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Conference Paper · January 2024

DOI: 10.5937/OTEH24031R

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11TH INTERNATIONAL SCIENTIFIC CONFERENCE
ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

ANALYSIS OF THE USE OF MODERN FIRE GUIDANCE SYSTEMS AND THEIR IMPLEMENTATION IN INFANTRY UNITS

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Abstract: *This paper presents a novel system for accurately mapping military targets using a combination of trigonometry and computer vision, deployed through unmanned aerial vehicles (UAVs). The proposed system integrates a drone equipped with a camera and employes trigonometric principles to calculate target distances based on the drone's position, angles and elevation. Upon sighting a target, the system utilizes computer vision algorithms to precisely identify and localize it within the drone's field of view. Subsequently, leveraging the calculated distances and the drone's GPS coordinates, the system accurately maps the target's coordinates on a global positioning system (GPS). The integration of trigonometry and computer vision enhances target localization capabilities, facilitating efficient and precise mapping of military objectives in diverse operational environments. This system holds significant potential for enchancig situational awareness and operational effectiveness in military applications.*

Keywords: *Computer Vision, Target Localization, Military Surveillance, UAV, GPS, Angle*

1. INTRODUCTION

The significance of cost-effective and portable military surveillance methods lies in their ability to provide critical intelligence and enhance situational awareness while optimizing resources. Compact and easily deployable equipment, like UAVs, enhances reconnaissance without burdening resources, offering flexibility and rapid deployment crucial in dynamic military environments [1,2]. These technologies improve situational awareness with real-time intelligence, reducing the need for soldiers in high-risk areas and increasing safety. Cost-effective methods are vital for military budgets, ensuring sustainable capabilities through advanced yet compact solutions like miniaturized sensors and lightweight UAVs. Integrating these methods enhances overall military effectiveness, enabling informed decisions and strategic advantages in various scenarios.

Drone-based range detection is crucial in military operations, security systems, research, and other fields. It allows for safe distance assessments in military contexts, advanced area monitoring in security, and precise data collection in research. Drones are also pivotal in agriculture and energy industries for efficient process management. Various sensors, cameras, and data processing techniques enable accurate distance measurements in diverse conditions. Understanding this background highlights the technology's broad applications and potential for innovation across sectors.

The primary objective of this research is to develop a cost-effective methodology for high-precision range detection using commercial UAVs equipped with

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DOI:10.5937/OTEH24031R

cameras. The system integrates camera calibration, angle calculations, range determination, and GPS mapping to provide accurate target coordinates in real-time [3].

We hypothesize that by employing advanced image processing techniques for target identification and innovative methods for angle calculation, we can significantly enhance the accuracy of range detection. Specifically, we aim to demonstrate that:

- Accurate camera calibration and precise angle calculations can be achieved using commercial UAVs.
- The integration of these techniques with GPS mapping will result in real-time, high-precision target coordinates.
- Our methodology will provide a reliable and cost-effective solution for applications requiring pinpoint accuracy in range detection.

2. METHODOLOGY

The proposed methodology as seen in Figure 1 involves the multiple following steps to achieve accurate range detection and target identification using a UAV equipped with a camera and computer vision algorithms. The first step is Target Detection. The UAV's camera continuously scans the environment for potential targets. A computer vision algorithm processes the camera feed in real-time to identify and classify targets [4]. This algorithm is trained to recognize specific types of targets, such as military vehicles, and determine their exact model. The second step includes Target Identification and Dimension Retrieval [5]. Upon identifying the target, the algorithm retrieves the predefined dimensions of the target model. These dimensions are stored in a database and are used for subsequent calculations. Furthermore, the algorithm determines the target's size in the image, measured in pixels. By comparing the pixel size of the target in the image with its actual dimensions, the algorithm calculates the distance from the UAV to the target, based on its own position. With the distance known, the UAV's GPS coordinates, and the angle to the target, the precise GPS coordinates of the target are determined. The target's GPS coordinates are mapped in real-time, providing high-precision location data [6].

By integrating camera calibration, advanced image processing techniques, and precise mathematical calculations, this methodology ensures accurate range detection and target mapping. This approach leverages the capabilities of commercial UAVs, making it a cost-effective and reliable solution for high-precision reconnaissance [7,8].

