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Performance comparison of optical flow and background subtraction and discrete wavelet transform methods for moving objects

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ABSTRACT

Self-driving cars and other autonomous vehicles rely on systems that can recognize and follow objects. The ways help people make safe decisions and navigate by showing things like people, cars, obstacles, and traffic lights. Computer vision algorithms encompass both object detection and tracking. Different methods are specifically developed for picture or video analysis not only to identify items within the visual content but also to accurately determine their precise locations. This can operate independently as an algorithm or as a constituent of an item-tracking system. Object tracking algorithms can be used to follow objects over video frames, providing a contrasting approach. The research article focuses on the mathematical model simulation of optical flow, background subtraction, and discrete wavelet transform (DWT) methods for moving objects. The performance evaluation of the methods is done based on simulation response time, accuracy, sensitivity, and specificity doe several images in different environments. The DWT has shown optimal behavior in terms of the response time of 0.27 seconds, accuracy of 95.34 %, selectivity of 95.96 %, and specificity of 94.68 %.

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1. INTRODUCTION

Object detection is a technique used in computer vision to identify and locate items in both video and still images. Object detection algorithms typically rely on machine learning or deep learning techniques to obtain meaningful findings. Humans can quickly identify and find objects of interest when they view visual material [1]. Object detection seeks to replicate this level of cognitive ability in a computational framework. Various disciplines are currently allocating resources to the investigation of automated video surveillance. Advancements in modern technology have reached a stage where it is economically advantageous to install cameras in a certain location and capture video footage, rather than employing individuals to constantly examine the recorded footage [2]. Numerous enterprises have already installed security cameras, capable of capturing footage that can be stored on tape, subject to being overwritten or stored in a video archive. Subsequently, detectives can scrutinize the recorded video material to ascertain the sequence of events in the occurrence of a criminal act [3], such as a robbery in a store or the pilfering of a valuable automobile. However, then, it is evidently beyond the point of prevention or intervention. To mitigate the occurrence of these situations, we can implement continuous monitoring and analysis of video surveillance systems. In this manner, if security agents identify an ongoing robbery or someone exhibiting suspicious behavior in the parking lot, they can promptly intervene to avert criminal activity.

Video-based surveillance systems [4] allow for the monitoring of many scenes. Video streams can be utilized to extract information that captures our attention in various applications, such as security, entertainment, safety, and efficiency enhancement. Task Video surveillance is utilized in the field of recognition. Recognizing events from an area of interest has numerous possible applications, including but not limited to traffic analysis [5], tracking limited vehicle movements, and analyzing multi-object interaction. Compared to the need for continuous human supervision, it helps solve several problems. The first crucial step in this approach is to determine whether video samples include motion. The approach must not only be free from noise, but it must also segment the video stream to eliminate the presence of moving objects. The presence of rapid variations in light intensity, such as those caused by a light switch, poses a substantial challenge for detecting moving objects. If the algorithm fails to cope with variations in lighting and camera movement, it will result in the inclusion of background noise in the final output [6]. The problem would be worsened by dynamic backgrounds, which would enable objects to move around. Weather variations and swaying trees may create inaccurate results during the detecting step. Alterations in scenery introduce an additional level of difficulty. Regardless of whether one is asleep or awake, a moving item has the potential to momentarily halt and gradually blend into the surrounding environment. A motion detection system should possess the capability to effectively navigate through these various hurdles [7].

The video surveillance system commences [8] with the detection of motion and objects. Motion detection involves the process of separating the areas of an image that contain moving objects from the rest of the image. Background modeling and motion segmentation are commonly employed in the task of detecting motion and identifying objects. In an image sequence, the objective of motion segmentation is to identify the sections or areas that correspond to moving objects, such as automobiles, birds, humans, animals, and so on [9]. When motion is identified in a specific area or region, it is necessary to study these detected regions for further procedures such as object tracking and behavior analysis. Following the process of motion and object identification, the video surveillance system typically traces the movement of objects from one frame to the next in a sequence of images. Behavior analysis entails the examination and identification of motion patterns, the description of actions, and the relationships between things.

