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# Target Localization Using Cooperative Unmanned Aerial Vehicles

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**Abstract**

Unmanned aerial vehicles (UAVs) are ideal platforms for remote sensing due to their point of view and freedom of movement. This paper introduces the cooperative localization of the interested target using four quad-rotors UAVs equipped with stereo vision systems. The system contains a vision-based algorithms for the detection and identification of the target on the video stream. An algorithm based on Kalman filter used to estimate the position of the target, in addition a method offered based on Kalman filter. This method applied to fusion of each UAV's estimation together. Simulation results compared with non-cooperative and Two UAV cooperative systems. Results indicates that four UAV cooperative systems perform more accurate estimation of the target location.

***Keywords:*** *Unmanned Aerial Vehicles, Kalman Filter, Data Fusion, Vision-Based localization, Cooperative.*

## 1. Introduction

Unmanned aerial vehicles, or UAVs, are well suited to play an important role in both the military and commercial operations: for example, disaster monitoring, and search and rescue operations, as well as reconnaissance and surveillance mission. Towards a need of UAVs performing such a complex mission in an unknown remote site, an autonomous flight system of UAVs has been progressively developed in recent years [1].

For many mission scenarios, the use of video cameras and machine vision techniques is special interest due to the wealth of information they can provide. Researchers have used on-board camera for remote sensing of forest fires [2-5]. Coifman and McCord groups developed a machine vision-based roadway traffic monitoring system by using fixed-wing unmanned aerial vehicle [6]. In addition a number of researchers have used vision-based techniques for target detection and tracking. The use of vision for estimation and tracking of ground based targets has also been studied by Bethky and Yorks groups [7], [8]. Using of a quad-rotor UAV with an on-board camera for autonomously identifying and tracking of marine animals has been developed in another paper [9]. A vision based tracking of interested target with two quad-rotor UAV equipped with stereo vision systems have been developed by the researchers [10]. Yoon et al. presented a ground target detection method using a Gaussian classifier in the normalized RGB (Red-Green-Blue) color space [11]. Pack et al. [12] presented a cooperative, decentralized searching system using rudimentary angle-of-arrival sensors onboard multiple SUAVs for an application to search and detect multiple mobile targets.

When the target moves or the environment has some obstacles, the ability to estimate the exact location of a target with single UAV could be limited. Multiple systems for localizing targets can be useful and provide a more accurate estimation of the target position. The use of multiple UAVs provide redundancy, allowing for continuous monitoring even if individual vehicles experience failures [7].

This paper, presents a vision-based localization algorithm that takes advantage of the cooperation between four quad-rotors UAV that equipped with a stereo-vision system. This system contains two critical parts 1) computer vision technics for stereo vision based depth estimating and 2) a computer vision algorithm for detecting and identify the target. Kalman filters are often employed to estimate object state [13]. Designed system has a Kalman filter based Algorithm to estimate the target location in the environment. To provide a more accurate result, cooperative system proposed. Combining estimation of UAVs will achieve the desired objective of accuracy.

The paper is organized as follows. Section 2 presents a method for identifying and estimating target position using stereo cameras. Section 3 explains how to locate the target in environment. Section 4 describes a method for combination of UAVs estimated data. Section 5 presents the experiments and the results obtained. The conclusions and future trends in section 6 complete the paper.

## 2. Machine Vision

The goal of the proposed machine vision system is searching and identifying the target in the video stream and also estimating target position relative to the camera.

At first, images are garbed from a stereo camera with BGR color system (OpenCV library standard color system). In order to implement a stereo depth estimation with a reasonable level of accuracy, it is important to calibrate the camera system. It is a process of finding the intrinsic and extrinsic parameters of the camera.

Because of different light conditions prevailing in various parts of the test environment, images are converted to the HSV color system. Thresholds are defined in each image channel for improving robustness of the target recognition system in various light conditions. After thresholding process, there is still some noise on the binary image. The median filter is used for removing noise from the image and smoothing. With the smoothing process, we may still have some disconnected shape of points left in the binary image Mathematical morphology is a set of tools that can be used to manipulate the shape of objects in an image. Two advanced operations in morphology, opening and closing [14], have been selected and used in the target recognition process.

