UNIVERSITI PUTRA MALAYSIA

AGRICULTURE • INNOVATION • LIFE

Object Detection in UAS Videos for Homeland Security: Current and Future Directions

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Presentation Outline

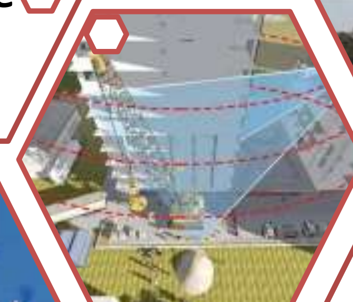
Data Acquisition

Background and why UAS

Object Detection

Surveillance

Homeland Security



Current & Future Direction

Why do we need an Malaysia Costal Patrol & Border Surveillance system?

Border Surveillance

- Some months ago, Malaysia found 'migrant' mass graves near

The several mass graves thought to contain bodies of migrants have been found in Malaysia, the graves were found in 17 abandoned trafficking camps near the Thai border. Every year thousands of people are trafficked through Thailand into Malaysia.

NEW STRAITS TIMES ONLINE

Human trafficking: Kg Puyu, Satun believed to be main entry point

SATUN (Thailand): Kampung Puyu here or known as Kampung Puju by Malaysians is believed to be one of the main entry points for human trafficking syndicates bringing Rohingya and Bangladeshi immigrants into the country.

This village is located next to Kampung Syed Omar and Bukit Bintang in Perlis and separated by the dense forest at Gunung Perlis, which is also along the Malaysia-Thailand border.

The Muslim-majority village can only be accessed by sea, a one-and-a-half hour journey from Kuala Perlis, Malaysia and 30 minutes from the Tammalang jetty in Satun.

Bernama learnt that the village is believed to have been used as the first location to house victims of human trafficking syndicates right after boats carrying refugees reached the Andaman Sea shore on the Thai side.

The route starts from Kawthaung (Myanmar) to Ranong (Thailand)-Phuket-Phang Nga-Krabi-Trang to the final destination at Satun before the migrants are smuggled into Malaysia.

Many people are wondering how the Rohingya refugees and Bangladeshi immigrants are able to enter Malaysia and where they were housed before being 'sold' in the black market.

The writers met a tour guide in Satun who only wanted to be known as Lan to find the answer. However, he asked us to pose as university students to avoid untoward incidents.

Lan, who agreed to take us to the hot spots for human trafficking boats to transit, said Kampung Puyu, although bordered by the dense forest, it was still considered as a strategic location because it has many small villages as well as rat trails to enter Malaysia.

Cuba masuk melalui sempadan Malaysia-Thailand selepas naik bot dari Ankara

PGA tahan 62 pendatang Turki

Oleh MEGAT LUTFI MEGAT RAHIM

PADANG BESAR - Keinginan untuk menikmati hidup senang dengan gaji lumayan seperti diceritakan rakan-rakan yang telah menetap di Malaysia menjadi punca 62 warga Turki bertekad menyelinap masuk ke negara ini secara haram melalui sempadan Thailand semalam.

Bagaimanapun kesemua mereka termasuk 24 orang kanak-kanak ditahan anggota Pasukan Gerakan Am (PGA) yang menjalankan rondaan rutin berdekatan pagar sempadan Malaysia-Thailand di Pos Padang Besar 16 dan 17 di sini pada pukul 6 pagi.

Pemangku Pegawai Pemerintah Batalion Tiga PGA Bidor, Deputi Superintendan S. Sivam berkata, kehadiran PATI terbabit disedari anggota PGA yang berkawal di pos berkenaan yang terlihat sekumpulan manusia.

"Semasa ditemui, mereka dalam keadaan keletihan dan kelaparan kerana berjalan kaki dari Thailand ke sempadan di sini. Hasil pemeriksaan mendapati mereka tidak memiliki sebarang dokumen perjalanan yang sah.

"Mereka mendakwa menaiki bot dari Ankara, Turki ke Thailand dan menetap selama dua hari di negara tersebut sebelum cuba masuk ke negara ini pagi ini (semalam)," katanya ketika ditemui di Kem PGA Padang Besar di sini semalam.

Jarak di antara Ankara, Turki ke Padang Besar di sini adalah kira-kira 10,650 kilometer.

Katanya, warga Turki terbabit terdiri daripada 23 lelaki dan 15 wanita berumur antara 19 hingga 40 tahun manakala 24 kanak-kanak yang ditahan pula berusia lima bulan hingga 11 tahun.

Jelas Sivam, salah seorang daripada warga Turki terbabit yang boleh berbahasa Inggeris, Abdullah Zaid, 20, memberitahu, mereka merupakan anggota keluarga, suami dan isteri serta kenalan rapat.

"Abdullah memberitahu sahabat-sahabat mereka di sini memaklumkan kehidupan di Malaysia sangat aman dan makmur tanpa konflik peperangan selain mudah mendapatkan pekerjaan yang dibayar gaji lumayan.

"Oleh kerana itu, mereka bertekad mengambil risiko dengan cuba memasuki negara ini secara haram. Kita turut menemui wang tunai berupa dolar Amerika Syarikat sebanyak A$6,500 (RM20,659.58) daripada mereka," katanya.

Katanya, kesemua mereka telah dibawa ke Depoh Tahanan PATI di Kangar dan kes disiasat mengikut Seksyen 6(1)(c) Akta Imigresen 1959/63.

SIVAM (kanan) memeriksa dokumen perjalanan 62 rakyat Turki yang ditahan di sempadan Malaysia-Thailand, Padang Besar, Perlis semalam.

Smuggle diesel at Malaysia Thai border

Thai authorities in the border towns have detected a rise in the smuggling of petrol and diesel from Malaysia following a sharp increase in domestic fuel prices in Thailand.

Ops Titik berjaya tangani penyelewengan diesel

KUALA PILAH – Menteri Perdagangan Dalam Negeri, Koperasi dan Kepenggunaan, Datuk Seri Hasan Malek (**gambar**) menegaskan Ops Titik yang dilaksanakan bagi menangani penyelewengan diesel mula membuahkan hasil dengan 151 kes dicatat membabitkan sitaan bernilai RM8.05 juta sejak dilancar pada 15 Mei lalu.

Katanya, operasi bersepadu itu menyasarkan semua pihak, bukan setakat individu tertentu tetapi juga syarikat dan kawasan panas yang dikenal pasti menerusi risikan.

"Semalam sahaja, dua kes dilapor di Selangor dengan nilai sitaan berjumlah RM116,006, manakala pada Jumaat lalu sebanyak lapan kes iaitu empat di Kelantan, dua di Negeri Sembilan dan satu kes masing-masing di Sabah dan Sarawak dengan nilai sitaan RM186,560," katanya kepada pemberita di sini semalam.

Menurut Hasan sepanjang Ops Titik, Johor dan Putrajaya mencatatkan kes tertinggi iaitu enam kes, namun dari segi nilai sitaan, Johor mencatat jumlah tertinggi dengan jumlah RM2.166 juta, manakala Putrajaya RM1.592 juta.

Selain itu, beliau berkata, [illegible]

dang menambah baik peruntukan undang-undang sedia [illegible]

Traditional border monitoring:

Artificial monitoring ways include standing guard, lookout, patrol, video camera, ground sensors, physical barriers, land vehicles and manned aircraft.

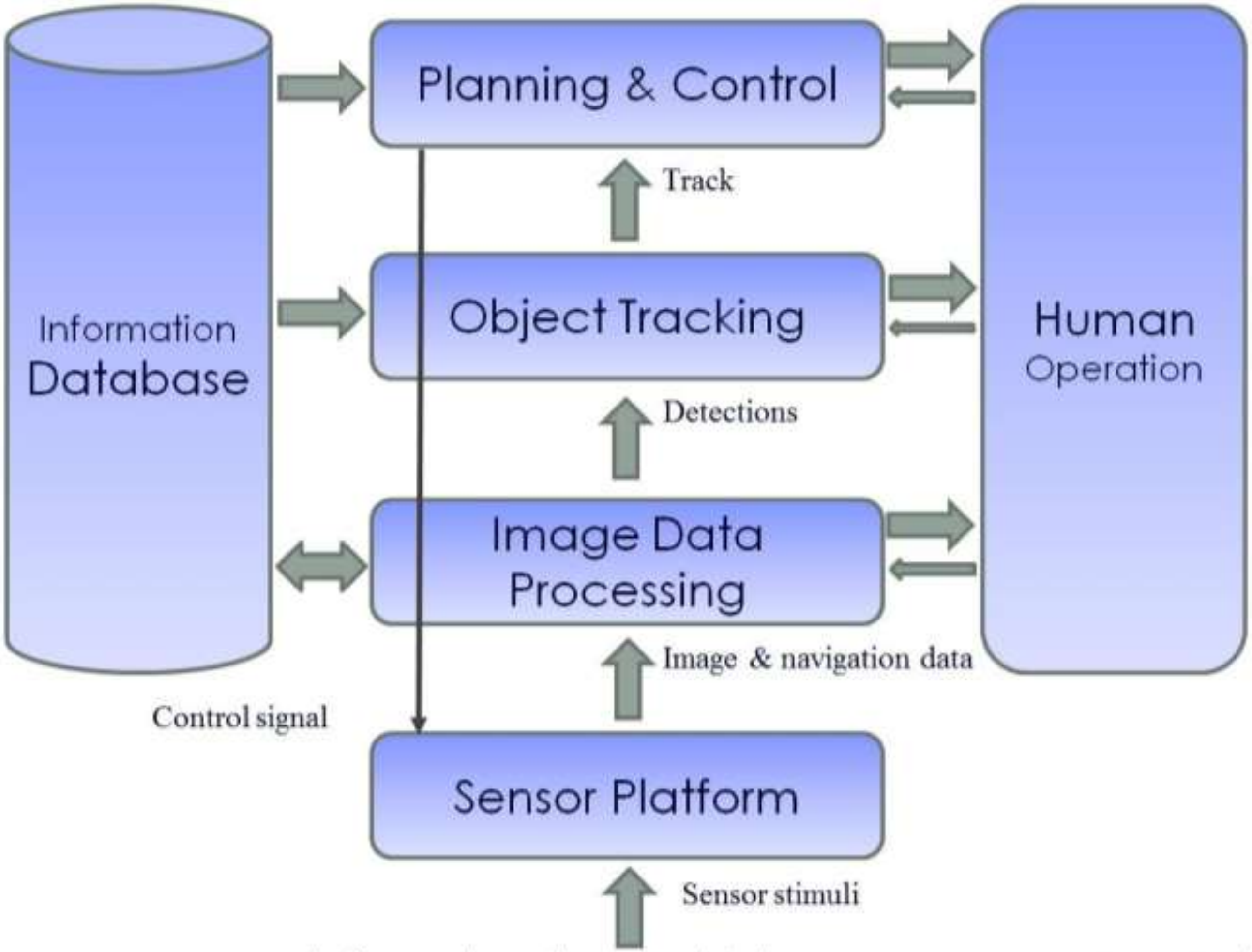
Disadvantages

1. small surveillance scope
2. cumbersome for human operators to monitor for long durations

