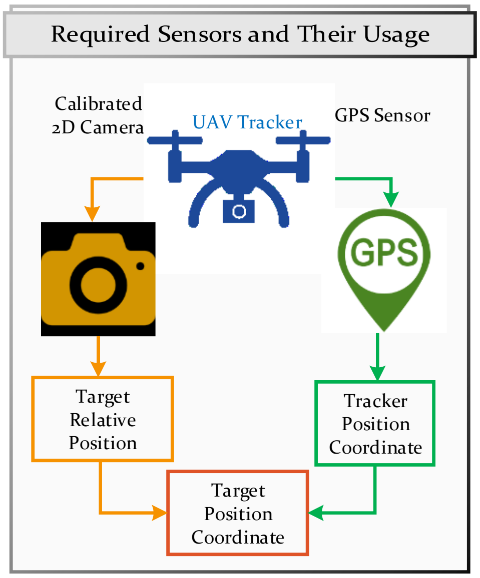

Fig. 1 The Main Concept for Gathering Intruder Location Data

Because each tracker has a GPS sensor, combining a tracker location data with an intruder drone relative-position, a tracker can obtain the intruder's coordinate in the real world. After a tracker has this coordinate, it can send it to the command center as a pinpoint location data of an intruder. Figure 1 shows the main concept used by each tracker to pinpoint an intruder location coordinate. According to Figure 1, the key feature of the proposed method is shown from its simple sensor requirements that every UAV should have, which are a 2D camera and a GPS sensor [6] .

As described earlier, the problem formulation of this paper is developing a framework that is able to detect intruder drone position although they conduct a hiding maneuver. To achieve the goal, the proposed method equips all the trackers with tailing capability. By using our own developed algorithm, each tracker can follow an intruder drone wherever they go by only using data obtained from its 2D camera. By doing this, every intruder drone should be captured in front of the tracker camera, thus, their pinpoint location can always be sent to the command center.

To prevent the loose sight condition, every tracker should maintain the tailing distance. Every tracker should never be too close or too far from its target (intruder drone). In general, the tracker tries to keep the intruder drone in the center of its camera view. Whenever a UAV is not located in the center area of the tracker camera, the tracker will change its direction to face the UAV directly. When an intruder size becomes smaller and below its minimum size in an image, the tracker will move forward to the intruder position. Figure 2 exposes the movement principle used by every tracker when gathering an intruder position. Notice that Figure 2 shows the movement consideration on ideal condition where there is no obstacle between intruder and UAV_ tracker. However, when there is an obstacle between the both UAV, UAV_ tracker can perform obstacle avoidance maneuver towards the last known position of intruder. For this maneuver, there are some alternative methods can be used, for example [7].

The proposed method described in this paper focuses on developing a framework to dynamically detect the location of intruder drone although they try to hide in a specific spot. This paper doesn't explain further about what the system (command center) will do after gathering the intruders' location data, which is beyond this paper's scope. The main objective of this paper is to propose a cost-effective method to gather a radar-like information system that can detect intruder drone data. By doing so, this paper can contribute to the development of the military defense system, especially towards a high-technology based attack.