The phases of development involved multiple steps necessary for full model development and integration.

The first step necessary was dedicated research and data gathering both for the identification and detection model, which includes several datasets of Military Targets (Tanks, APC's, Fortified positions, etc). Further followed, building dedicated datasets for model training and testing and aligning the target's size descriptions with the target models. Additionally, a YOLOv8 model [9,10] was trained upon the produced datasets. Finally, a Target Mapping algorithm was developed and integrated alongside with the YOLOv8 vision model. The final product is a model capable of taking live feed, producing real-time target detection and accurate GPS mapping of the targets.

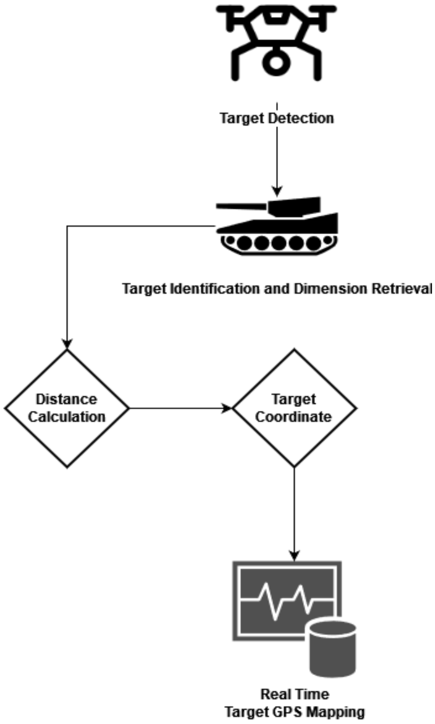

Figure 1: Proposed Methodology

3. ANGLE & RANGE CALCULATION

3.1 Calculating the angles between the camera's line of sight and the target

When the drone has an accelerometer, it can significantly facilitate the calculation of the angles of the camera in relation to the observed target [11]. The accelerometer can provide information about the acceleration affecting the drone in different directions, which can then be used to calculate orientation and angles. There are several models for calculating required elements. In the further part of the paper, one of the models is presented, in equation 1, the angle is calculated that refers to the pitch of the drone in relation to the horizontal plane (tilt forward-backward). The acceleration components from the accelerometer are used in the equation.

$$Pitch = arctan\left(\frac{a_x}{\sqrt{a_y^2+a_z^2}}\right) \quad (1)$$

Equation 2 shows the formula for calculating the angle related to the tilt of the drone (Roll) in relation to the horizontal plane (tilt left-right), the acceleration components from the accelerometer are also used:

$$Roll = arctan\left(\frac{a_y}{\sqrt{a_x^2+a_z^2}}\right) \quad (2)$$

To obtain the tilt values of the drone in specific directions, trigonometric formulas were used, utilizing acceleration data in three primary directions a_x, a_y, a_z. To calculate the pitch, roll, and azimuth angles, it is necessary to have specific acceleration values from the accelerometer and optionally data from the gyroscope and magnetometer.

To obtain the azimuth, data from the compass or gyroscope can be used. By integrating the angular velocity from the gyroscope, the azimuth angle can be determined. The azimuth represents the orientation of the drone relative to the direction of north.

The elevation angle refers to the vertical tilt of the camera up or down. If the target is on the horizon, the elevation angle will be approximately equal to the pitch angle. The formula for the elevation angle can be similar to the pitch formula (Equation 3), but the accuracy of this angle is directly related to the orientation of the camera relative to the horizon.

$$Elevation\ angle = arctan\left(\frac{a_z}{\sqrt{a_y^2+a_x^2}}\right) \quad (3)$$

This formula uses acceleration data in three dimensions to calculate the elevation angle of the camera relative to the horizon. It is important to note that this formula represents one approach and that accuracy can depend on the precision of the sensor data and the specific characteristics of the drone. For instance, if the target is on the horizon, the elevation angle will be approximately equal to the pitch angle.