Border Surveillance

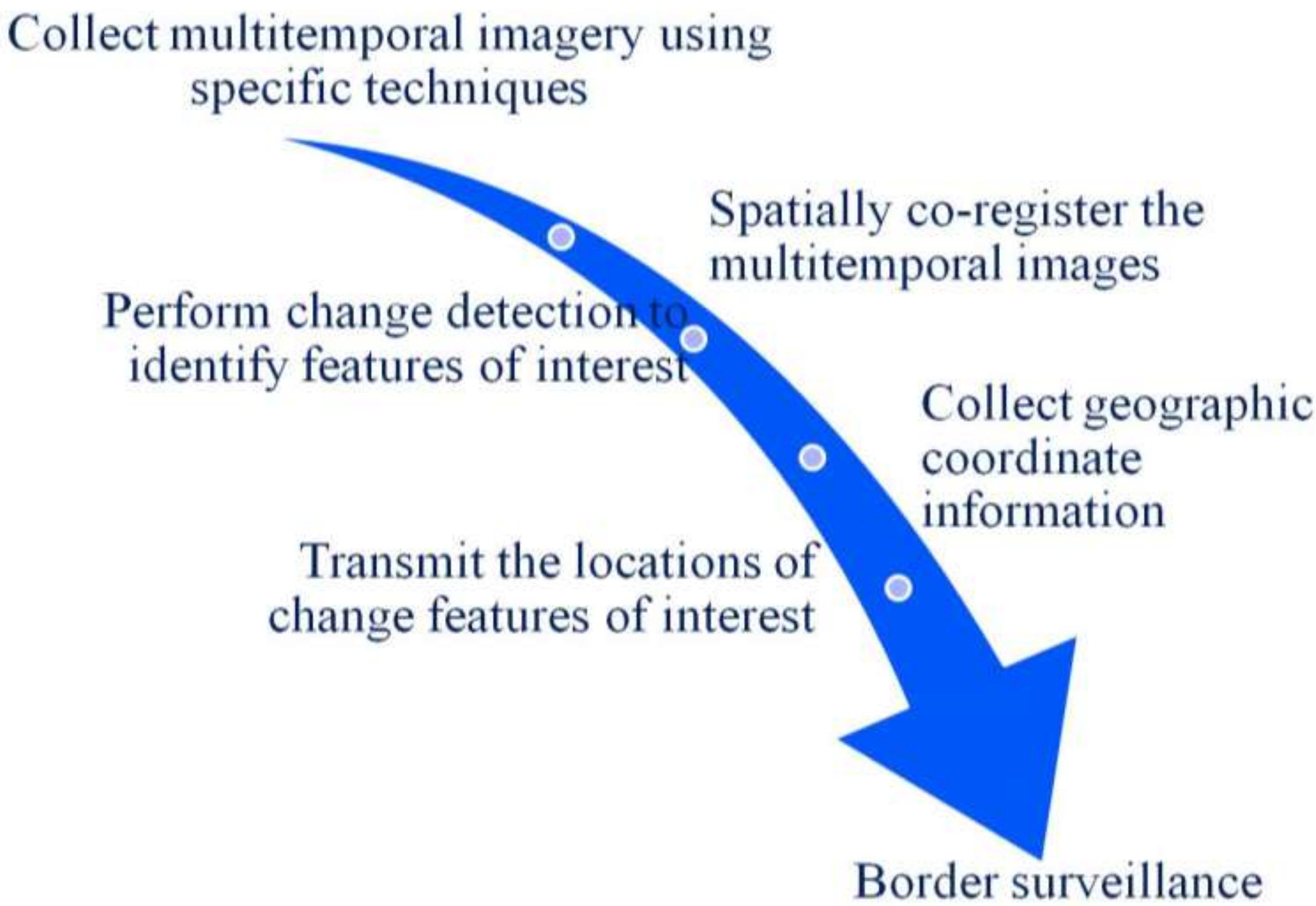
Illegal migrant routes along Malaysia-Thailand border still open and in use (Illegal forest crossing from Thailand to Malaysia still exist).

Border Surveillance Framework



Thick arrows represent sensor or information data, and thin arrows represent control signals.

Five basic steps for Border Surveillance



Land Phases

Phase 1 Strategic Level	Phase 2 Strategic/ Operational level	Phase 3 Operational/ tactical level
Static – reference maps (prerequisite for Phase 2)	Low-time critical – background changes	Punctual monitoring – volume/flux of actual crossings

Land Surveillance- Phase 1 & 2

a) This service include following functionalities:

- Obtain a reference situational picture on the topography, transport infrastructure, routes, hubs/nexus points, stopovers etc.

- Conduct change analysis by comparison to the reference picture on a regular basis to detect any changes;

- Detect or verify the routes potentially used by illegal migrants and smugglers of contraband and to adapt border control measures (patrols, deployment of surveillance infrastructure) accordingly;

- Gather further information expanding on intelligence (e.g. on gathering points; in situation of urgent and exceptional pressure at certain external land border sections as result of a political crisis, natural catastrophes);

Land Surveillance- Phase 1 & 2

b) Requirements:

Static:

- Enable mapping of terrain, including topography, land cover, buildings, roads, tracks, demarcations, etc., by virtue of adequate spatial resolution (horizontal and vertical), spectral power, etc.;
- Product must be ortho-rectified and terrain geo-coded, which implies that also a DEM at the proper resolution must be available;
- Geographic features should be in vector form in order to facilitate their automatic identification, selection and query;
- Data must be in such a form that they can be combined with existing maps used by the authorities (projection, datum, format, standards).

Indicative Performance Requirements

Attribute	Optical	Radar	Remarks
Resolution	50 cm – 5 m	1 m – 50 m	Higher resolutions are classified. Lower resolutions are not used for surveillance.
Image Size	For the highest resolution, 10 x 10 km. For lower resolutions, up to 60 x 60 km.	For the highest resolution, 10x10 km. For lower resolutions, up to 400x400 km.	The higher the resolution, the smaller the image.
Tasking Time	Normal: 12h to days before overpass. Fast: asap to 12h before overpass.	Normal: several days ahead. Fast: 6 to 24 h ahead	Precise times vary per satellite operator. Orders at short notice are (much) more expensive.

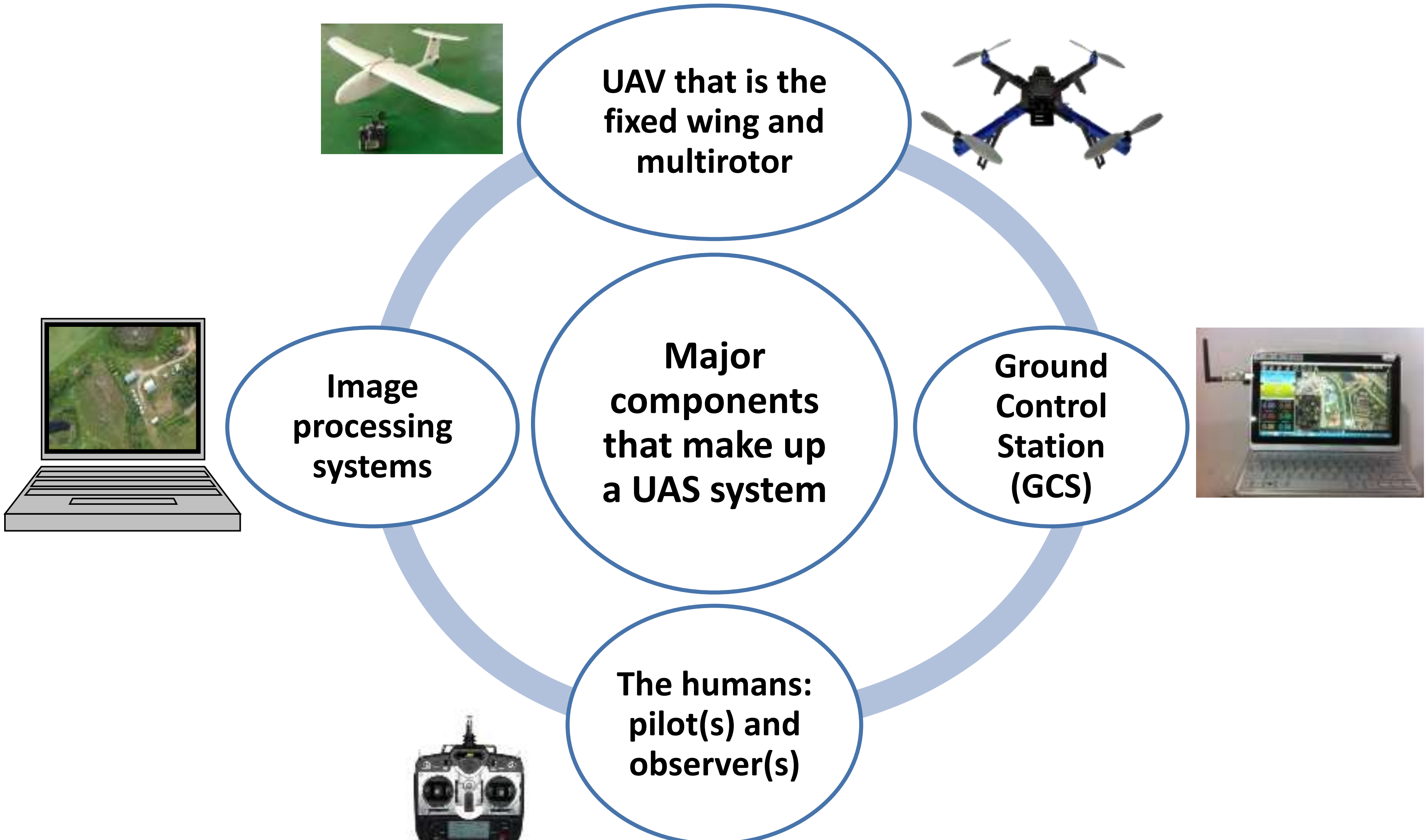
Indicative Performance Requirements

Attribute	Optical	Radar	Remarks
Delivery Time (after image acquisition)	Normal: 1 day. Fast: few hours	Normal: up to 1 day. Fast: up to 30 min	Precise times vary per satellite operator. Very fast times can be obtained only for a few images, not for all. VHR data may be intentionally delayed on national security laws. Faster delivery is more expensive.
Processing and analysis time	Over land: Fast analysis: 1-3 hr. Full analysis: 1 day. Ship detection at sea: Fast analysis: 1 hr. Full analysis: 6 hr.	Over land: Fast analysis: 1-3 hr. Full analysis: 1 day. Ship detection at sea: Fast analysis: 30 min. Full analysis: 1h – 1h30 min.	The time depends on the area of interest within the image that needs to be analysed, the density of objects, the exact nature of the analysis, etc.