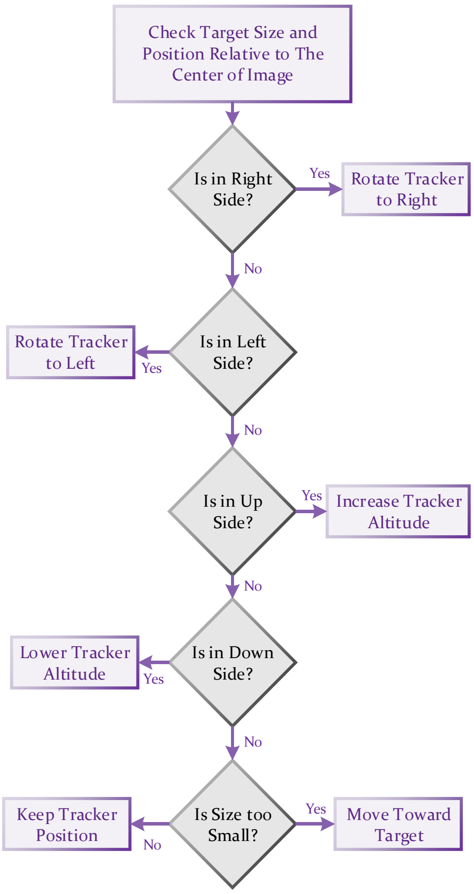

Fig. 2 The Movement Consideration of A UAV tracker

III. PROPOSED FRAMEWORK

The paper proposed concept is a radar system that determines the presence of enemies. The target to be identified is an unmanned aerial vehicle that is not detected by conventional radar. Fig. 3 shows the proposed framework. The proposed system uses UAVs as UAV_tracker. These UAVs will be spread to several areas to look for the presence of the target UAV. Each UAV_tracker identifies the target. After identifying the target, the UAV_tracker follows and tracks the target using a visual-based tracking approach. The UAV_tracker develops a real time visual-based target

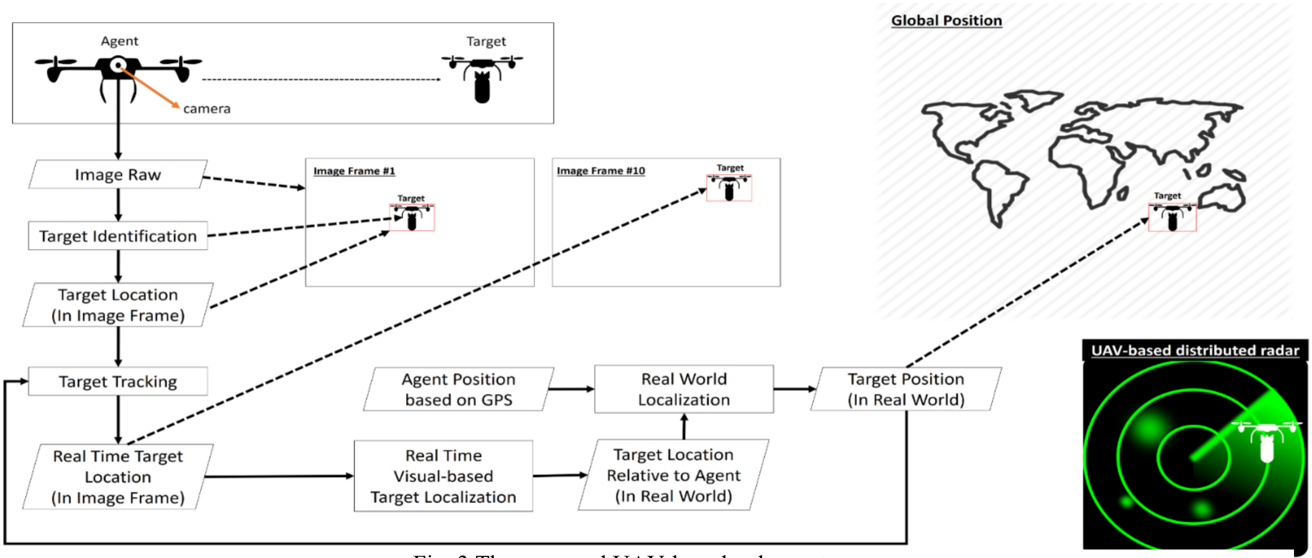

Fig. 3 The proposed UAV-based radar system

localization system, which will produce the target's real position in the real world. The radar system uses several UAV_tracker that report the target's position, also referred as AUV-based radar. In detail the proposed radar system consists of several sub-systems as follows

A. *Unmmanned Aerial Vehicle (UAV) as UAV_tracker*

UAV_trackers have a primary role as an agent for identification, tracking and localization of targets. Therefore, the UAV is equipped with visual sensing capabilities using a camera sensor. The camera used is assumed to be calibrated so that the pixel scale can be known to the actual size. This paper uses camera that produces frames with a size of width 720 pixels and height 480 pixels. Fig.4 shows an example of the image from the camera sensor. The data is an image taken from open dataset in Long term object tracking challenge [8].

The UAV_tracker also has the ability to fly and maneuver in low, destroyed, or even confined locations. Therefore, the UAV must be equipped with additional sensor at least measurement inertia units, gyroscope, accelerometer, and Global Positioning System (GPS). In addition, UAVs need to be equipped with computing devices in order to process the obtained visual data. Computational capabilities are used to run the detection, tracking, and localization procedure.