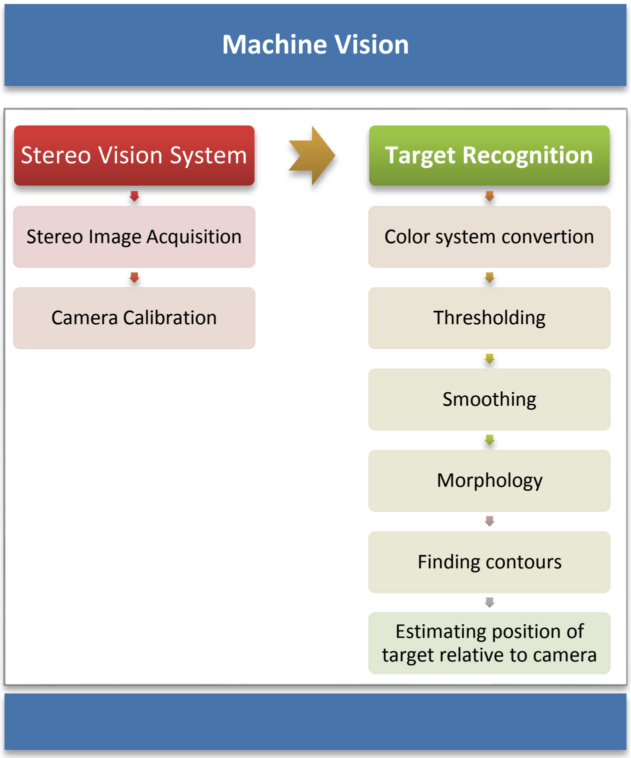


Fig. 1 Diagram of machine vision system

After multiple steps of pre-processing on the image, it is necessary to find the external contours of interested target to compute the center of the target in the images.

When the center of the target in both images is obtained, the position of the target relative to the camera can be estimated using the Eq. (1), (2) and (3) [15].

Fig. (1) Shows the diagram of proposed machine vision system. Fig. (2) displays the stereo images from one of the UAVs.

$$Z_{cam} = \frac{Bf}{d} \tag{1}$$

$$X_{cam} = x_l * \frac{Z}{f} \tag{2}$$

$$Y_{cam} = y_l * \frac{Z}{f} \tag{3}$$

$X_{cam}, Y_{cam}, Z_{cam}$ are coordinates of the target relative to the camera, $B$ is the stereo camera based line and $f$ is the focal length of camera and $x_l$, $y_l$ Represent coordinate of target on the left image plane.

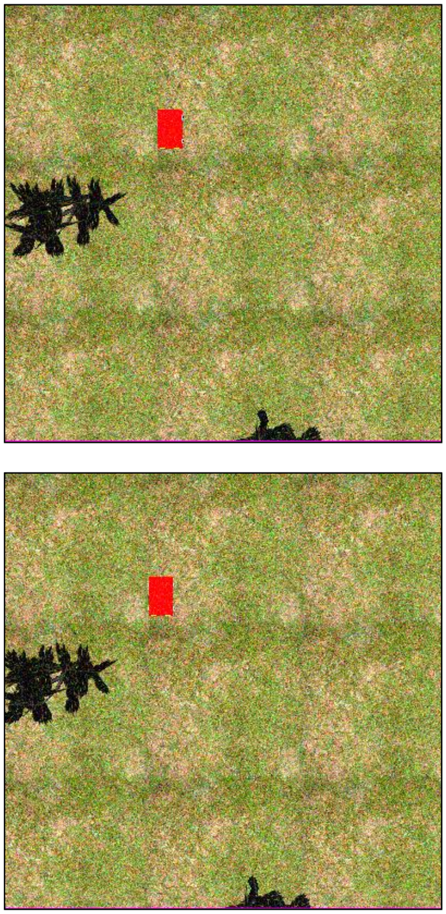

Fig. 2 Stereo camera images

## 3. Target Localization

This section explains about generating an estimation of the target position in the testing environment. To get the coordinates of target in the test field, we need to have coordination of UAV in the environment. This information can be obtained via the localization sensors which are mounted on the UAV. Also a simulated inertial measurement unit (IMU) mounted on each drone to obtain the rotational angles. The target location can be expressed using Eq. (4)

$$\begin{pmatrix} x_{target} \\ y_{target} \\ z_{target} \end{pmatrix} = \begin{pmatrix} x_{uav} \\ y_{uav} \\ z_{uav} \end{pmatrix} + \begin{pmatrix} x_{cam} \\ y_{cam} \\ -z_{cam} \end{pmatrix} \quad (4)$$