Optical Satellites

Satellites	Spatial resolution (after pan-sharpening)	Frequency	Equator Crossing Time
Worldview-4	0.31 m	< 1.0 day	10.30 am
Worldview-3	0.31 m	<1.0 day	10.30 am
Worldview-2	0.46 m	1.1 days	10.30 am
Worldview-1	0.46 m	1.7 days	10:30 am
GeoEye-1	0.46 m	2.1 days	10:30 am
Pleiades-1A	0.5 m	Daily	10.30 am
KOMPSAT-3A	0.55 m	Daily	10.30 am
KOMPSAT-3	0.7 m		10.30 am
QuickBird	0.65 m	1-3.5 days	10:30 am
Gaofen-2	0.8 m		10.30 am
TripleSat	0.8 m	daily	10:30 am local time
IKONOS	0.82 m	3 days	10:30 am solar time
SkySat-1	0.9 m		10.30 am
SkySat-2	0.9 m		10.30 am
SPOT-6	1.5 m		10.30 am
SPOT-7	1.5 m		10.30 am
Other Satellites	2 m-20 m		

UAS system


UAV that is the fixed wing and multirotor
Major components that make up a UAS system
Image processing systems
Ground Control Station (GCS)
The humans: pilot(s) and observer(s)

Types of UAS

Attribute	**Multirotor**	**Fixed Wing**
Size of Project	Up to 100 acres (~30 ac /flt)	1200 ac + (~400 ac / flt)
Learning Curve	Easiest + smaller datasets	More complex (+ larger datasets)
Landing/takeoff area	Vertical (Very small)	Larger clear area for takeoff/landing
Altitude / detail	Lower alt / higher detail / less coverage	Higher alt / less detail / greater coverage
Flt times	~21 mins	~50 mins
Cost of entry	$2000 – $3000	$12,500 – $34,000

Sensors

Visual / Near Infrared Imaging Camera	
Type	Interchangeable lens digital camera
Image sensor	APS-C
Pixel resolution	16.1 (MP)
Color depth	23.7 (bit)
Size	111 x 59 x 39 (mm)
Weight	466 (g)
Power consumption	2.7 (W)

Multispectral Imaging Camera Array	
Type	Array of 4, 6 or12 aligned and synced camera's
Optics	9.6 (mm) fixed lens
Filters	450 (nm) to 1000 (nm)
Pixel resolution	5.2, 7.8 or 15.6 (MP)
Size	154.4 x 78.3 x 87.6 (mm)
Weight	600, 700 or 1300 (g)
Power consumption	4, 5.4 or 9 (W)

Hyperspectral Imaging Sensor	
Type	Silicon CCD
Spectral resolution	1.9 (nm)
Spectral/spatial bands	325 / 640
Frame rate	200 (fps)
Size	76 x 76 x 119 (mm)
Weight	670 (g)
Power consumption	9 (W)

LIDAR	
Laser	Class 1 - 905 (nm)
Sensor	32 laser/detector pairs
Field of View V	+10.67 to - 30.67 (degrees)
Field of View H	360 (degrees)
Size	150 x 86 (mm)
Weight	1000 (g)
Power consumption	12 (W)

Sensors

Object Tracking

Allows you to designated a region of interest on the video as a target. The gimbal automatically steers to keep the object center of frame throughout platform movements. The template matching algorithm allows you to track objects even if they are partially obscured.

Motion Detection

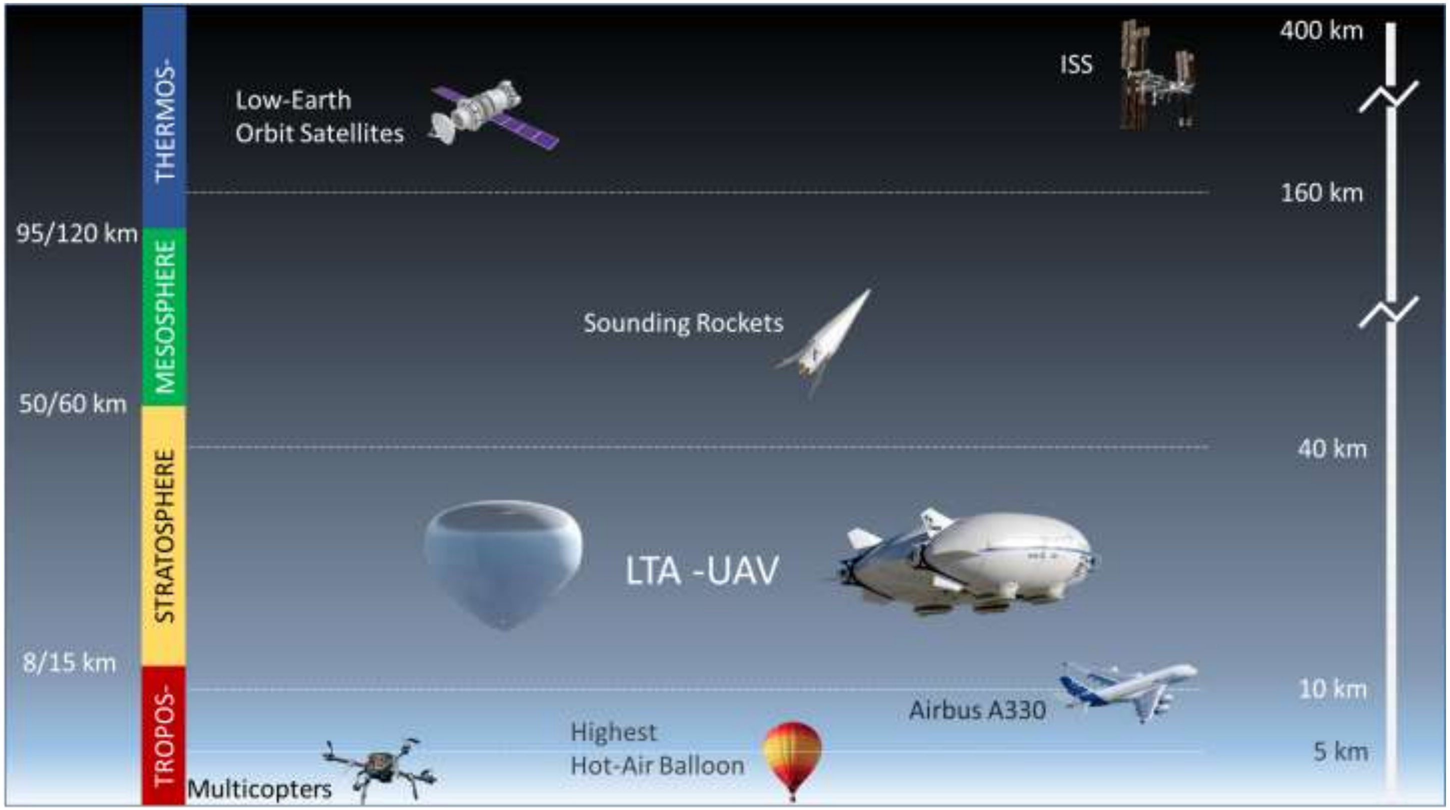
You can follow multiple cars travelling on a road-will automatically tag up to 5 moving object within its FOV

Lighter-than-Air Unmanned Aerial Vehicle (LTA-UAV)

Refers to aerial vehicle that

- Generates all or a fraction of its lift using gases e.g. helium or hydrogen
- Operates without pilot, either under remote control or full-autonomously by an onboard computer
- Examples: airship, hybrid airship, high-altitude balloon

LTA-UAV Operating Altitude Capability



Station-Keeping and High-Altitude Observation
Free-floating Balloon vs HTA (Glider) vs LTA