B. *Target Identification*

Target identification is an important component that must be owned by each UAV_tracker. Target identification uses machine learning approach that can be installed to the UAV_tracker. Based on previous publication [9], Adaboost Classifier method had been developed to identify objects with military characteristics or other suspicious objects. That research 71% hit rate and 21% false which is reliable for surveillance task [9] .

In this paper, we utilized the method to identify the target. Furthermore, UAV_tracker determines the target location in the image frame coordinates (x and y).

Fig. 4 Example Image Frame retrieved by camera sensor

C. *Target Tracking*

The UAV_tracker encounters a target that has dynamic motion capabilities. The system tracks object to observe target movements. In this paper, we utilize Bayesian-based tracking method developed in previous studies [10]. The tracking method used can follow targets that move dynamically with precision value is above 0.9 from 1.0 [10].

The tracking system will produce target bounding boxes (BB) that has $x, y,$ $width,$ $height$. Acceleration, deceleration, and dynamic maneuvers that are created by the target, making the target view transformation. Target bounding box can do rotation, scaling, translation, shearing, and reflection. Therefore, system tracking produce target bounding box that adjust dynamically based on that transformation. The accurate size of target bounding box is important to estimate relative distance between the UAV_tracker and the target that is seen in the image frame.

D. *Real-time visual-based Target Localization*

UAV_tracker calculates the target location relative to the tracker in the real world. Coordinate *x, y,* and *z* of the target can be determined using resultant vector in 3D space. Figure 5 depicts our coordinate system that is used in the proposed framework. Based on the coordinate system, *x, y,* and *z* of the target can be determines using equation 3.1.

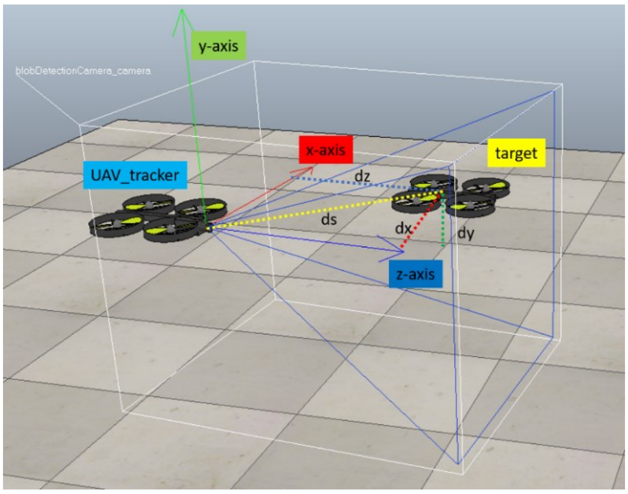

Fig. 5 Proposed UAV tracker in 3D coordinate system.

$$ds^2 = dx^2 + dy^2 + dz^2 \quad (3.1)$$

where

ds : *straight line distance between tracker and target*

dx : *distance between tracker and target in x – axis*

dy : *distance between tracker and target in y – axis*

dz : *distance between tracker and target in z – axis*

ds , dx , dy , dz units in pixel.

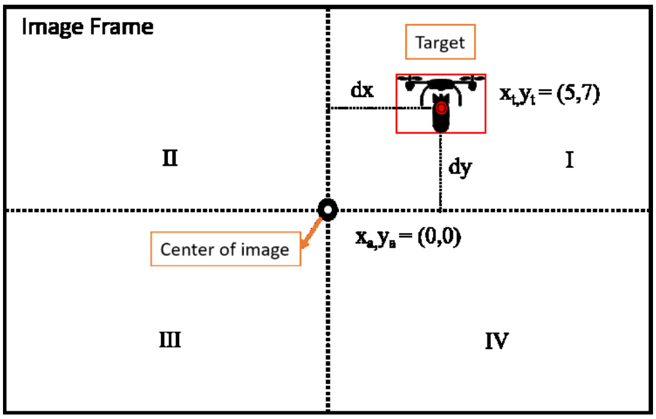

Fig. 6 UAV tracker camera point of view that is depicted in 2D coordinate

Based on the 3D coordinate system, we can describe image frame that is capture by camera in 2D coordinate system. UAV_tracker will determine target x and y position in four quadrants as seen in Figure 6. Therefore, the system has calibration camera K which simply calibrates one pixel in the image into real-world distances in meters. This paper assumes that the K value has been obtained from a calibrated camera. Then, the dx and dy distance in real world can be calculated directly using equation 3.2 and 3.3.

