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A HYBRID AUTONOMOUS VISUAL TRACKING ALGORITHM FOR MICRO AERIAL VEHICLES

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ABSTRACT

An efficient image tracking algorithm plays a major role in an autonomous surveillance and monitoring the environment from micro aerial vehicle. A hybrid autonomous visual tracking algorithm is proposed based on cam-shift and extended kalman filter estimator for micro aerial vehicle. The proposed algorithm identifies and tracks the ground moving target continuously, even ground moving target moves quickly, and the color of the other ground moving target or background similar to that of the ground moving target. A MATLAB based simulation tool is developed for determining the proposed algorithm performance. The results exhibit that the proposed algorithm tracks the ground moving target very accurately.

KEYWORDS: Cam Shift Algorithm; Extended Kalman Filter Estimator; Gimballed Camera Control Law; Ground Moving Target State Estimator; Hybrid Autonomous Visual Tracking Algorithm; Micro Aerial Vehicle Guidance Law.

INTRODUCTION

The scope of computer vision usage is rapidly increasing from commercial applications [1-2] to complex military applications [3-4] such as using Micro Aerial Vehicles (MAVs) or Small Unmanned Aerial Vehicles (SUAVs) [5-6] to perform surveillance [7-9] and monitoring the environment [10-12] where human beings are not accessible [13-15]. These MAVs are in very small size. These MAVs are operated by Autonomous Visual Tracking System (AVTS) from On-board or Ground Control System (GCS) [16-17].

On-board AVTS contains Gimballed Camera and along with a hybrid autonomous visual tracking algorithm. Even though, the MAV guidance and Camera control algorithms are used to operate MAV autonomously in the real world environment [18-20], the computer vision based visual tracking algorithms [21-25] are also playing a major role in the autonomous surveillance and monitoring the environment [26-28]. Due to the use of computer vision algorithm [29-31], we can reduce the expenses, improve quality and increase environmental safety [32-34]. The experimental simulation allows determining the proposed algorithm performance.

The Ground Moving Target (GMT) is detected based on image processing techniques such as the template of the GMT or color space histogram. We considered a hybrid autonomous visual tracking algorithm based on the Cam-Shift and Extended Kalman Filter (EKF) estimator in the autonomous visual tracking software, which identifies the GMT based on its color space histogram.

The autonomous visual tracking software extracts the GMT from the video sequence. This autonomous visual tracking software draws a rectangular box around the GMT. Later, this software searches the neighborhood of the previous position in the region that best matches the property of GMT. On-board autonomous visual tracking software provides the GMT parameters to the AVTS. On-board INS/GPS measures and provides the present position and the velocity of MAV to the On-board AVTS. Based on the above computations, an On-board AVTS computes and provides the MAV Guidance, Camera Control to the MAV for operating the MAV such way that the GMT continuously in the range of vision of On-board Gimballed Camera.

The main motivation is to identify the GMT, apply the proposed algorithm and tracks the GMT continuously from an On-board AVTS. On-board subsystems of AVTS are shown in Fig. 1.

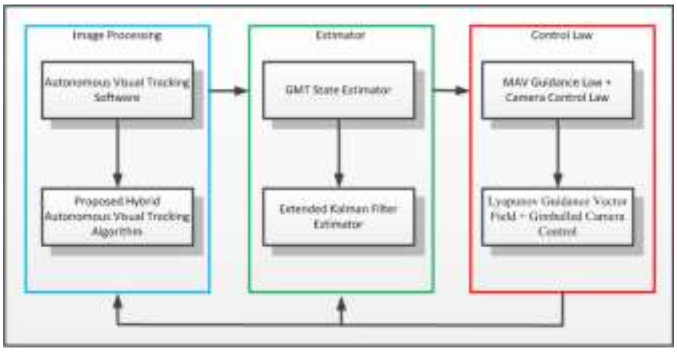

Fig. 1. On-board Subsystems of AVTS.

PROPOSED HYBRID AUTONOMOUS VISUAL TRACKING ALGORITHM

Acquire the input image frame from the Gimballed Camera, enhance the image frame using Retinex algorithm, apply the proposed hybrid autonomous visual tracking algorithm, estimate the GMT state using EKF estimator, control MAV using Lypnav Guidance Law, control the pan-tilt using Camera control Law, and the output image frame has an object of interest or GMT.

An Image Pre-processing Algorithm

The image frames are acquired from Gimbaled Camera video sequences using MATLAB Image Acquisition Toolbox [35], as frame by frame for further processing. After acquiring the image frame from video sequences, it enhances and improves the image using Retinex image pre-processing algorithm. The Retinex image pre-processing algorithm is implemented and included in a Graphical User Interface (GUI) tool using MATLAB for simulation purpose.