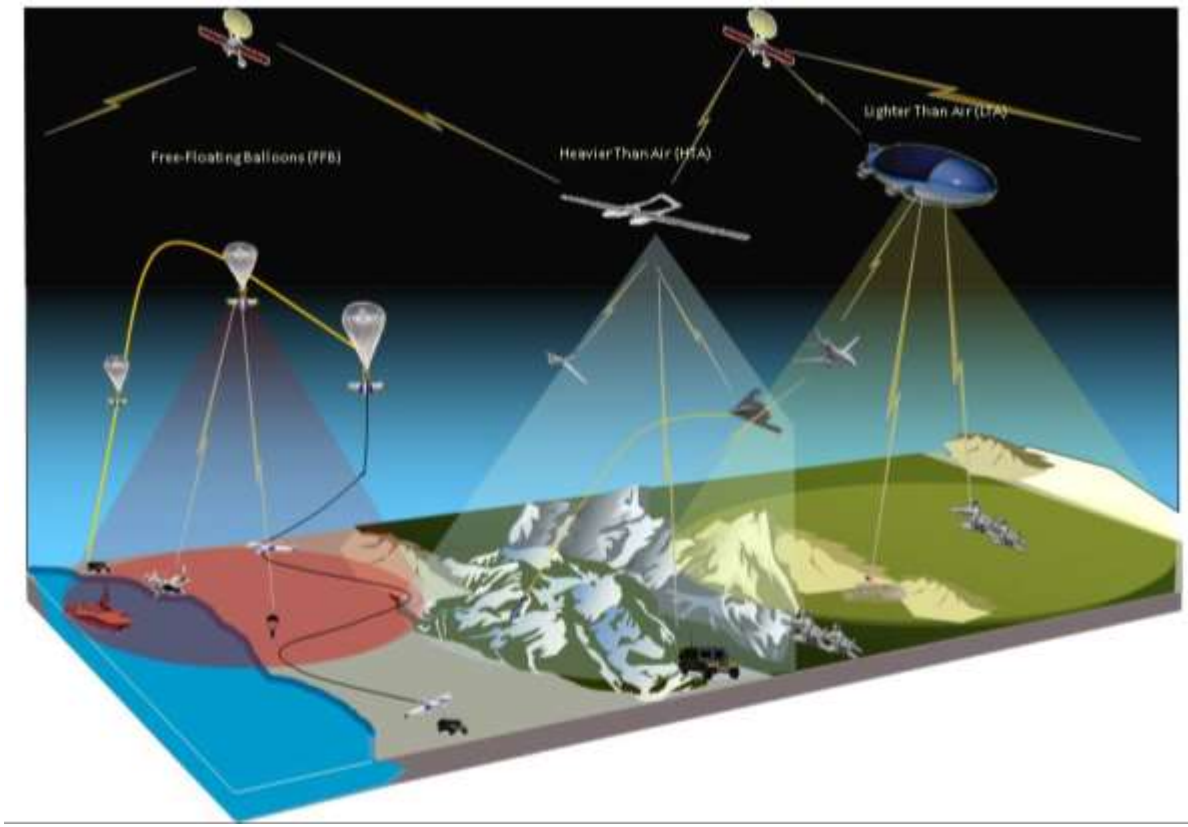
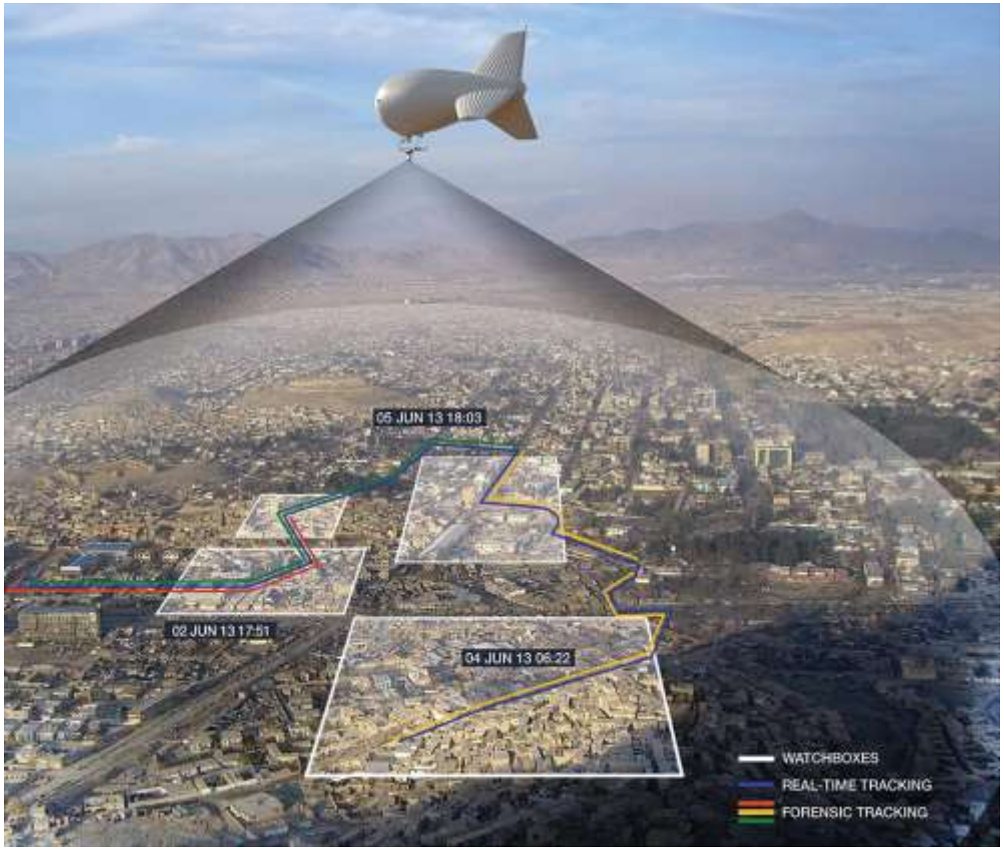


Photo credit: Courtesy graphic https://www.army.mil/article/62316

Persistent Surveillance & Wide-area Motion Imagery



Graham Warwick, *Aviation Week & Space Technology,* Defense & Space Technologies to Watch in 2016

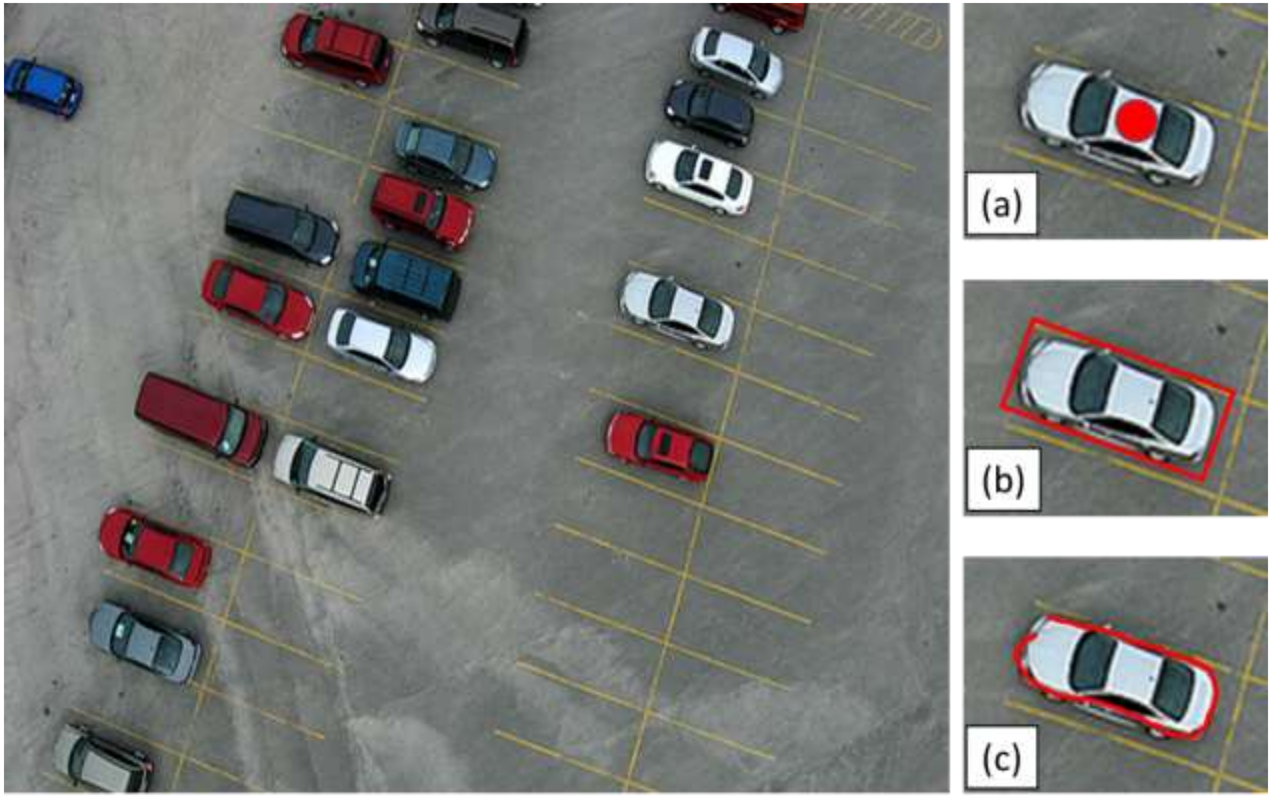
Comparison with other Surveillance Options

Multicopter	Balloon/Airship	Airplane/Heli	Satellite
			
Altitude: up to 700 m	**Altitude:** 10km-40km	**Altitude:** 50-3500 m	**Altitude:** 160- 500 km
Coverage: Small	**Coverage:** Large	**Coverage:** Large	**Coverage:** Very large, global
Cost: Low	**Cost & Usage :** Medium	**Cost & Usage :** High	**Cost & Usage :** High
Maneuver: Flexible & Narrow	**Maneuver:** Persistent	**Maneuver:** Flexible, semi-persistent	**Maneuver:** Fixed path, non-persistent
Concern: Battery, Weather	**Concern:** Helium, maneuverability (wind)	**Concern:** Fuel, High-risk (Manned)	**Concern:** Cloud, frequency of revisit

Object Tracking

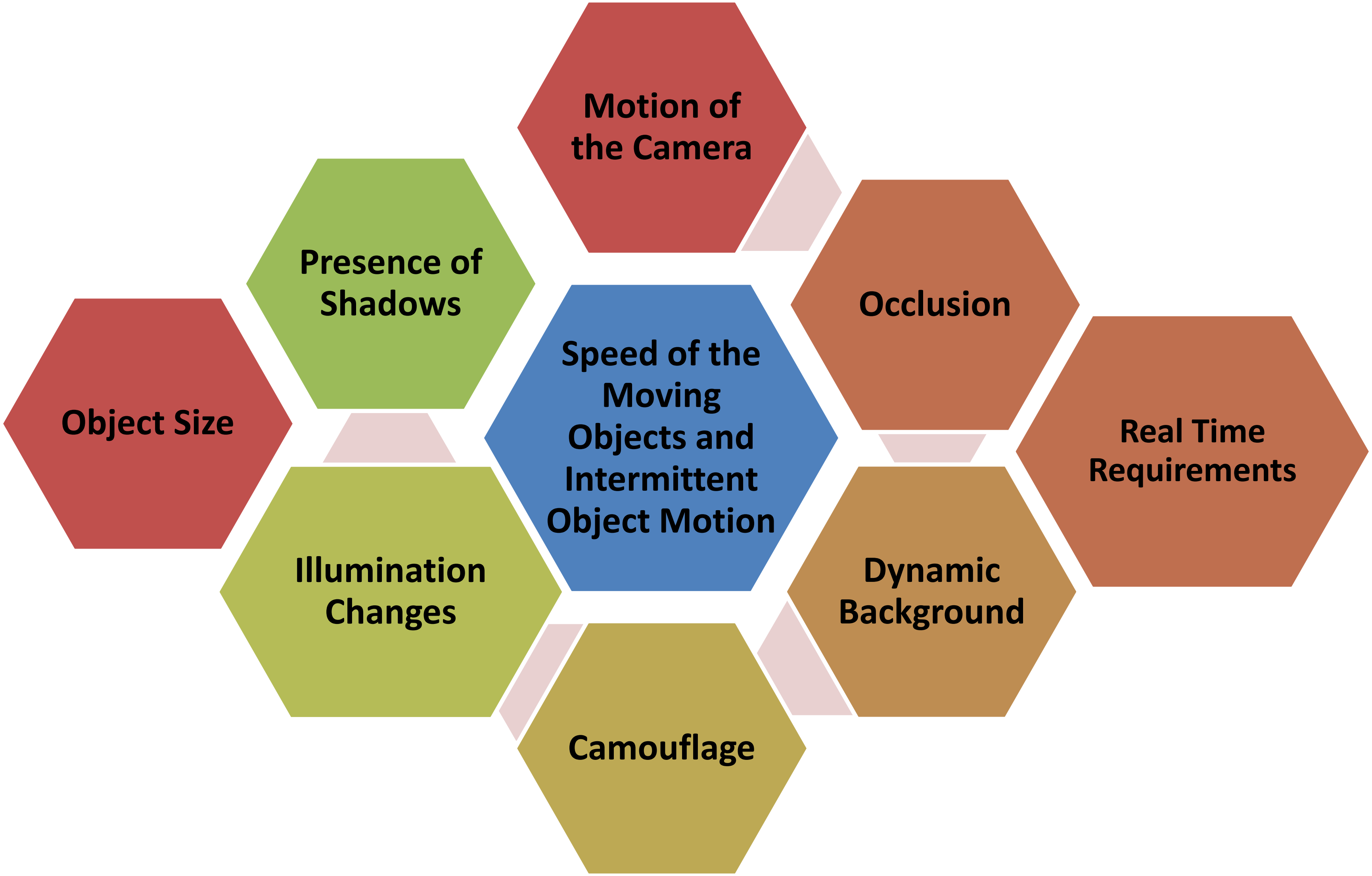
- Track an object (or multiple objects) over a sequence of images.
- Tracking is usually performed in the context of higher-level applications that require the location and/or shape of the object in every frame.

