A multi-level visual tracking algorithm for autonomous vehicles

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A MULTI-LEVEL VISUAL TRACKING ALGORITHM FOR AUTONOMOUS VEHICLES

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Abstract: A multi-level visual tracking algorithm is proposed for autonomous vehicles based on mean-shift algorithm, cam-shift algorithm and extended kalman filter estimator. The proposed multi-level visual tracking algorithm is implemented and included in simulation to check its performance. Simulation results are captured after applying existing algorithms, proposed multi-level visual tracking algorithm and observed their performance. The simulated results show that the proposed multi-level visual tracking algorithm identifies and tracks the ground moving target efficiently.

Keywords: Autonomous Vehicles; Cam-Shift; Extended Kalman Filter; Mean-Shift; Multi-level Visual Tracking Algorithm; Probability Density Function; Retinex Algorithm.

1. INTRODUCTION

The autonomous vehicles are commonly known as Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs), and Autonomous Underwater Vehicles (AUVs).

The UAVs are commonly used in surveillance and situational awareness applications. The UAVs are very useful in environment monitor where humans are not accessible. These UAVs are also useful for military applications [1] and civil applications [2].

The autonomous visual tracking algorithm is an estimation of a moving target path in an image plane [3]. These visual tracking algorithms can be categorized based on the representation of target shape and selection of target feature.

The representation of target shape uses the target points, target shapes, target silhouette, target contour and target skeletal. The selection of target feature uses the target color, target edge, target texture.

The detection of target uses target background subtraction, target optical flow and target segmentation. The tracking of target uses kernel tracking, point tracking, and silhouette tracking.

The main challenges of target tracking [4], [5], [6], [7] are as follows: 1) target lost, 2) background objects are moving along with the target, 3) light brightness changes on the target, 4) noise in the image.

An efficient multi-level visual tracking algorithm is proposed for target tracking to overcome the target tracking challenges. The process of proposed multi-level visual tracking algorithm is as follows: 1) acquisition, 2) pre-processing, 3) execute the multi-level visual tracking algorithm, 4) post-processing.

The template matching of image processing algorithm is used to detect the Ground Stationary Target (GST) or Ground Moving Target (GMT).

The main motivation is to design and develop an efficient multi-level visual tracking algorithm for UAVs. This algorithm identifies the GST or GMT and tracks the GMT autonomously. The On-board Autonomous Visual Tracking System (AVTS) contains the proposed multi-level visual tracking algorithm.

The main goal of autonomous visual tracking of UAV is to monitor the environment where humans are not accessible [8], [9], [10].

The main purpose of on-board multi-level visual tracking algorithm is to develop and demonstrate the ability to autonomously tracking of GMT from UAV without Ground Control System (GCS) support [11], [12], [13], [14], [15], [16], [17], [18].

The steps of proposed multi-level visual tracking algorithm: 1) GMT selection, 2) GMT detection, 3) GMT tracking, are as shown in Fig. 1.

In this paper, sections are: Section 2 Existing Tracking Algorithms, Section 3 Proposed Multi-level Visual Tracking Algorithm, Section 4 On-board AVTS, Section 5 Simulation Results and Analysis, Section 6 Conclusions.
2. EXISTING TRACKING ALGORITHMS

This section explains the existing tracking algorithms [19], [20], [21], [22], [23] in detail.

The various visual tracking algorithms are Mean-Shift (MS) algorithm, Cam-Shift (CS) algorithm, Extended Kalman Filter (EKF) estimator.

A. MS Algorithm

This MS algorithm identifies and tracks the GMT based on Red-Green-Blue (RGB) color histogram Probability Density Function (PDF) of frame [24], [25], [26], [27], [28], [29], [30].

B. CS Algorithm

This CS algorithm identifies and tracks the GMT based on Hue-Saturation-Value (HSV) color histogram new PDF of each frame [31], [32], [33], [34], [35], [36].

C. EKF Estimator

This EKF estimator predicts the GMT position based on GMT previous position [37], [38], [39], [40], [41].

The main problems of the existing GMT tracking algorithms [42], [43], [44], [45], [46], [47], [48], [49], [50] are as follows: 1) GMT lost 2) background GMTs are moving along with the GMT 3) light brightness changes on the GMT 4) noise in the image.

An efficient multi-level visual tracking algorithm is proposed for GMT tracking to overcome the existing GMT tracking problems.

3. PROPOSED MULTI-LEVEL VISUAL TRACKING ALGORITHM

This section explains the proposed multi-level visual tracking algorithm in detail.

The process of the proposed multi-level visual tracking algorithm is as follows:

- Acquisition: acquire image frame-by-frame.
- Pre-processing: image enhancement using Retinex algorithm.
- Execute proposed algorithm: execute proposed multi-level visual tracking algorithm.
- Post-processing: export image frame-by-frame to graphs and reports.