$$dx_{calibrated} = |K * dx| \quad (3.2)$$

$$dy_{calibrated} = |K * dy| \quad (3.3)$$

After the dx and dy, are calculated, this paper proposed a method to calculates ds . This paper modifies Expansion Area Coefficient principle [11] to estimate the ds distance based on bounding box area. The idea is converting the bounding box area to the target distance. The camera is placed at the center of the UAV_tracker so that the target distance to the camera is the same value as the target distance to UAV_tracker. In this case, when a target moves away or closer to the UAV, it appears to be larger or smaller, respectively. Therefore, our framework proposed equation 3.4 until 3.10 to determines $ds_{calibrated}$ value.

$$A_{BB} = BB_{width} . BB_{width} \quad (3.4)$$

$$\Delta A_{BB} = A_{BB_0} . \beta . ds_{calibrated} \quad (3.5)$$

$$A_{BB_{tracker}} = A_{BB_0} - \Delta A_{BB} \quad (3.6)$$

$$A_{BB_{tracker}} = A_{BB_0} - (A_{BB_0} . \beta . ds_{calibrated}) \quad (3.7)$$

$$A_{BB_{tracker}} = A_{BB_0} . (1 - \beta . ds_{calibrated}) \quad (3.8)$$

$$\frac{A_{BB_{tracker}}}{A_{BB_0}} = 1 - \beta . ds_{calibrated} \quad (3.9)$$

$$ds_{calibrated} = \frac{A_{BB_0} - A_{BB_{tracker}}}{A_{BB_0} . \beta} \quad (3.10)$$

Where,

A_{BB} : bounding box area in pixel^2

BB_{width} : bounding box width in pixel

BB_{height} : bounding box height in pixel

A_{BB_0} : bounding box area of reference target in pixel^2

$A_{BB_{tracker}}$: bounding box area of target in pixel^2

ΔA_{BB} : bounding box area difference in pixel^2

β : Coefficient of bounding box expansion in meters/pixel^2

$ds_{calibrated}$: straight line distance tracker to target in meters

Let us assume that β value is of 5.10^{-3} meters/pixel^2. This value is obtained from the calibrated camera calibration to compensate bounding box change. Then the A_{BB_0} variable is fine tuned to 12000 pixels^2. This value is a reference pixel when the target is close to UAV_tracker an determine in fine tuning. This value is the calibration-made variable so, it is depended on the camera. Finally, UAV_tracker calculates $dz_{calibrated}$ using equation 3.11 .

$$dz_{calibrated}{}^2 = ds_{calibrated}{}^2 - dx_{calibrated}{}^2 - dy_{calibrated}{}^2 \quad (3.11)$$

E. *Real World Localization*

The proposed framework combines the two information, that is the target's location relative to UAV_tracker and UAV_tracker position in real world. The first information is produced using the real-time visual-based target localization procedure that has been carried out at the previous stage. The second information is the real position of the UAV_tracker that can be obtained using the GPS. To compute the target's position in real world, this paper use equation 3.12, 3.13, and 3.14. In addition, the final target position can be converted in latitude, longitude, and altitude value.

$$x_{target} = x_{UAV\_tracker} + dx_{calibrated} \quad (3.12)$$

$$y_{target} = y_{UAV\_tracker} + dy_{calibrated} \quad (3.13)$$

$$z_{target} = x_{UAV\_tracker} + dz_{calibrated} \quad (3.14)$$

However, if in certain conditions such as restricted areas that block GPS signal. The UAV_tracker position can be identified by the probability-based localization approach such as Expended Kalman Filter [9].

IV. RESULT AND ANALYSIS

A. Target Identification

This UAV_tracker detect targets based on the target characteristics. After the identification is successfully done, the system calculates the target position at the frame image coordinates, for example in the first frame #1 the target position is located in the third quadrant or [x,y] is of [-156, -119]. Fig.7 shows the target identification result.