$x_{target}$, $y_{target}$ and $z_{target}$ represent the position of the target in the environment, $x_{uav}$, $y_{uav}$ and $z_{uav}$ are the position of UAV and $x_{cam}$, $y_{cam}$ and $z_{cam}$ are the position of the target in the camera image, respectively. The rotation around X, Y and Z axis are expressed using Eq. (5), Eq. (6) and Eq. (7).

$$\begin{cases} y' = y \text{ Cos } \emptyset - z \text{ Sin } \emptyset \\ z' = y \text{ Sin } \emptyset + z \text{ Cos } \emptyset \\ x' = x \end{cases} \quad (5)$$

$$\begin{cases} z' = z \text{ Cos } \theta - x \text{ Sin } \theta \\ x' = z \text{ Sin } \theta + x \text{ Cos } \theta \\ y' = y \end{cases} \quad (6)$$

$$\begin{cases} x' = x \text{ Cos } \psi - y \text{ Sin } \psi \\ y' = x \text{ Sin } \psi + y \text{ Cos } \psi \\ z' = z \end{cases} \quad (7)$$

$x$, $y$, and $z$ are the coordinates of the target on the image plane, and $x'$, $y'$ and $z'$ are target coordinates by applying UAV rotation around the x, y and z axis, which is characterized by $\emptyset$ , $\theta$ and $\psi$.

It assumes that the position of the UAV and target position measured relative to the camera, are not perfectly accurate due to the sensors noise or other artifacts. It leads to uncertainties in both knowledge of UAV and target location. In this work Kalman filter was applied to reduce this uncertainty. This paper uses system model with state vector according to Eq. (8):

$$X = [x, y, z, \dot{x}, \dot{y}, \dot{z}] \quad (8)$$

Process model and measurement model are then given by Eq. (9).

$$X_{k+1} = AX_k + w_k \qquad Y_k = HX_k + v_k \quad (9)$$

$w_k$ and $v_k$ are *process noise* and *measurement error* of the system model. *A* denotes the state transition matrix and *H* is measurement matrix.

## 4. Data Fusion

In this section, a data fusion algorithm for creating a cooperative estimated of the interested target position is developed. The basic idea of the proposed fusion algorithm is to combine local estimate of multiple UAV's. The aim of the algorithm is to provide an accurate and continues, target state estimation while being robust to failures. Ideal localization is not needed for a single vehicle to perform maneuvers to achieve a better vantage point. In this system, observation of each UAV provides an estimation of target position by the local Kalman filter and this estimation is input of a global Kalman filter for fusion of other observations. Fig. (3) displays the schematic of the data fusion system.