Object Representation



Car object representation, (a) point, (b) primitive geometric shape, (c) skelton model (complete contour).

Object Detection Challenges



Common Algorithms for Object Detection

Object detection methods	Advantages	Disadvantages
Optical flow	✓ it can work even in the presence of camera motion	✓ sensitive to illumination changes and noise. ✓ often can only detect partial edge shapes of moving objects. ✓ computationally complex.
Temporal differencing	✓ The algorithm is simple and can quickly detect motion object while it appears. ✓ adaptive to dynamic environments	✓ unable to detect all relevant pixels and complete shapes of foreground objects. ✓ small changes in object movements or stopping objects can cause temporal differencing to fail
Background subtraction	✓ flexible and fast ✓ Low memory requirement ✓ its computational simplicity	✓ camera vibration and speckle noise also seriously affects the accuracy of detection ✓ background scenes need to be consistent while the camera should also be fixed.

Current approaches

	Advantages	Disadvantages
Coarse-to-Fine and Boosted Classifiers	Real time, it can work at small resolutions	Features are predefined
Dictionary Based	Representation can be shared across classes	It may not detect all object instance
Deformable Part-Based Model	It can handle deformation and occlusion	It cannot detect small objects
Deep Learning	Representation can be transferred to other classes	Large training sets specialized hardware (GPU) for efficiency
Trainable Image Processing Architectures	General purpose architecture that can be used in several modules of a system	The obtained system may be too specialized for a particular setting

Registration Methods

- A popular approach to moving object detection involves image registration by discovering correspondences between consecutive frames based on image appearances under rigid and affine transformations.

- However, spatial feature layouts and correlations between pixels are ignored and illumination changes in consecutive frames make correspondences between feature points unreliable.

- More importantly, the transformations that align points are simply assumed to be parametric (e.g., rigid, and affine), which is not the case in real life situations.

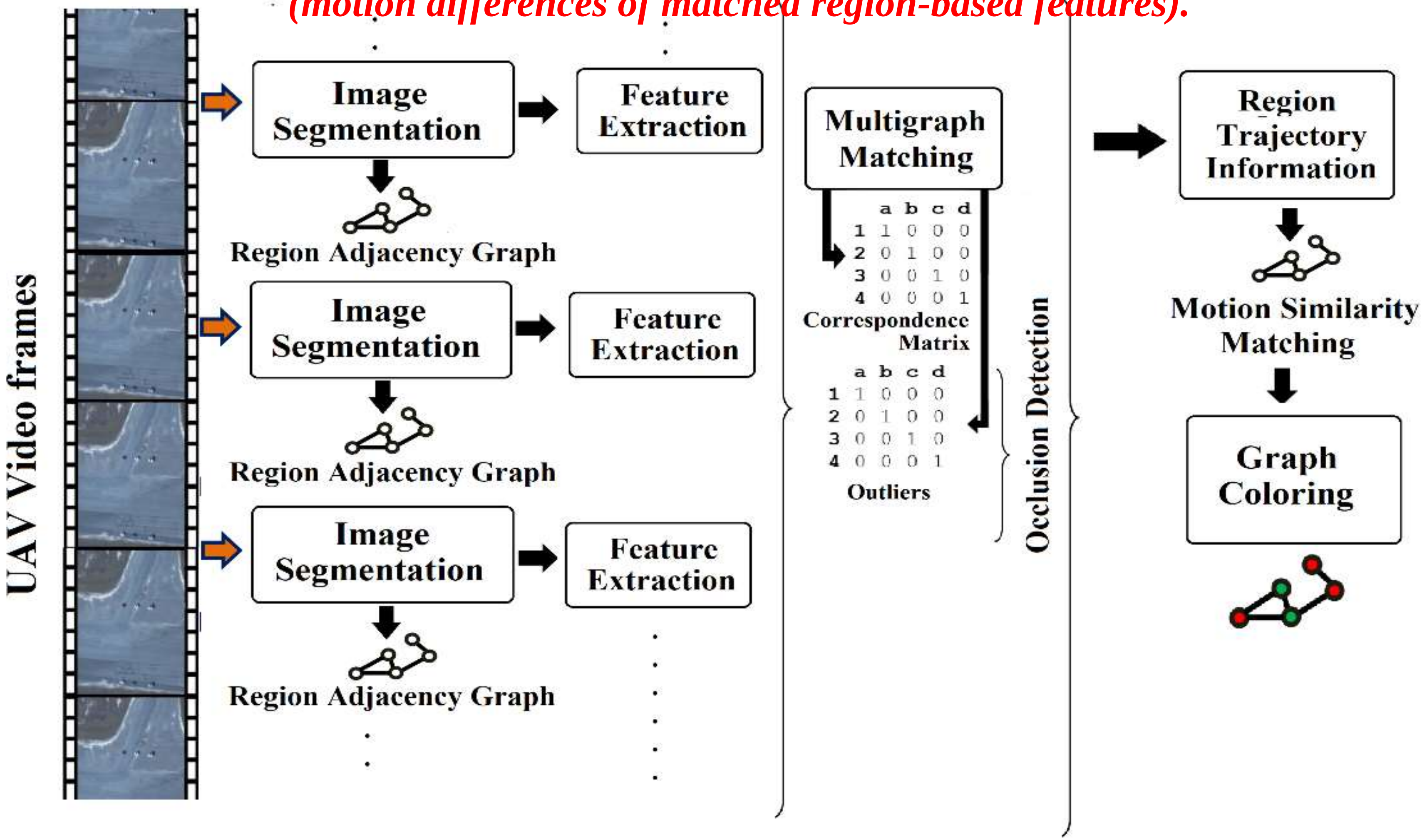
Automatic Registration Methods

Registration method	Advantages	disadvantages
ABM	✓ can produce real-time results due to their easy hardware configurations.	✓ provide little information for the transformation estimation . ✓ not robust to image distortions and illumination changes. ✓ They assume the presence of discriminatory information in pixel intensities, and thus, making salient structures undetectable.
FBM	✓ salient image structures can be identified from the extracted features. ✓ able to handle image distortions and illumination variations ✓ Determine correspondence and the underlying spatial transformation between local features (reduce feature matching problem.	✓ the correspondence set can include false matches (outliers) in addition to the inliers due to the ambiguity caused by the descriptors

Methodology (Moving Object Detection)

MDMRBF

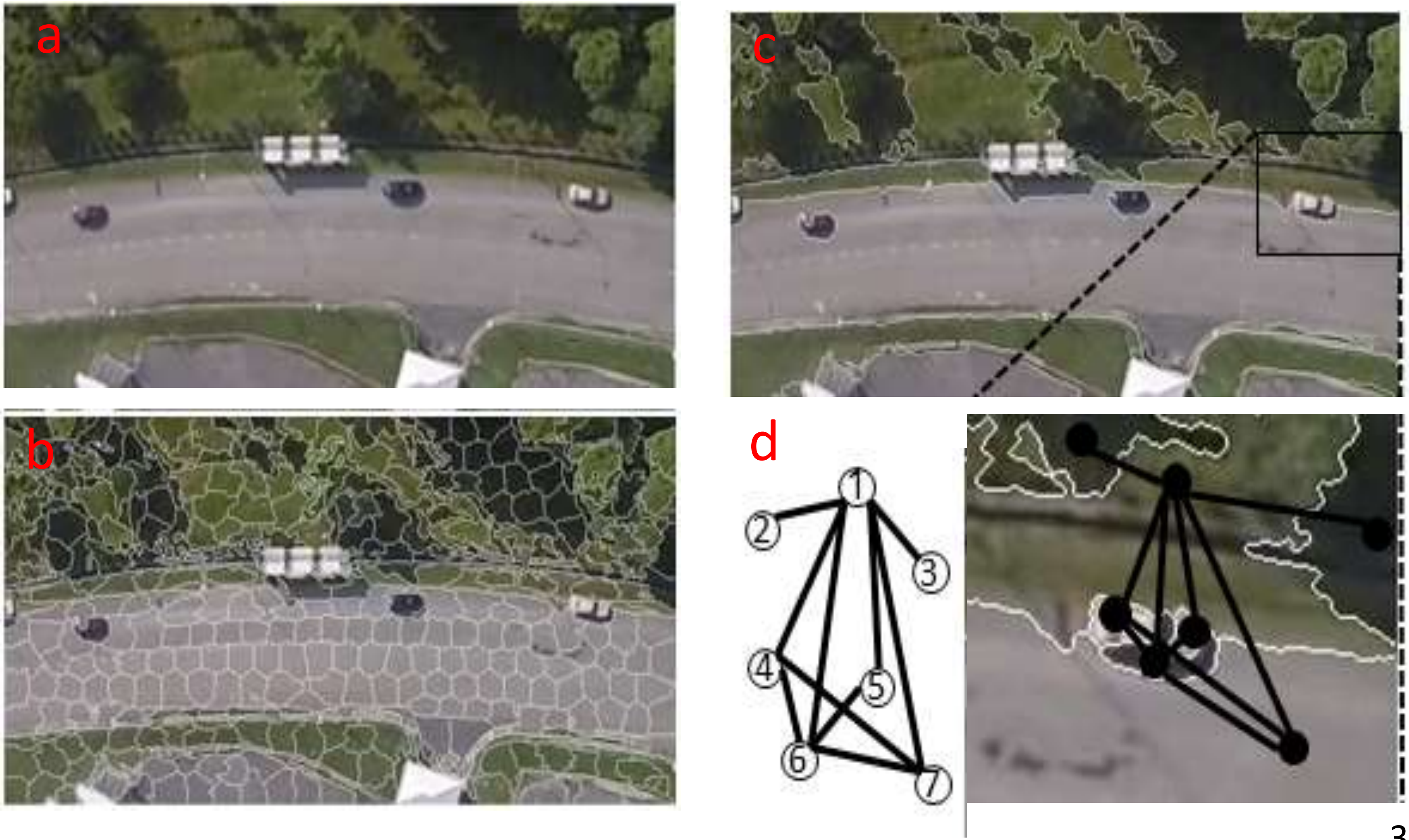
(motion differences of matched region-based features).



