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A MULTI-LEVEL VISUAL TRACKING ALGORITHM FOR AUTONOMOUS VEHICLES

K. Narsimlu
Ph.D. Research Scholar
Dept. of CSE
JNT University
Hyderabad, India
narsimlu@gmail.com

Dr. T. V. Rajini Kanth
Professor
Dept. of CSE
SNIST
Hyderabad, India
rajinitv@gmail.com

Devendra Rao Guntupalli
Senior Vice President
Information Systems
Cyient Ltd
Hyderabad, India
devendra.guntupalli@gmail.com

Anil Kuvvarapu
M.S. Student
Dept. of CS
University of Michigan
Michigan, USA
kuvvarapua@gmail.com

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.

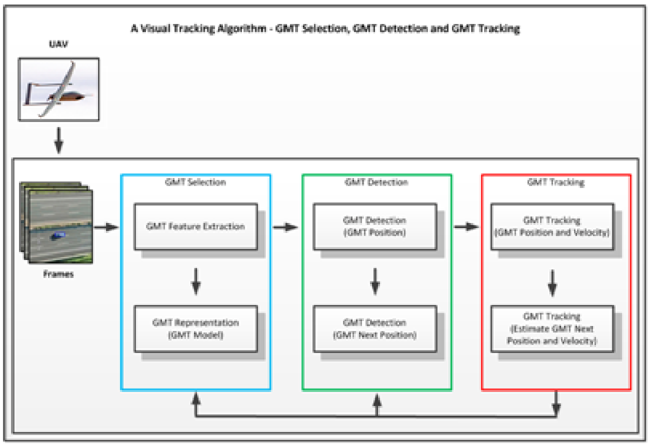

Fig. 1. Proposed Multi-level Visual Tracking Algorithm Steps: GMT Selection, GMT Detection and GMT Tracking.

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:

Algorithm 1: Multi-level Visual Tracking Algorithm

Step 1: Source frame (s: 0 to 11 frames) = $f_s(x_i, y_j)$.

Step 2: Reference frame (s: 0 frame) = $f_0(x_i, y_j)$

Last Frame (s: 11 frame) = $f_{11}(x_i, y_j)$.

Step 3: Select frame $f_0(x_i, y_j)$.

Step 4: Enhance frame $f_0(x_i, y_j)$ using Retinex algorithm.

Step 5: Select object frame $f_{obj}(x_i, y_j)$ of the GMT from $f_0(x_i, y_j)$ frame.

Step 6: Compute $f_{obj}(x_i, y_j)$ object frame PDF.

Step 7: Calculate object frame centre using MS algorithm:

$$f_{obj-c}(x_{obj-c}, y_{obj-c}) = \left(\frac{\sum_i \sum_j x_i * f(x_i, y_j)}{\sum_i \sum_j f(x_i, y_j)}, \frac{\sum_i \sum_j y_j * f(x_i, y_j)}{\sum_i \sum_j f(x_i, y_j)}\right)$$

Step 8: Compute $f_t(x_i, y_j)$ GMT frame PDF.

Step 9: Calculate target centre using MS algorithm:

$$f_{t-c}(x_{t-c}, y_{t-c}) = \left(\frac{\sum_i \sum_j x_i * f(x_i, y_j)}{\sum_i \sum_j f(x_i, y_j)}, \frac{\sum_i \sum_j y_j * f(x_i, y_j)}{\sum_i \sum_j f(x_i, y_j)}\right)$$

Step 10: IF (($f_{t-c}(x_{t-c}, y_{t-c})$ < 10) OR (PDF of $f_t(x_i, y_j)$ < 0.16)) THEN

$$f_{obj-c}(x_{obj-c}, y_{obj-c}) = f_{t-c}(x_{t-c}, y_{t-c})$$

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 $f_t(x_i, y_j)$ == last frame $f_{11}(x_i, y_j)$) 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.