For more details of the Retinex image pre-processing, see [36-42].

A Hybrid Autonomous Visual Tracking Algorithm

The Cam-Shift algorithm is computationally efficient, which results fast performance [43-50]. However, it is difficult to detect when a GMT moves quickly and the similar color of another GMT enters or background color similar to that of the GMT. Hence, a Cam-Shift algorithm with an EKF [51-55] estimator is proposed for autonomous visual tracking. Whenever the GMT lost the tracking by Cam-Shift algorithm, the EKF takes the initial state of GMT from the Cam-Shift algorithm, and it estimates the GMT position accurately.

The proposed hybrid autonomous visual tracking algorithm steps are:

Step 1, Acquire the Image Frame: Acquire the $\text{Image}(x_i, y_i)$ frame from Gimballed Camera video sequences using MATLAB Image Acquisition Toolbox.

Step 2, Apply the Image Pre-processing Algorithm: Enhance and improve the Image (x_0, y_0) frame using a Retinex image pre-processing algorithm.

Step 3, Select the Initial Search Region Size and Position: Select the initial search region around the GMT in the Image (x_0, y_0) frame.

Step 4, Set the Calculatation Region of the Image Probability Distribution: Set the calculated region in the $\text{Image}(x_i, y_i)$ frame.

Step 5, Check the Color Histogram in the Image Calculation Region: Check the color histogram in the $\text{Image}(x_i, y_i)$ frame the calculation region of the HSV (Hue, Saturation, Value) image.

Step 6, Compute the Image Color Histogram Probability Distribution: Compute the $\text{Image}(x_i, y_i)$ frame color histogram probability distribution.

Step 7, Calculate the GMT Center in the Search Region: Calculate the GMT center (GMT_{11}, GMT_{20}, GMT_{02}) in the search region.

The pixel value of GMT position x in the $\text{Image}(x_i, y_i)$ is x_i, the pixel value of GMT position y in the $\text{Image}(x_i, y_i)$ is y_i, the pixel value of GMT position in the $\text{Image}(x_i, y_i)$ is (x_i, y_i), the GMT second-order moment is GMT_{11}, as follows:

$$GMT_{11} = \sum_{x_i}\sum_{y_i} x_i * y_i * \text{Image}(x_i, y_i) \tag{1}$$

The pixel value of GMT position x in the $\text{Image}(x_i, y_i)$ is x_i, the pixel value of GMT position in the $\text{Image}(x_i, y_i)$ is (x_i, y_i), the GMT second-order moment is GMT_{20}, as follows:

$$GMT_{20} = \sum_{x}\sum_{y} x_i^2 * \text{Image}(x_i, y_i) \tag{2}$$

The pixel value of GMT position y in the $\text{Image}(x_i, y_i)$ is y_i, the pixel value of GMT position in the $\text{Image}(x_i, y_i)$ is (x_i, y_i), the GMT second-order moment is GMT_{02}, as follows:

$$GMT_{02} = \sum_{x}\sum_{y} y_i^2 * \text{Image}(x_i, y_i) \tag{3}$$

Step 8, Calculate the Center of Search Region: Calculate the search region center (x_c, y_c) and the zeroth-order moment (GMT_{00}) using Mean-Shift.

The search region center position x in the $\text{Image}(x_i, y_i)$ is x_c, the GMT Scale Probability Distribution is SPD_{20}, as follows:

$$SPD_{20} = \frac{GMT_{20}}{GMT_{00}} - x_c^2 \tag{4}$$

The search region center position x in the $\text{Image}(x_i, y_i)$ is x_c, the search region center position y in the $\text{Image}(x_i, y_i)$ is y_c, the GMT Scale Probability Distribution is SPD_{11}, as follows:

$$SPD_{11} = 2 * (\frac{GMT_{11}}{GMT_{00}} - x_c * y_c) \tag{5}$$

The search region center position y in the $\text{Image}(x_i, y_i)$ is y_c, the GMT Scale Probability Distribution is SPD_{02}, as follows:

$$SPD_{02} = \frac{GMT_{02}}{GMT_{00}} - y_c^2 \tag{6}$$

The orientation of GMT is O, as follows:

$$O = \frac{\arctan\left(\frac{SPD_{11}}{SPD_{20} - SPD_{02}}\right)}{2} \tag{7}$$

The length of the search region is L, as follows:

$$L = \sqrt{\frac{A+B}{2}} \tag{8}$$

Where,

$$A = (SPD_{20} + SPD_{02})$$

$$B = \sqrt{SPD_{11}^2 + (SPD_{20} - SPD_{02})^2}$$

The width of the search region is W, as follows:

$$W = \sqrt{\frac{A-B}{2}} \tag{9}$$

Where,

$$A = (SPD_{20} + SPD_{02})$$

$$B = \sqrt{SPD_{11}^2 + (SPD_{20} - SPD_{02})^2}$$

Step 9, Move the Search Region to the Center of Image Frame: Move the search region to the center position of Step 7. Set the search region size to the zeroth-order moment in Step 7.