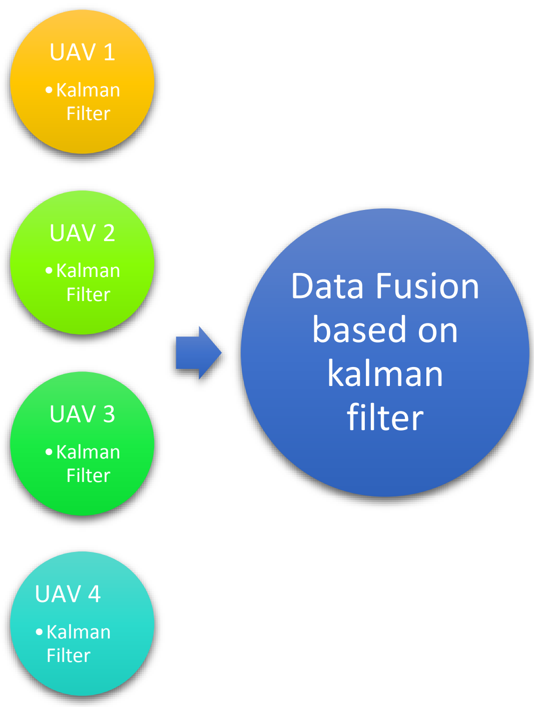


Fig. 3 The diagram of data fusion system

## 5. Results

In this section the results of localization algorithm are presented. In order to increase the similarity of an actual camera image in simulating environment, Gaussian noise with mean (m = 0.1) and variance (v = 0.01) is added.
Also the Gaussian white noise with signal-to-noise ratio (SNR = 25 dB) is combined by UAV location coordinates data in the simulation environment. The webots software

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package used to verify the performance of stereo vision estimation and tracking system. For simulating system, four quad-rotor UAV equipped with a stereo vision system was used as the test platform. The UAVs are simulated version of Airrobot drone. A small UGV robot was used as a target on the ground. In the experiment, the objective of drones was two goals. Hovering with the target in the field of view and estimating the target position in test filed. For compering performance of demonstrated system. This experiment performed with a single drone and also cooperatively with two UAV. Fig. (4) indicates the configuration of the experiment using a screenshot from testing environment.

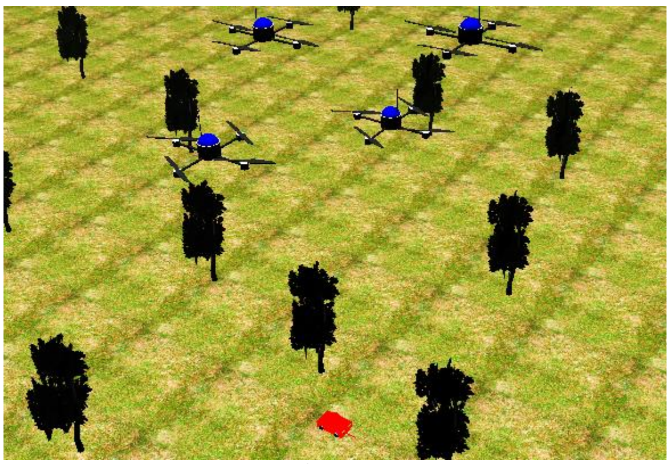

Fig. 4 Screenshot from test environment

The result of the first experiment with single, two and four UAV are shown in Fig. (5), Fig. (6) and Fig. (7). The plot shows the x-y position of the target and black rectangle illustrates the target actual position. Table 1 and Table 2 are demonstrating Standard deviation and Mean absolute error of the estimation. Fig. (7) shows the result of cooperative target localization with two UAV team and 4 UAV team.

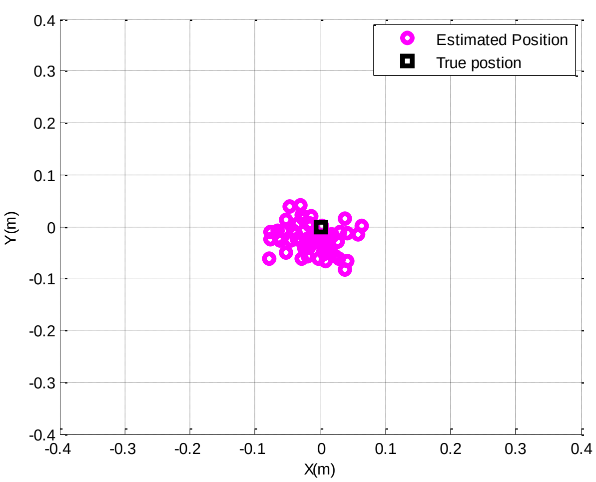


Fig. 5 Estimating the target position in test filed, single UAV

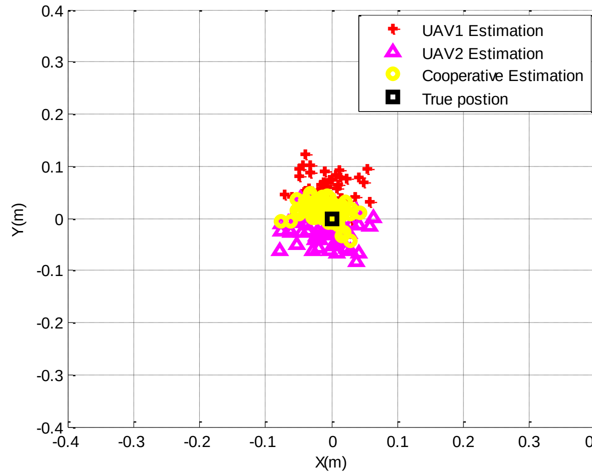


Fig. 6 Estimating the target position in test filed, cooperative (Two UAV)