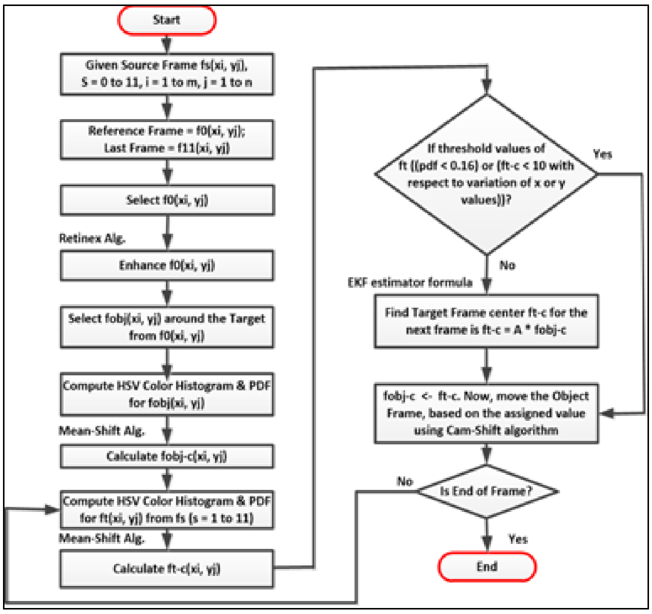

Fig. 2. Proposed Multi-level Visual Tracking Algorithm Data Flow Diagram.

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.

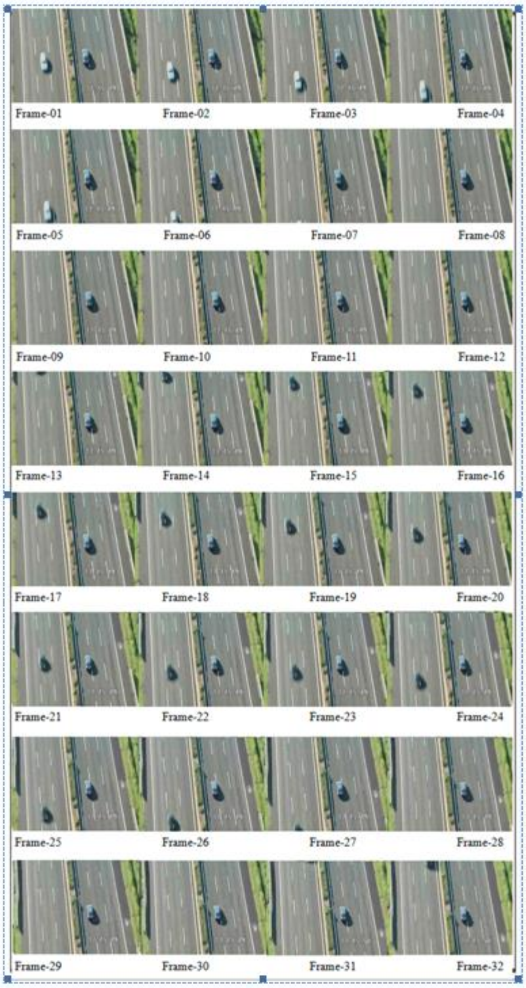

Fig. 4. Input Image Frames (Frame-by-Frame).

The pre-processed image frames using Retinex algorithm are shown in Fig. 5.

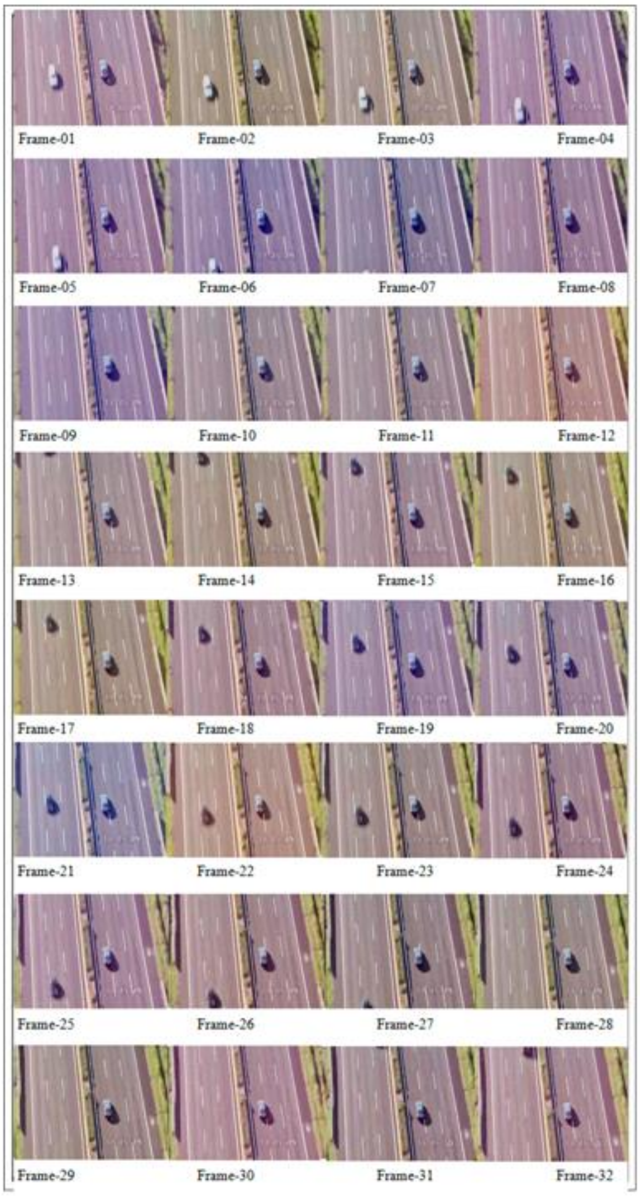

Fig. 5. Pre-processed Image Frames (Frame-by-Frame) using Retinex Algorithm.