Regional adjacency graph construction. (a) original image (b) segmented image (c) after region combination and (d) a part of the segmented image where the constructed RAG shows region connectivity.

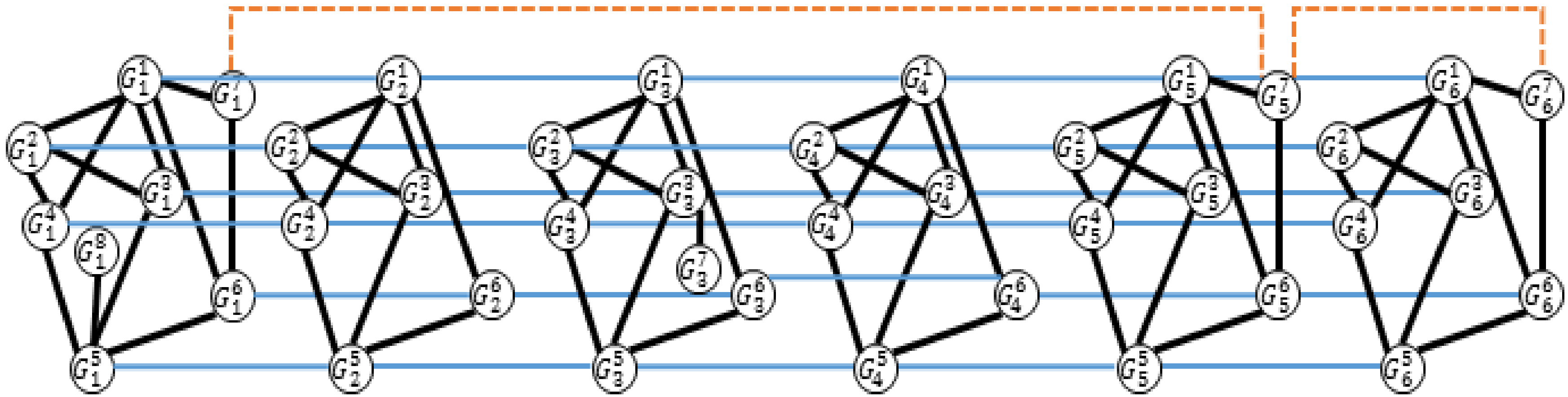
$$S(dcd_1, dcd_2) = \sum_{i=1}^{N_1}\sum_{j=1}^{N_2} a_{i.j}\theta_{i,j}$$

$$\theta_{i,j} = [1 - |p_1^i - p_2^j|] \times min(p_1^i, p_2^j),$$



Region Matching

Multigraph Matching Algorithm



frame 650 frame 680 frame 710

* The detected inliers are connected by solid lines, and the dashed lines connect outliers.

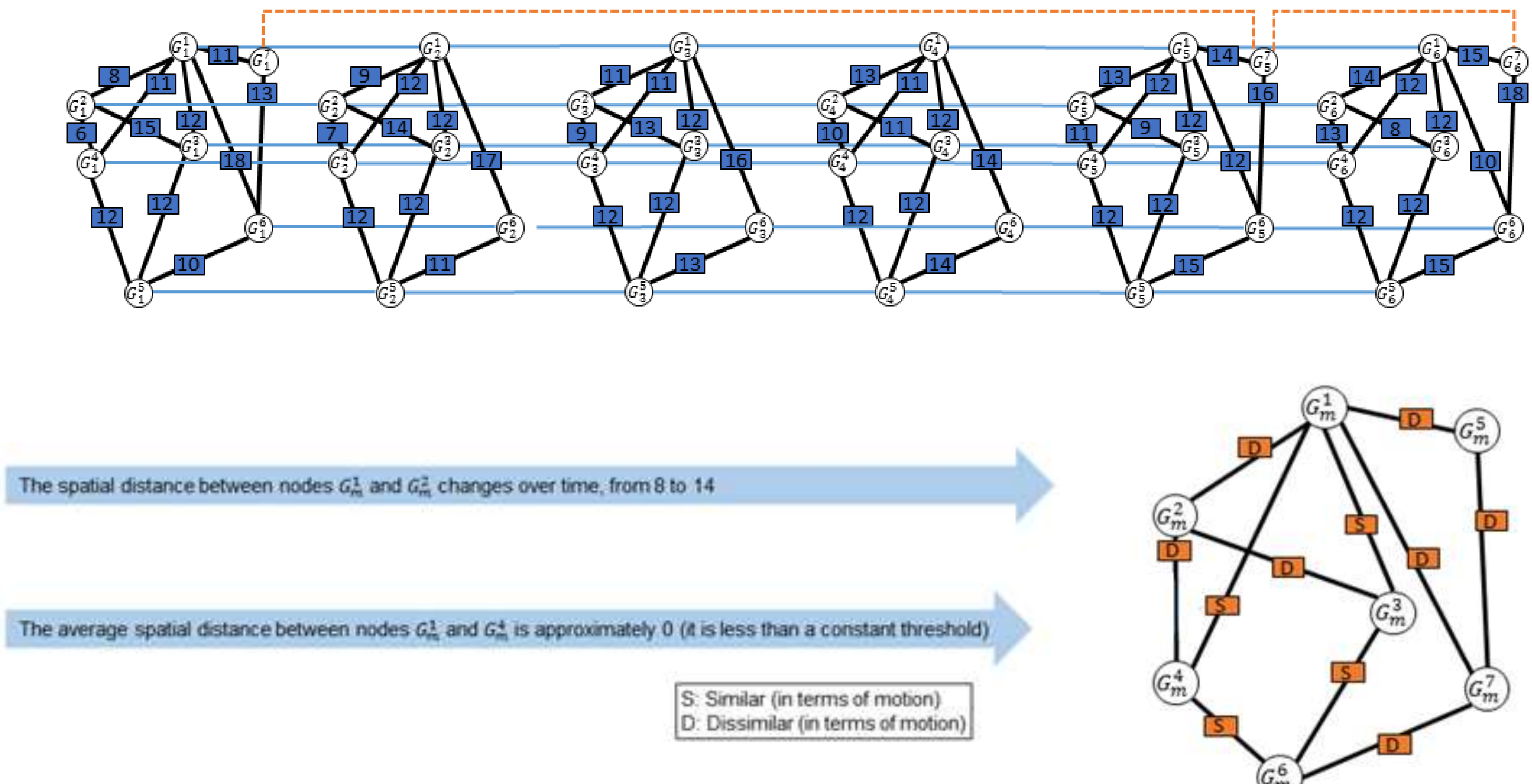
Two consecutive frames I_1 and I_2, $\mathcal{G}_1 = \{P_1, Q_1, G_1, H_1\}$ with n_1 nodes and m_1 edges, and $\mathcal{G}_2 = \{P_2, Q_2, G_2, H_2\}$ with n_2 nodes and m_2 edges are respectively constructed.

$$J(X) = vec(X)^T K_\alpha \, vec(X) + vec(X)^T K_\beta \, vec(X),$$

$$K_\alpha = d\left(vec\left(k_{\alpha}^{p}\right)\right) + (G_2 \otimes G_1) d(vec(k_{\alpha}^{q}))(H_2 \otimes H_1)^T,$$

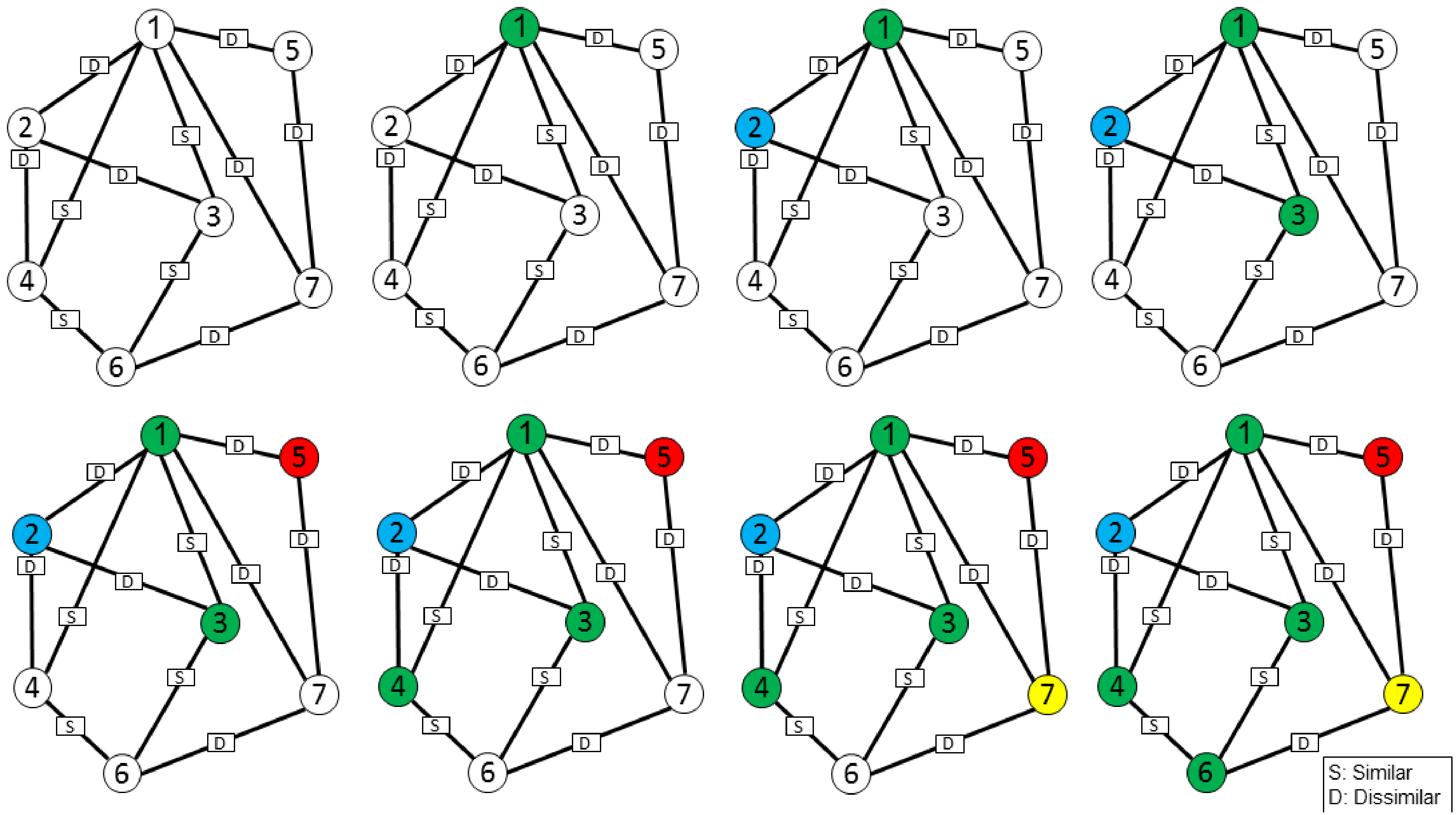
$$K_\beta = d\left(vec\left(k_{\beta}^{p}\right)\right) + (G_2 \otimes G_1) d(vec\left(k_{\beta}^{q}\right))(H_2 \otimes H_1)^T,$$