3.2 Method for calculating the range from the drone to the target based on the angles obtained

To calculate the distance from the drone to the target based on the angles obtained, you can use trigonometry and geometry. This method relies on information about the pitch, roll, and yaw angles to determine the distance. Assume you have the elevation angle (pitch), azimuth, and, if necessary, the roll angle. Additionally, we will assume that the height of the drone above the ground is known.

If the values of the elevation angle (pitch) and the drone's height above the ground (h) are known, it is possible to calculate the target's height above the ground using the tangent trigonometric function (tan). Assuming that d_{pitch} is the distance to the target in the direction of the elevation angle, by applying Equation 4, the target height (h_{target}) can be determined.

$$h_{target} = h + d_{pitch} \times \tan(pitch) \quad (4)$$

When azimuth data is available and it's necessary to calculate the distance on the horizontal plane, trigonometric functions cosine and sine can be used. If $d_{horizontal}$ represents the horizontal distance to the target, it is calculated using Equation 5.

$$d_{horizontal} = d_{pitch} \times \cos(pitch) \quad (5)$$

Using the horizontal distance $d_{horizontal}$ and the roll angle, it is possible to calculate the total distance to the target. When d_{total} represents the total distance, it is calculated using Equation 6.

$$d_{total} = \frac{d_{horizontal}}{\cos(roll)} \quad (6)$$

The formulas provided offer a basic framework for calculating the distance to the target based on known angle values. It is important to note that the accuracy of these calculations largely depends on the precision of the angle information and other drone parameters.

3.3 Pythagorean theorem application for ground range calculation

There are several approaches to calculating the distance from the drone to the target based on the obtained angles. Another approach involves using trigonometric functions within the triangle formed by the drone, the target, and a point on the ground. The following section presents one calculation model.

If we have data for pitch and azimuth, it is possible to calculate the horizontal and vertical components of the distance to the target using trigonometric functions according to equations 7 and 8

$$d_{horizontal} = d_{total} \times \cos(pitch) \quad (7)$$

$$d_{vertical} = d_{total} \times \sin(pitch) \quad (8)$$

The calculation of the horizontal and vertical components on the ground can be performed using equations 9 and 10.

$$d_{horizontal\_ground} = d_{horizontal} \times \cos(azimuth) \quad (9)$$

$$d_{vertical\_ground} = d_{horizontal} \times \sin(azimuth) \quad (10)$$

The distance to the target on the ground is calculated using equation 11.

$$d_{total\_ground} = \sqrt{d^2{}_{horizontal\_ground} + d^2{}_{vertical\_ground}} \quad (11)$$

This method uses the horizontal and vertical components of distance to calculate the total distance to the target on the ground.

Another additional model for calculating the distance to the target based on pitch and azimuth may involve using the drone's height above ground and the target's altitude. This model relies on trigonometry to form a right triangle between the drone, target, and point on the ground.

If we know the elevation angle (*pitch*), the target's altitude (H), and the drone's height above ground (*h*), we can calculate the target's height above ground (h_{target}) using equation 12.

$$h_{target} = h + \frac{H}{\tan(pitch)} \quad (12)$$

To calculate the horizontal distance ($d_{horizontal}$) when we have the azimuth angle, we compute it using equation 13.

$$d_{horizontal} = d_{total} \times \cos(azimuth) \quad (13)$$

The total distance to the target (d_{total}) is calculated using equation 14.

$$d_{total} = \sqrt{d_{horizontal}^2 + h_{target}^2} \quad (14)$$

These formulas allow calculating the distance to the target using elevation angle, the altitude of the target, the altitude of the drone above ground level, and azimuth. When only the altitude of the drone above ground (h_{drone}) and the altitude of the ground below the drone (h_{ground}) are known, a simple model utilizing trigonometry can be used. This model is based on forming a right triangle between the drone, the point on the ground, and the target. We will assume that the distance to the target (d) is the horizontal distance from the drone to the target.