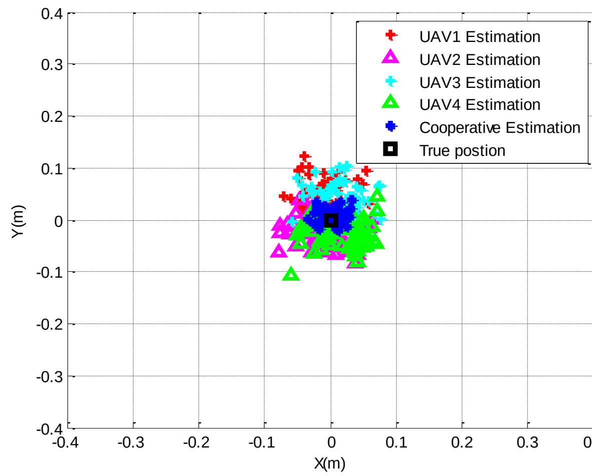


Fig. 7 Estimating the target position in test filed, cooperative (Four UAV)

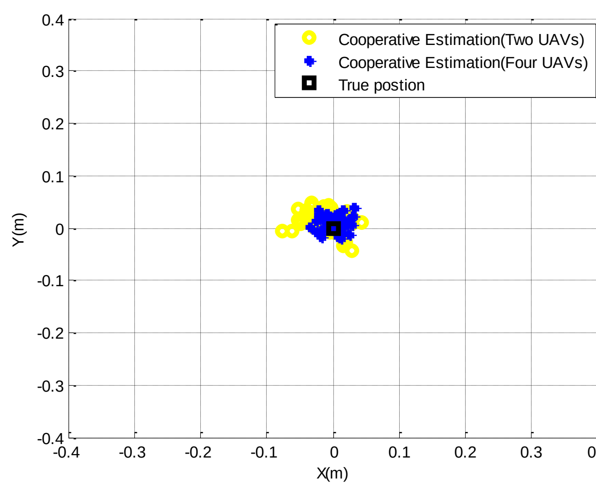


Fig. 8 Comparison of cooperative estimation with Two UAV system and Four UAV system

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Table 1: Standard deviation via single and cooperative methods

| Method | X (m) | Y (m) | Z (m) |
|---|---|---|---|
| Single | 0.034 | 0.027 | 0.030 |
| Cooperative (Two UAV) | 0.024 | 0.018 | 0.020 |
| Cooperative (Four UAV) | 0.015 | 0.012 | 0.014 |

Table 2: Mean absolute error via single and cooperative methods

| Method | X (m) | Y (m) | Z (m) |
|---|---|---|---|
| Single | 0.026 | 0.052 | 0.053 |
| Cooperative (Two UAV) | 0.020 | 0.018 | 0.051 |
| Cooperative (Four UAV) | 0.012 | 0.014 | 0.037 |

According to the results presented four UAV cooperative target localization performed more accurate against non-cooperative ways. The cooperative system also performed better then Two UAV system. The estimated location of the target for X and Y axis remains within about 0.015 m of its true location and its excellent result considering that the target itself is over 0.2m length.

## 6. Conclusions

This study demonstrated a vision-based system for cooperative localizing of interested target. The system uses stereo cameras for identifying and estimating target position relative to the camera. This work uses a Kalman filter for estimating the target position and also for fusion of each UAV's estimated data. Simulation results verify the performance of the system in cooperatively localization of target. Proposed system offer high accurate result against single UAV and also Two UAV system by filtering multiple observations. The presented system is robust in face of estimation errors cause location sensors or UAV failures. As future work we plan for improving the proposed approach to better deal with a nonlinear target motions.

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