Step 10, Check the Search Window Center Coincides with the GMT Center or within Acceptable Value: Compute Step 4 to Step 9 and check whether the search region center coincides with the GMT center or within acceptable value.

Step 11, Apply the EKF Estimator: Whenever the GMT lost the tracking by Cam-Shift algorithm in Step 10, the EKF takes the current state of GMT from the Cam-Shift algorithm from Step 10 as the initial state of GMT and its tracks GMT continuously. Go to Step 1 and acquire the next frame.

GMT State Estimator

On-board AVTS equipped with Gimballed Camera, INS/GPS and Autopilot. The on-board Gimballed Camera provides real-time video frames to the on-board AVTS. The pixel position corresponding to the center of the GMT image is being provided by autonomous visual tracking software. This pixel position is being used to find out the GMT location in the real world. The on-board INS/GPS provides the current MAV position and velocity. The GMT state estimator uses the EKF [51-55] to estimate the GMT position and velocity when the GMT loss. Fig. 2, shows the perspective view on an object $P_c(x_c, y_c, z_c)$ in camera coordinate system. The point O_c is the centre of the camera lens. $O_c x_c$, $O_c y_c$, and $O_c z_c$ are X, Y and Z axis of the camera coordinate system correspondingly. The point P_i (U, V) is the corresponding image position (X, Y) of the ground moving target in the image plane, in which centre of the image plane is being represented by O_i and $O_i x_i$, $O_i y_i$, and $O_i z_i$ are X, Y and Z axis of the image frame coordinate system correspondingly. All three axis of camera coordinate system aligned with all three axis of the image frame coordinate system. The centre of image frame coordinates system O_i is being shifted from center of the camera coordinate system by distance F along Z axis. Here, F is the focal length of the lens of the camera.

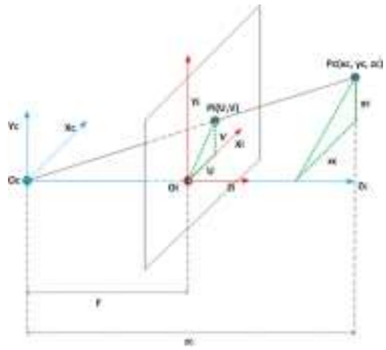

Fig. 2. Pinhole Camera Perspective Projection along Z-axis.

Fig. 3, depicts the top view of the pin-hole camera perspective projection. The Triangles $P_i O_i O_c$ and $P_c z_c O_c$ are similar triangles.

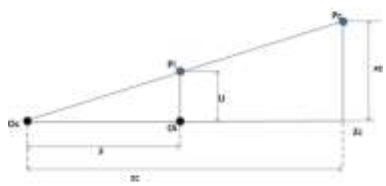

Fig. 3. Top View of the Pinhole Camera Perspective Projection.

The relation between F, U, x_c and z_c is given as:

$$\frac{U}{F} = \frac{x_c}{z_c} \qquad (10)$$

Fig. 4, depicts the side view of the pin-hole camera perspective projection. The Triangles $P_i O_i O_c$ and $P_c z_c O_c$ are similar triangles.

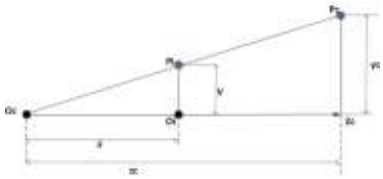

Fig. 4. Side View of the Pinhole Camera Perspective Projection.

The relation between F, V, y_c and z_c, is given as:

$$\frac{V}{F} = \frac{y_c}{z_c} \tag{11}$$

In Equation 10 and 11, the value of U, V and F are known, where as the GMT position in camera frame x_c, y_c, z_c are unknown and altitude (z_c or h) of MAV is known from Radalt.