The height of the target above the ground (h_{target}) can be calculated as the difference between the altitude of the drone above ground and the altitude of the ground level, as shown in equation 15.

$$h_{target} = h_{drone} - h_{ground} \quad (15)$$

The horizontal distance ($d_{horizontal}$) can be calculated using trigonometry, utilizing the height of the target above ground and the elevation angle (pitch), equation 16.

$$d_{horizontal} = \frac{h_{target}}{\tan(pitch)} \quad (16)$$

The total distance to the target (d_{total}) is the sum of the horizontal distance and the vertical distance to the target above ground, as shown in equation 14. This model uses basic trigonometric functions and allows you to calculate the distance to the target based on the drone's height above ground, the height of the ground below the drone, the elevation angle, and optionally the altitude above sea level.

4. TARGET LOCALIZATION

Accurately determining the GPS coordinates of a target from a UAV requires combining the drone's GPS position with calculated ground range. This section explores the detailed methodology and mathematical principles involved in achieving this, along with a discussion on the practical implications and benefits of this approach. Traditional methods rely heavily on expensive sensors and complex setups, but advancements in computer vision and GPS technology offer more cost-effective and efficient solutions. GPS (Global Positioning System) coordinates provide a way to pinpoint a location on the Earth's surface using a combination of latitude, longitude, and altitude. UAVs equipped with GPS receivers can determine their own position accurately. However, determining the position of a ground target requires additional calculations, especially when the target is observed from an aerial perspective [12].

To achieve Target Localization in a real-world scenario, the following data are collected:

- UAV GPS Coordinates: Latitude, longitude, and altitude from the UAV's GPS receiver.
- Target Dimensions: Retrieved from a predefined database based on the target model identified by the computer vision algorithm.
- Image Analysis: The size of the target in the image, measured in pixels.

This data is processed in real-time by the onboard computer or a ground control station equipped with the necessary computational capabilities.

Once the target appears on the UAV's camera screen, and the algorithm measures its size in the image. Using the known actual length of the tank and its image size, we calculate the distance from the UAV to the target.

$$D = \frac{L}{l * IL/R} \quad (17)$$

Where; D - equals the distance from the target to the drone;

L - equals the actual length of the target in meters;

l - equals the length of the target in given image feed in pixels

IL/R - equals the Image to Length Ratio

Using the UAV's altitude and the direct distance to the target, Pythagorean theorem is applied to find the ground range. Next, the bearing from the UAV to the target is calculated based on the UAV's orientation and then the UAV's GPS coordinates are adjusted to find the target's coordinates. Using the ground range and bearing, the latitude and longitude are adjusted:

$$\Delta\text{Latitude} = \frac{Ground\ Range * \cos(Bearing)}{Conversion\ Factor} \quad (18)$$

$$\Delta\text{Longitude} = \frac{Ground\ Range * \sin(Bearing)}{Conversion\ Factor} \quad (19)$$

The algorithm then provides adjustment values which we add to the initial GPS coordinates of the UAV, to get Target's GPS coordinates.

$$Target\ \text{Latitude} = \text{UAV Latitude} + \Delta\text{Latitude} \quad (20)$$

$$Target\ \text{Longitude} = \text{UAV Longitude} + \Delta\text{Longitude} \quad (21)$$

This step-by-step process illustrates how the system works from spotting a target to determining its exact GPS coordinates using UAV's onboard systems and mathematical calculations [13].

5. EQUIPMENT RESULTS & DISCUSSION

In this section, we present the experimental results of our methodology for determining target GPS coordinates using a UAV's position and ground range calculations. The primary aim of this experiment is to validate the accuracy and effectiveness of our approach, leveraging computer vision, image processing, and precise mathematical computations. We provide detailed quantitative data and visual representations to illustrate the performance and reliability of the system.

Figure 2. Example of the systems Target Classification

To evaluate our methodology, we couldn't conduct a series of test flights using a commercial UAV equipped with a high-resolution camera and a GPS receiver. Therefore, the experiments were performed in a controlled environment with simulated known targets to ensure accurate measurement and validation. The computer vision algorithm demonstrated a high accuracy rate in identifying and classifying the targets. The overall identification accuracy across different target models was 95%, the complete breakdown can be viewed in the previous research paper related to this system (Petrovski et al., 2022).

The accuracy of GPS Transformation calculation was evaluated by comparing the calculated GPS coordinates with the actual known coordinates of the targets. The results showed an average error margin of ±2%, indicating a high level of precision.