The proposed multi-level visual tracking algorithm steps are:

| Step | Description |
|------|-------------|
| Step 1: | Source frame (s: 0 to 11 frames) = \( f_x(x_s, y_s) \). |
| Step 2: | Reference frame (s: 0 frame) = \( f_0(x_0, y_0) \). |
| Step 3: | Last frame (s: 11 frame) = \( f_{11}(x_11, y_11) \). |
| Step 4: | Select frame \( f_0(x_0, y_0) \). |
| Step 5: | Enhance frame \( f_0(x_0, y_0) \) using Retinex algorithm. |
| Step 6: | Select object frame \( f_{obj}(x_0, y_0) \) of the GMT from \( f_0(x_0, y_0) \) frame. |
| Step 7: | Compute object frame PDF. |
| Step 8: | Calculate target centre using MS algorithm: \( \sum \sum x_i f(x_i, y_i) \). |
| Step 9: | Compute GMT frame PDF. |
| Step 10: | If \( (f_{t-c}(x_{t-c}, y_{t-c}) < 10) \) OR (PDF of \( f_x(x_s, y_s) < 0.16) \) THEN \( f_{t-c}(x_{t-c}, y_{t-c}) \) GO TO Step 8 ELSE Compute GMT frame centre using EKF estimator: \( f_{t-c}(x_{t-c}, y_{t-c}) = A f_{obj-c}(x_{obj-c}, y_{obj-c}) \) ENDIF |
| Step 11: | Move the object frame using CS algorithm: \( f_{obj-c}(x_{obj-c}, y_{obj-c}) = f_{t-c}(x_{t-c}, y_{t-c}) \) |
Step 12: IF (target frame \( f'(x', y') \) == last frame \( f_{11}(x', y') \)) THEN

STOP
ELSE
GO TO Step 8
ENDIF

The MS and CS algorithms are computationally efficient. But, it is difficult to track GMT when the GMT moves out of frame. Hence, MS and CS with EKF based multi-level visual tracking algorithm, is proposed for GMT tracking.

Whenever the GMT moves out of frame or PDF value more than 0.16 (GMT lost by MS algorithm), then CS algorithm takes the current state of GMT and tracks the GMT continuously. Whenever the GMT moves out of frame or new PDF value more than 0.16 (GMT lost by CS algorithm), then EKF estimates the GMT position and tracks the GMT continuously.

The proposed multi-level visual tracking algorithm data flow diagram is shown in Fig. 2.

4. ON-BOARD AVTS

The On-board AVTS contains gimbaled camera along with proposed multi-level visual tracking algorithm, INS/GPS, UAV guidance [51], [52], [53], camera control [54], [55], [56] and autopilot [57], [58], [59].

5. SIMULATION RESULTS AND ANALYSIS

A MATLAB based simulation is developed for determining the proposed multi-level visual tracking algorithm performance. A Simulation of the On-board AVTS is shown in Fig. 3.

Fig. 3. On-board AVTS Simulation.

This On-board AVTS simulation acquires the image, enhances the image using a Retinex algorithm, executes the proposed multi-level visual tracking algorithm and exports the data to the graphs and reports.

We have provided the aerial input video [60] as an image frames to an On-board AVTS for GMT tracking real-time simulation, are as shown in Fig. 4.

Fig. 4. Input Image Frames (Frame-by-Frame).

The pre-processed image frames using Retinex algorithm are shown in Fig. 5.
The GMT tracking using proposed multi-level visual tracking algorithm is shown in Fig. 6.

We have considered the thirty-two input image frames (resolution is 640x480 pixels) with an On-board AVTS for experimental analysis.

The computed error between the MS algorithm, CS algorithm, EKF estimator and proposed multi-level visual tracking algorithm, are as shown in a Table I.

The computed GMT pixel position by MS algorithm, CS algorithm, EKF estimator and proposed multi-level visual tracking algorithm, are exported for off-line analysis.

The exported results are as shown in Fig. 7.

The execution times between the MS algorithm, CS algorithm, EKF estimator and proposed multi-level visual tracking algorithm are shown in a Table II.
TABLE I. COMputed Error: MS Algorithm, CS Algorithm, EKF Estimator and Proposed Multi-Level Visual Tracking Algorithm (in Pixels).

| No. | Algorithm/Estimator | Time (in msec) |
|-----|---------------------|----------------|
| 1.  | MS Algorithm        | 17.408675      |
| 2.  | CS Algorithm        | 19.523104      |
| 3.  | EKF Estimator       | 24.104903      |
| 4.  | Multi-level Visual Tracking | 15.938718 |

Fig. 7. Performance comparison: MS algorithm, CS algorithm, EKF estimator and Proposed Multi-level Visual Tracking Algorithm (in pixels).

TABLE II. MS ALGORITHM, CS ALGORITHM, EKF ESTIMATOR AND PROPOSED MULTI-LEVEL VISUAL TRACKING ALGORITHM EXECUTION TIME (IN MS).

| No. | Algorithm/Estimator | Time (in msec) |
|-----|---------------------|----------------|
| 1.  | MS Algorithm        | 17.408675      |
| 2.  | CS Algorithm        | 19.523104      |
| 3.  | EKF Estimator       | 24.104903      |
| 4.  | Multi-level Visual Tracking | 15.938718 |

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