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.

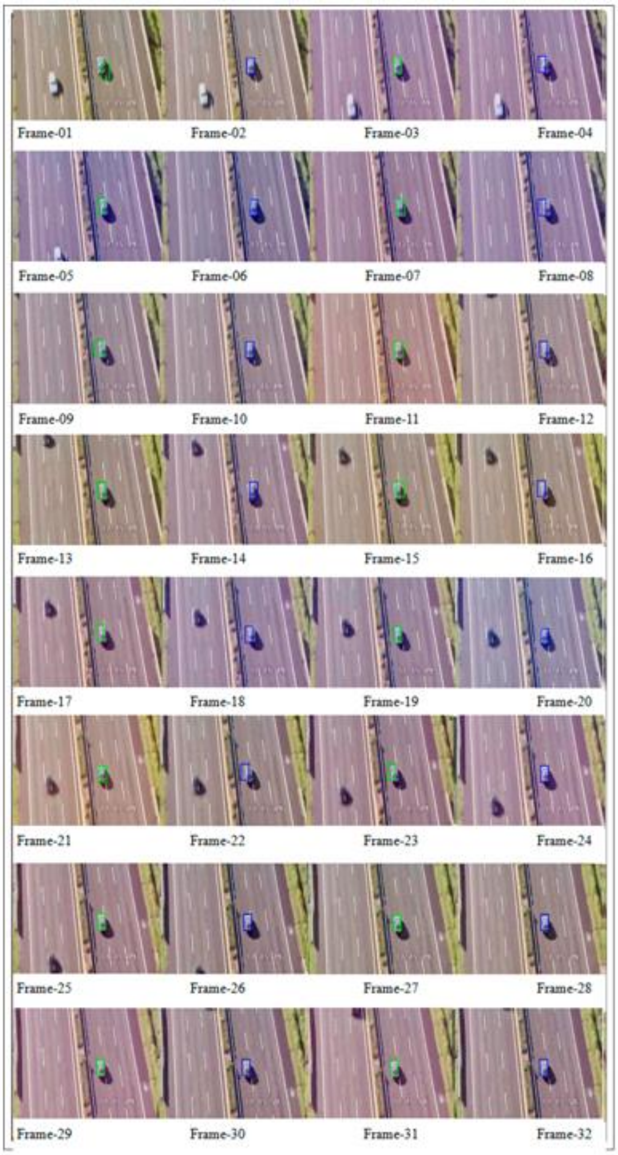

Fig. 6. GMT Tracking (Frame-by-Frame) using Proposed Multi-level Visual Tracking Algorithm.

The proposed multi-level visual tracking algorithm tracks the GMT more efficiently.

6. CONCLUSIONS

A multi-level visual tracking algorithm is proposed based on MS algorithm, CS algorithm and EKF estimator. A MATLAB based simulation is developed for determining the proposed multi-level visual tracking algorithm performance. The simulation is tested and observed the proposed algorithm performance. The simulated results prove that the proposed multi-level visual tracking algorithm identifies and tracks the GMT efficiently.

TABLE I. COMPUTED ERROR: MS ALGORITHM, CS ALGORITHM, EKF ESTIMATOR AND PROPOSED MULTI-LEVEL VISUAL TRACKING ALGORITHM (IN PIXELS).