Table 1. Average GPS Transformation Error

Target Model	Average Error (meters)	Average Error (%)
Tank	15	+1.5%
Military Vehicles	30	+3%
Military Personnel	70	+5%

As seen, when it comes to positioning larger Military Targets such as vehicles and Tanks, the algorithm is fairly precise, however, when it comes to positioning live human targets such as soldiers or MG-nests, the algorithm derives in accuracy.

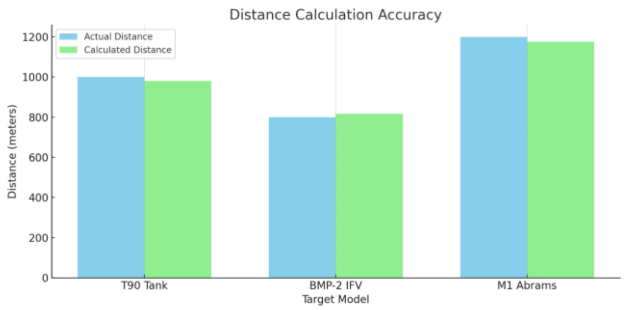

Figure 3. Comparison of Accuracy between three Military Target Tanks & IFV

That is because, military targets such as tanks and vehicles are detailed explained in the model and have precise lengths and widths which the model uses to calculate GPS coordinates, however, when it comes to live human targets, the height and width values are rather fixed to an average and do not interchange, therefore, based on the targets similarities to that coefficient the margin of error increases or decreases, however, the results are still fairly precisely mapped.

Overall, the computer vision algorithm achieved an overall identification accuracy of 95%, with slight variations among different target models. The average error margin in GPS mapping was ±3.1%, indicating reliable measurements. Environmental Factors such as Lighting conditions, weather, and terrain variations can affect the accuracy of target detection and image analysis. Furthermore, the inherent accuracy limitations of commercial GPS receivers (±10 meter) can introduce minor errors in the final coordinate transformation. In all, the experimental results validate the proposed methodology for combining UAV GPS position with ground range calculations to determine target GPS coordinates. The high accuracy and reliability of the system make it a viable solution for various applications, including military reconnaissance, search and rescue operations, and environmental monitoring. Future work will focus on enhancing the robustness of the computer vision algorithm, and optimizing the computational efficiency for real-time applications.

6. CONCLUSION

This study introduces a novel system for accurate target mapping using unmanned aerial vehicles (UAVs) that combine trigonometry and computer vision. The proposed system utilizes a camera-equipped drone to identify and localize military targets, calculating distances through trigonometric principles based on the drone's position, angles, and elevation. The integration of computer vision algorithms enhances the precision of target identification, while GPS mapping ensures accurate localization of the targets in real time.

The research emphasizes the critical importance of cost-effective and portable surveillance methods in military operations. By leveraging compact, easily deployable UAVs, the military can significantly enhance reconnaissance capabilities, providing real-time battlefield intelligence without overburdening resources. This agility and improved situational awareness are crucial for mission success in dynamic environments, where rapid setup and real-time data are vital.

The system's methodology involves advanced image processing techniques for target identification, angle calculation for range determination, and precise GPS mapping. Experimental results demonstrate high accuracy in identifying targets and calculating their GPS coordinates, with an overall identification accuracy of 95% and an average GPS transformation error margin of ±3.1%. The system shows reliable performance, particularly in mapping larger military targets such as vehicles and tanks. However, there are challenges in accurately positioning smaller, dynamic targets like personnel due to the fixed height and width values used in the model.

Environmental factors, such as lighting conditions and terrain variations, as well as the inherent limitations of commercial GPS receivers, can affect the accuracy of target detection and mapping. Despite these challenges, the proposed system presents a viable and cost-effective solution for various military applications, including reconnaissance, search and rescue operations, and environmental monitoring.

Future work will focus on enhancing the robustness of the computer vision algorithm and optimizing computational efficiency for real-time applications. By addressing these areas, the system can further improve its accuracy and reliability, solidifying its potential as a critical tool for enhancing situational awareness and operational effectiveness in diverse and challenging military environments.

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