Fig. 7 Result of target identification

B. Target Tracking

The UAV_tracker chase the target using the tracking method. The Tracker will give a mark to the target in the form of a bounding box. This bounding box is a guidance for UAV to decide next movement. Figure 8 is an example of the target that were successfully tracked in frame #3 and #155.

C. Target Localization

Based on the tracking results on Fig.8, UAV_tracker obtain target in frame #03 [x, y, width, height] as [-154, -116, 30, 13]. Then, $A_{BB_{tracker}}$ is 390 while in frame #155, target is located in [-73, -179, 24, 15] so $A_{BB_{tracker}}$ = 360.

UAV_tracker calculates $dx_{calibrated}$ and $dy_{calibrated}$ for target in frame #3 using equation 3.2 and 3.3. In this paper, assume that K has value 0.1 $^{meters}/_{pixel}$.

$$dx_{calibrated} = |-154 * 0.1| = 15.4 \text{ meters}$$

$$dy_{calibrated} = |116 * 0.1| = 11.6 \text{ meters.}$$

Fig. 8 Result of target tracking

After that, $ds_{calibrated}$ of target in each frame is computed using equation 3.10.

$$ds_{calibrated} \text{ in frame } \#3 = \frac{12000-390}{12000*5*10^{-3}} = 193.5 \text{ meters}$$

$$ds_{calibrated} \text{ in frame } \#155 = \frac{12000-360}{12000*5*10^{-3}} = 194 \text{ meters}$$

From these calculations, the system estimates the target's distance from UAV_tracker in frame #3 is 193.5 meters and in frame #155 is 194 meters. The target's distance in the frame #155 is further than the target distance in frame 3. This is confirmed by visually that the target in frame #155 is move away from UAV_tracker and produce smaller bounding box. Then, UAV_tracker computes dz target using equation 3.11.

$$dz_{calibrated} = \sqrt{193.5^2 - 15.4^2 - 11.6^2} = 192.5 \text{ meters}$$

In this stage, the UAV_tracker had known the relative position target UAV_tracker in frame #3 that is $dx_{calibrated}, dy_{calibrated}, dz_{calibrated}$ = [15.4, 11.6, 192.5] units in meters. Finally, to obtain the target's global position, the UAV_tracker calculate target position using equation 3.12, 3.13, and 3.14.

Our proposed method has a quite high-resolution position up to units of meters. UAV_tracker, which is equipped with an accurate GPS system, will certainly produce target coordinate information that can also be calculated accurately. Furthermore, based on the calculation system that is proposed the real coordinates of the target, the UAV_tracker system can send that information to the radar controller system.

In real world scenario, practically our proposed method can be implemented on nowadays available commercial UAV device. According to [3], tracking and localization can be executed using commercial UAV. For detection process, there are some technologies have been developed to support this. Even if the detection process requires high performance computing, this process can be delegated to server for further processing [3]. In practical, the development of UAV technology is always improved. For example, the battery capacity of UAV is getting bigger gradually. As the consequence, we analyze that our proposed method can be implemented using nowadays available UAV device.

Future research can be done using actual camera calibration data. Currently, the accuracy of proposed method depends on calibration of UAV size. As the consequence, it can lead to inaccuracies. Research in anti-UAV coordination is also needed to be done. In research [12], UAV had been proven to be able to communicate with each other but in case specific for anti-UAV radar system is not yet proven. In addition, there are several research challenges such as on the tracking side. Further research needs to be developed for the long-term tracking method, so that the UAV_tracker UAV can still follow the target even though the target has disappeared and then reappears visually.

V. Conclusion

This paper proposes a framework to detect the location of any intruder drone that wants to attack any vital property of a country, such as an airport or even a military base. The proposed method works as a radar-like system that can gather the position of UAV intruders as one integrated data in a command center. The proposed method develops a UAV tracker system that can detect and follow an intruder drone. By using a calibrated 2D camera and GPS sensor installed in each UAV tracker, UAV tracker can estimate the relative position of an intruder and calculate its coordinate in a real-world GPS system.

The proposed method has been tested in a simulator environment. According to the experiment result, the proposed method has good potential to be implemented as a real product to support military defense technology development. The calibrated 2D camera theoretically good to estimate intruder relative position. By performing this research, we conclude that a system approach is promising as an approach to support an area defense system.

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