Equation 10 can be written as:

$$U = F.\frac{x_c}{z_c} \tag{12}$$

Equation 11 can be written as:

$$V = F.\frac{y_c}{z_c} \tag{13}$$

From Equation 12 and 13 can be derived as:

$$\begin{bmatrix} U \\ V \\ F \end{bmatrix} = \frac{F}{z_c}.\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} \tag{14}$$

GMT position in camera frame $P_c(x_c, y_c, z_c)$ is given by the following, which shows that GMT position in camera frame can be obtained using GMT pixel position (U, V), camera focal length (F) and distance of the camera from the GMT (z_c) or altitude (h) above the GMT:

$$P_c = \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \frac{h}{F}.\begin{bmatrix} U \\ V \\ F \end{bmatrix} \tag{15}$$

MAV position in inertial frame $P_{MAV}(x_m, y_m, z_m)$, which is obtained from INS/GPS sensors:

$$P_{MAV} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} \tag{16}$$

The relative GMT position in inertial frame P is given as:

$$P = {}_B^I R . {}_C^B R . P_c \tag{17}$$

The GMT position $P_{GMT}(x_{GMT}, y_{GMT}, z_{GMT})$ can be computed in word coordinate system as:

$$P_{GMT} = P_{MAV} + P \tag{18}$$

After substituting Equation 16 and 17 in Equation 18, GMT position is as:

$$P_{GMT} = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + {}_B^I R . {}_C^B R . P_c \tag{19}$$

After substituting Equation 15 in Equation 19, GMT position is as:

$$P_{GMT} = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + {}_B^I R . {}_C^B R . \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} \tag{20}$$

The GMT position can be written from Equation 15 and 19 as:

$$P_{GMT} = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + {}_B^I R . {}_C^B R . \frac{h}{F} . \begin{bmatrix} U \\ V \\ F \end{bmatrix} \tag{21}$$

Where (U, V) is GMT pixel position, F is camera focal length, h is altitude above the GMT.
The GMT position in the inertial frame is denoted as:

$$P_{GMT} = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + {}_B^I R . {}_C^B R . \frac{h}{F} . \begin{bmatrix} U \\ V \\ F \end{bmatrix} \tag{22}$$

The GMT velocity in the inertial frame is denoted as:

$$P_{GMT} = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix} = \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + {}_B^I R . {}_C^B R . \frac{h}{F} . \begin{bmatrix} U \\ V \\ F \end{bmatrix} \tag{23}$$

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MAV Guidance and Camera Control Law

Based on the above visual tracking [56-60] computations by state estimator, an On-board AVTS computes and provides the MAV Guidance using Lyapunov Vector Field Guidance, Camera Control using Gimbaled Camera Controller [61-63], to the MAV for operating the MAV [64-65] such way that the GMT continuously in the range of vision of On-board Gimballed Camera [66-75].

AVTS Simulation

A MATLAB/Simulink simulation has been used to simulate the behavior of the MAV Model, Gimbal Camera Model, GMT Model to check if the autonomous visual tracking algorithm accomplishes the AVTS requirements.

RESULTS AND DISCUSSION

The method for testing the AVTS to use a realistic Simulink model to simulate all aspects of the requirements. This involved using the models of the autonomous visual tracking algorithm, pan-tilt unit, camera, and MAV.

Fig. 5, shows the test results with MAV linear model, MAV and GMT trajectory.

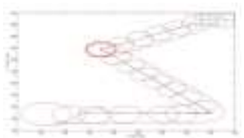

Fig. 5. MAV and GMT Trajectory.

Fig. 6, shows the test results with MAV linear model, MAV and GMT 3D trajectory.

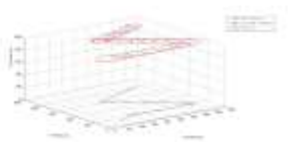

Fig. 6. MAV and GMT 3D Trajectory.

The above results exhibit that the proposed algorithm of MAV tracks the GMT very accurately.

CONCLUSION

An On-board AVTS provides the MAV Guidance, Camera Control to the MAV for the autonomous surveillance and monitoring the environment based on the computer vision visual tracking algorithm. An On-board AVTS Simulation is developed using the MATLAB GUIDE tool to identify the GMT, apply the proposed algorithm and tracks the GMT continuously. This algorithm identifies the GMT based on its color space histogram. Even, GMT moves quickly and when the color of the another GMT or background color similar to that of the GMT. An On-board AVTS is tested with MATLAB/Simulink simulation to simulate the behavior of the MAV Model, Gimbal Camera Model, GMT Model amd observed the proposed autonomous visual tracking algorithm performance. The results exhibit that the proposed algorithm of MAV tracks the GMT very accurately.

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