Region labeling



A motion similarity graph constructed from 6 consecutive graphs.

Graph Coloring Algorithm

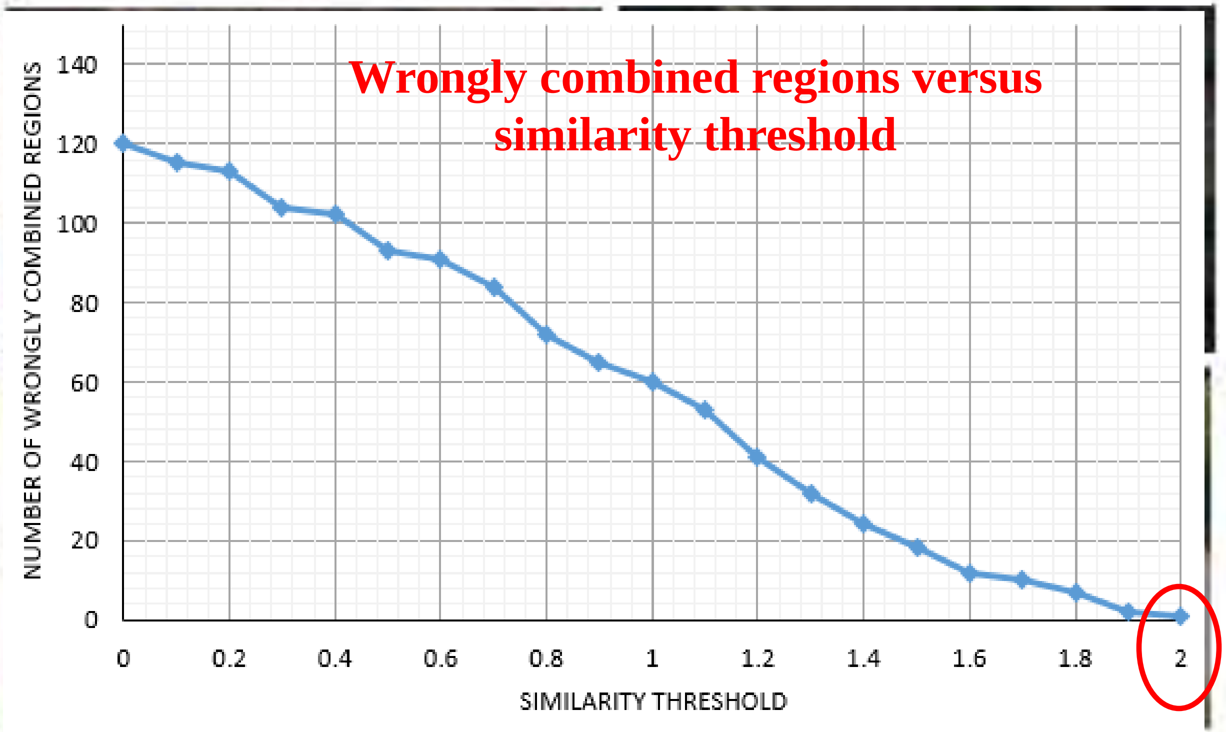


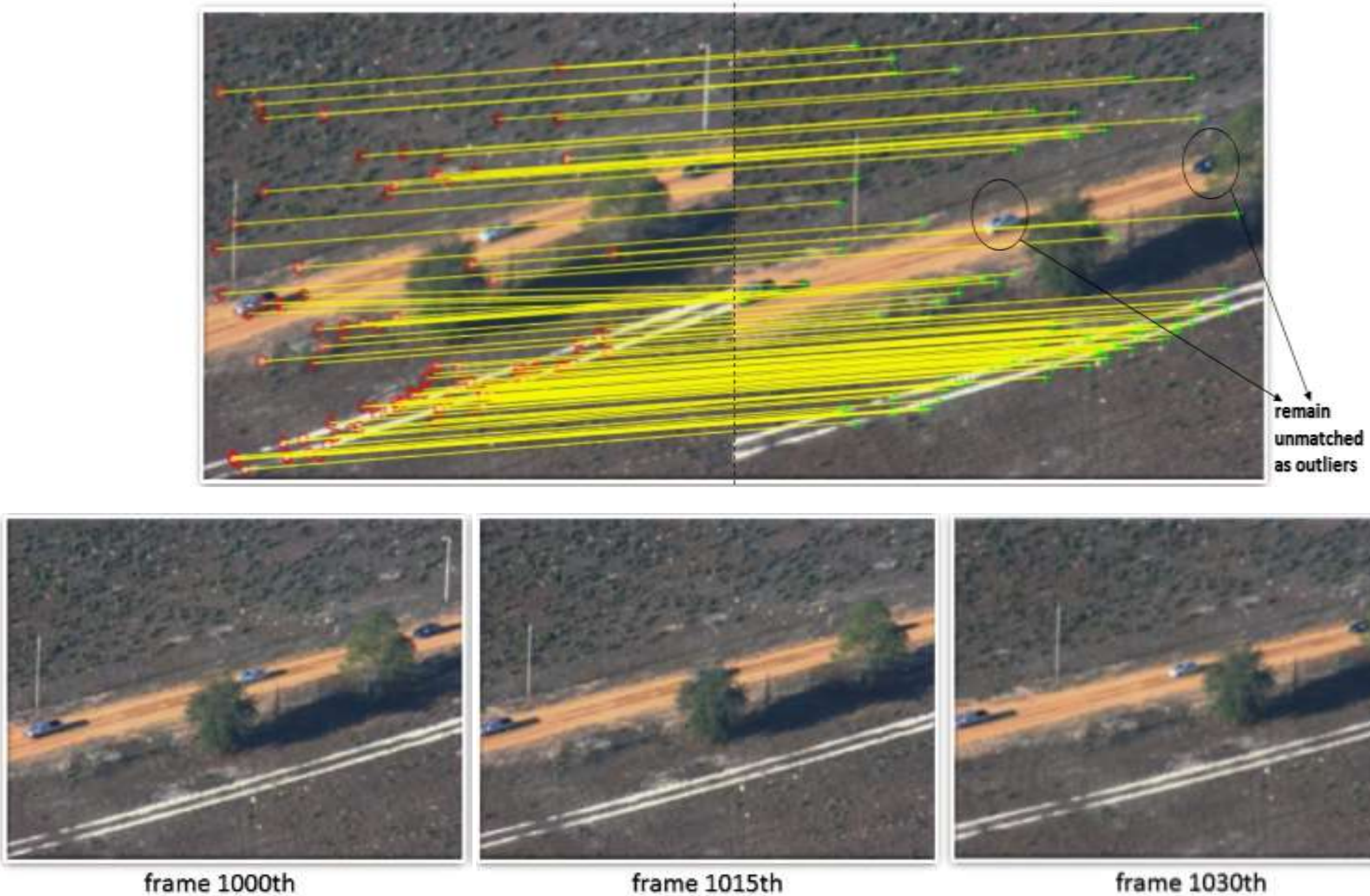
Dataset

	Sequence name	Properties
DARPA VIVID	**EgTest01**	Similar vehicles move on a runway, speed up, and pass by each other.
DARPA VIVID	**EgTest02**	Two groups of vehicles pass by each other on a runway. The scale is changed as the camera circles the scene.
DARPA VIVID	**EgTest03**	Two groups of vehicles pass by each other on a runway. The scale is changed as the camera circles the scene. The vehicles are occluded by each other.
DARPA VIVID	**EgTest04**	Vehicles move on a red dirt road. They are occluded by trees. Some frames are duplicated as the camera fails to record these frames. Thus, there is no motion followed by a sudden discontinuity in the sequence.
DARPA VIVID	**EgTest05**	Vehicles are tracked along a dirt road in a wooded area. Illumination changes, and vehicles are occluded by trees.
hexa-rotor UAV	**Seq01**	Vehicles are tracked along the outdoor campus environment. They are occasionally occluded by the background or each other.
hexa-rotor UAV	**Seq02**	Vehicles are tracked along the outdoor campus environment. It contains appearance variations and cluttered scenes.