Frame No.	GMT (X, Y) (1)		Mean-Shift (U, V) (2)		Cam-Shift (U, V) (3)		EKF (U, V) (4)		AVTS (U, V) (5)		Mean-Shift Error (1 - 2)		Cam-Shift Error (1 - 3)		EKF Error (1 - 4)		AVTS Error (1 - 5)	
	Pos X	Pos Y	Pos U	Pos V	Pos U	Pos V	Pos U	Pos V	Pos U	Pos V	Pos X	Pos Y	Pos X	Pos Y	Pos X	Pos Y	Pos X	Pos Y
1	382	232	357	205	361	208	364	212	367	215	25	27	21	24	18	20	15	17
2	385	236	361	206	365	214	368	217	371	221	24	30	20	22	17	19	14	15
3	388	233	366	208	368	211	372	215	374	218	22	25	20	22	16	18	14	15
4	388	231	370	210	370	211	372	214	374	218	18	21	18	20	16	17	14	13
5	395	237	372	211	378	217	378	219	380	225	23	26	17	20	17	18	15	12
6	392	238	375	214	376	219	379	224	380	227	17	24	16	19	13	14	12	11
7	395	237	374	215	380	220	381	223	382	225	21	22	15	17	14	14	13	12
8	392	238	376	217	378	221	380	225	382	227	16	21	14	17	12	13	10	11
9	390	238	378	218	377	222	380	225	381	228	12	20	13	16	10	13	9	10
10	391	239	381	221	379	224	382	227	383	229	10	18	12	15	9	12	8	10
11	389	240	383	224	378	226	381	228	382	232	6	16	11	14	8	12	7	8
12	387	240	384	225	377	227	380	230	382	233	3	15	10	13	7	10	5	7
13	386	241	385	227	376	228	380	231	381	235	1	14	10	13	6	10	5	6
14	387	242	386	228	378	230	381	232	382	236	1	14	9	12	6	10	5	6
15	387	242	388	230	378	231	382	234	383	238	-1	12	9	11	5	8	4	4
16	387	242	390	234	379	232	382	235	383	237	-3	8	8	10	5	7	4	5
17	386	243	391	235	380	233	381	236	382	238	-5	8	6	10	5	7	4	5
18	386	243	390	237	380	234	381	237	383	239	-4	6	6	9	5	6	3	4
19	384	244	392	238	378	235	380	237	381	240	-8	6	6	9	4	7	3	4
20	385	245	393	240	379	236	381	238	382	241	-8	5	6	9	4	7	3	4
21	385	248	395	241	380	239	381	240	382	244	-10	7	5	9	4	8	3	4
22	384	247	396	242	379	240	380	241	381	243	-12	5	5	7	4	6	3	4
23	385	249	398	243	380	241	381	243	381	245	-13	6	5	8	4	6	4	4
24	385	250	399	247	380	242	381	244	382	246	-14	3	5	8	4	6	3	4
25	386	250	400	250	381	243	382	245	383	246	-14	0	5	7	4	5	3	4
26	387	253	401	248	383	247	383	247	384	250	-14	5	4	6	4	6	3	3
27	388	255	402	250	384	249	384	249	385	252	-14	5	4	6	4	6	3	3
28	387	256	403	251	384	251	385	252	385	253	-16	5	3	5	2	4	2	3
29	388	257	404	251	385	253	386	254	386	254	-16	6	3	4	2	3	2	3
30	389	258	404	254	387	254	387	255	387	256	-15	4	2	4	2	3	2	2
31	391	261	405	255	389	258	389	258	390	259	-14	6	2	3	2	3	1	2
32	393	262	407	256	391	260	391	260	392	261	-14	6	2	2	2	2	1	1

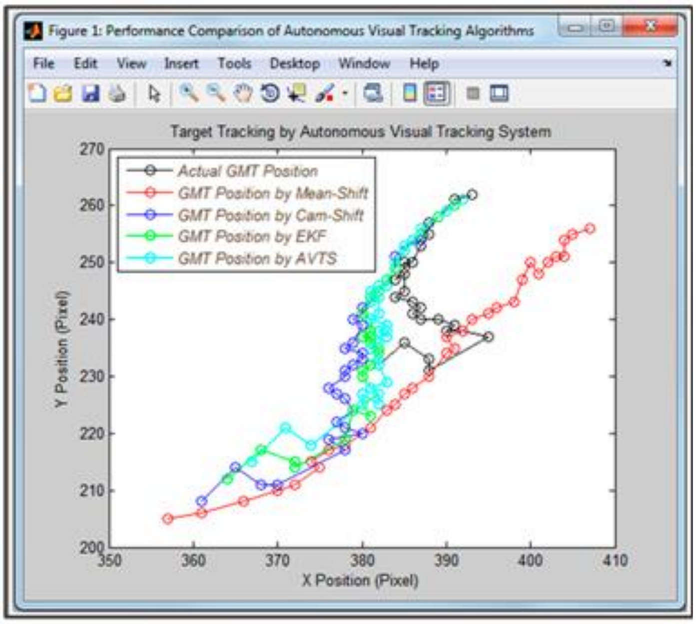

Fig. 7. Performance comparison: MS algorithm, CS algorithm, EKF estimator and Proposed Multi-level Visual Tracking Algorithm (in pixels).

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 Algorithm	15.938718

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