Over-segmentation and merging process

Original images | Oversegmented regions produced by SLIC | Segmented regions after the merging process



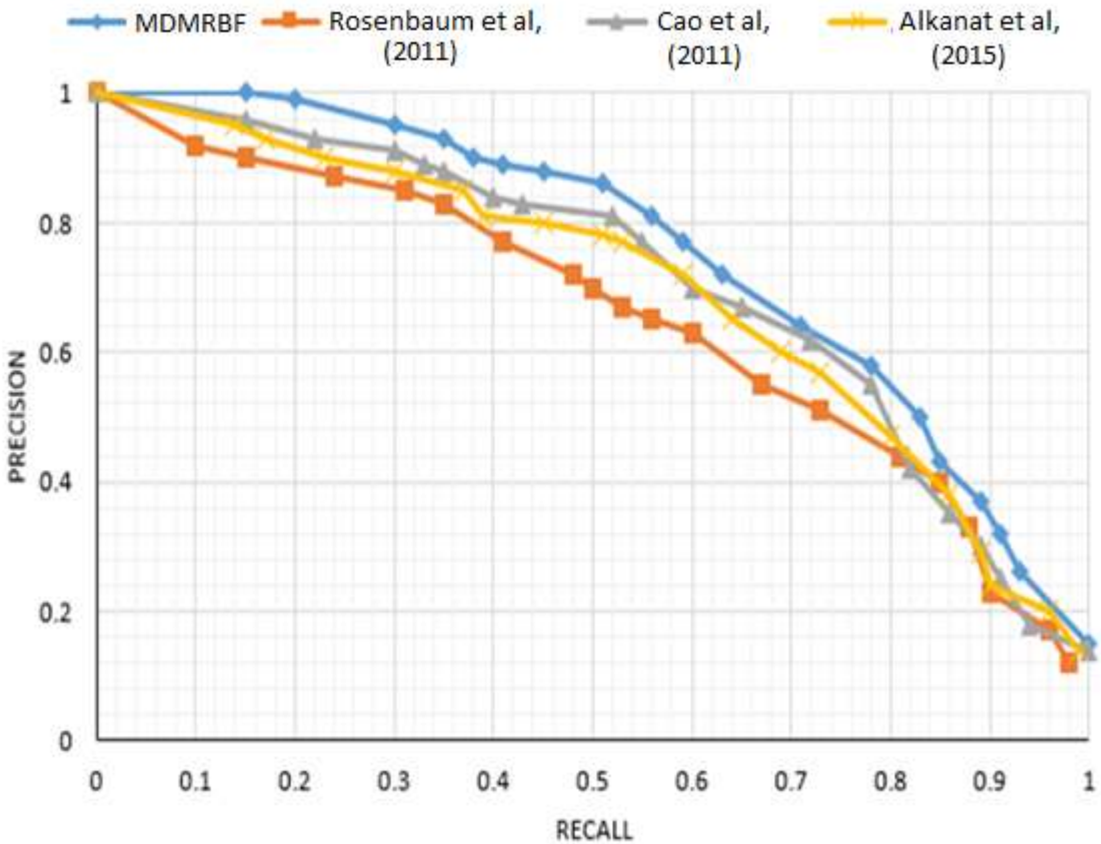


Multigraph matching algorithm on the frames from EgTest04. Top: the solid lines show the matched inliers in the frame sequence. The occluded regions remain unmatched as outliers; bottom: three frames that show how a vehicle becomes occluded and visible in successive frames.

Precision-recall curve averaged over all sequences.

$$P = TP/(TP + FP)$$

$$R = TP/(TP + FN)$$



Comparison results of different methods on the sequences of the DARPA VIVID dataset.

	Rosenbaum et al, (2011)	Cao et al, (2011)	Alkanat et al, (2015)	MDMRBF
Precision	86	89	90	94
Recall	85	88	82	89

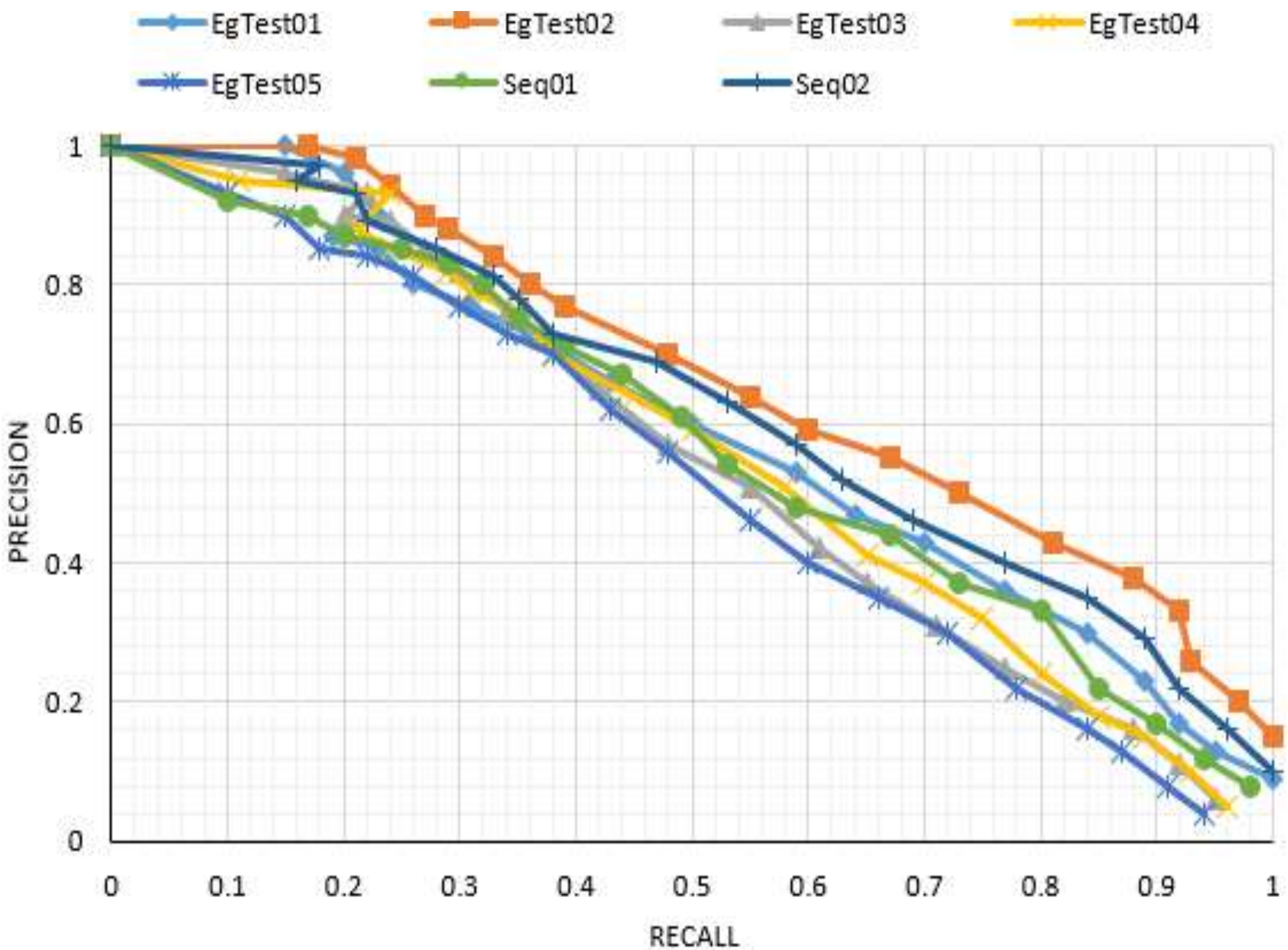
Properties of seq01 and seq02

	resolution (pixel)	flight altitude (m)	focal length (mm)	UAV speed (m/s)
Seq01	1280×720	100	5	0.1
Seq02	1920×1080	45	5	1.8

$$\text{GSD} = \frac{\text{pixel size} \times \text{flight height}}{\text{focal length}}$$

Thus, the GSDs for Seq01 and Seq02 are computed as ***8.40*** *and* ***2.51****, respectively.*

Precision-recall curve for different sequences



Illustrative examples of different sequences.

Novelty

- Firstly, in order to establish accurate and robust correspondences between consecutive frames, a novel approach is proposed where both appearances and geometrical information are taken into account in a multigraph structure.
- This approach not only establishes the correspondences between regions existed in all frames, but also detects the occluded regions which are not visible in the whole considered trajectory.
- Secondly, a graph coloring algorithm is proposed to find multiple moving objects using motion similarity information of the adjacent regions. .

Future Direction

1. ***Object tracking***, the proposed framework can be used for an effective video object tracking in future study.
2. ***Object classification and identification***, object classification framework can be applied to classify moving object in different groups such as class of people or sub classes like cars, vans, trucks, and motorcycles.
3. ***Human motion analysis***, visual analysis of human motion is currently one of the most active research topics in computer. It attempts to detect, track and recognize people, and more commonly, to understand human behaviors, from image sequences involving humans.
4. ***Behavior understanding and description***, it will be vital future study that describing objects behaviors, the modelling of semantic perceptions of motions, and the automatic learning of semantic concepts of behavior.
5. The suitably for ***real-time*** MOD also remains for our future plan.

References

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Multiple Moving Object Detection From UAV Videos Using Trajectories of Matched Regional Adjacency Graphs

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***Abstract*—Image registration has been long used as a basis for the detection of moving objects. Registration techniques attempt to discover correspondences between consecutive frame pairs based on image appearances under rigid and affine transformations. However, spatial information is often ignored, and different motions from multiple moving objects cannot be efficiently modeled. Moreover, image registration is not well suited to handle occlusion that can result in potential object misses. This paper proposes a novel approach to address these problems. First, segmented video frames from unmanned aerial vehicle captured video sequences are represented using region adjacency graphs of visual appearance and geometric properties. Correspondence matching (for visible and occluded regions) is then performed between graph sequences by using multigraph matching. After matching, region labeling is achieved by a proposed graph coloring algorithm which assigns a background or foreground label to the respective region. The intuition of the algorithm is that background scene and foreground moving objects exhibit different motion characteristics in a sequence, and hence, their spatial distances are expected to be varying with time. Experiments conducted on several DARPA VIVID video sequences as well as self-captured videos show that the proposed method is robust to unknown transformations, with significant improvements in overall precision and recall compared to existing works.**

***Index Terms*—Graph matching, motion models, moving object detection, region-based matching, unmanned aerial vehicle (UAV).**

I. Introduction

moving object detection from video sequences captured by mounted surveillance cameras on airborne vehicles such as unmanned aerial vehicles (UAVs). In such a setting, moving object detection becomes challenging as the camera motion is independent of the moving objects' motions. Typically, UAVs fly at low altitudes, render high mobility, fast deployment, and large surveillance scope [10]. Furthermore, there is a need to cope with the undesirable yet common characteristics of UAV-captured videos such as multiple moving objects, large/small displacements of fast/slow moving objects, object occlusion (either by terrain or other objects), and objects leaving/re-entering the field of view.

Several approaches have been proposed in the past for multiple objects detection from UAV videos. One popular strategy is to align each frame to its temporally adjacent frame to eliminate the effect of the camera motion. This can be achieved by using image stabilization and registration methods, where two images of the same scene taken at different times are geometrically overlaid. Image registration is the seemingly popular trend for remote sensing applications, which involves the discovery (matching) of feature correspondences between geometrically aligned image pairs [11]–[13]. In general, feature detection and matching are the two fundamental steps in the majority of registration approaches where the bags-of-features representation is commonly adopted [14], [15].

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