2. RELATED WORK

Automated cars must be able to access accurate, real-time data on the state of objects in their immediate surroundings if we are to guarantee safe driving. Object occlusion, clutter interference, and a limited sensor-detecting capability produce false alarms and missed object detection [10]. Thus, it is difficult to guarantee tracking stability and state prediction in complex traffic conditions. Background subtraction [11] requires a training sequence devoid of objects to construct a background model, in contrast to object detectors, which require instances that have been explicitly tagged to train a binary classifier. An important step toward analytical automation is object recognition without a distinct training phase. Attempts to solve this problem by analyzing motion data have been made. A popular method for detecting moving objects is discriminative modeling (DM), which seeks to improve performance in foreground-background separation using discriminative features and well-designed classifiers [12]. Because class separability is typically poor in camouflaged locations, DM may fail when confronted with the camouflage problem. To detect foreground pixels that have been camouflaged, we present a novel approach in this work: camouflage modeling (CM). Because of the two-part nature of camouflage, we must represent both the foreground and the backdrop.

An innovative framework that incorporates information about color and texture has been developed for backdrop modeling [13]. The foreground choice equation in this framework is composed of three components: the left section is for the integration of the two parts, the right portion is for the information about the texture, and the third part is for the information about the color. The use of this structure allows you to take advantage of the power of color and texture while avoiding the downsides associated with them. To accelerate the modeling of the background even more, we recommend using a block-based technique. To be more specific, texture information modeling is distinct from the traditional multi-histogram model for block-based background modeling in that it creates a single histogram model for each block. This model contains bins that indicate the occurrence probabilities of various patterns. Based on this process, the dominant background patterns are selected to determine the background likelihood of upcoming blocks. A novel method based on fuzzy color difference histogram (FCDH) has been suggested to incorporate fuzzy c-means (FCM) clustering [14]. The utilization of the FCM clustering technique in CDH mitigates the impact of intensity variation resulting from fake motion or changes in background illumination, while also reducing the substantial complexity of the computation's histogram bins. The suggested approach was tested using various publicly accessible video sequences featuring complex scenarios. The method is suggested based on extracting moving objects from a frame sequence, hence neither human interaction in the form of empirical threshold tuning, nor background modeling with which other systems are built are necessary [15]. The suggested approach rents out moving objects to be extracted without using any of them. The saliency map of the current frame with complete resolution is created by use of the constant symmetric difference between the frames adjacent to the present frame. Saliency variables on this map help to highlight moving items while also hiding the backdrop.

An image descriptor and nonlinear classification technique for optical flow orientation and a histogram-based method have been used to characterize motion information in each video frame [16]. The nonlinear one-class support vector machine classification approach initially learns from training frame behavior to identify unusual events in the current frame. The optical flow approach begins with a Gaussian filter to remove noise from each frame [17]. Next, it calculates the optical flow for the present frame the previous frame the current frame, and the forthcoming frame. Merging the two optical flow constituents yields the gross optical flow. An adaptive thresholding post-processing phase removes distracting foreground components. Morphological techniques are then used to the equalized output to locate moving items. The methodology was implemented, deployed, and evaluated on numerous authentic video datasets [18]. The 2D discrete wavelet transform (DWT) and variance approach were used for object detection and tracking [19]. An examination of the proposed variance-based method for object detection and localization in comparison to the widely utilized mean-shift method reveals that the latter is slower, leading to slower item detection overall. To wrap things up, this analysis helps detect and track moving objects by using only the bandpass components of the 2D-DWT outputs. The Daubechies complex wavelet transform is well-suited for tracking because of its approximate shift-invariance property. The recommended method can perform object segmentation from scenes [20]. Following the initial segmentation of the first frame, achieved through the computation of multiscale correlation of the imaginary component of complex wavelet coefficients, the subsequent frames track the object by calculating the energy of the complex wavelet coefficients assigned to the object's region and comparing it to the energy of the surrounding region. The research gap is in the identification of suitable methods for specific object detection problems. Optical flow provides the most accurate and detailed motion data, but it is also the most computationally expensive. Background subtraction usually works well when used in real-time scenarios with well-maintained backdrop models. To ensure its efficacy in motion detection, additional processing may be necessary after using the DWT, which provides a unique type of information.

3. METHODS

Identification and tracking objects that are in motion in photos or videos is a fundamental task in the field of computer vision. This task has a wide range of applications, including surveillance, autonomous driving, and human-computer interaction. Various methodologies and strategies are employed for the detection of moving objects. Below are many frequently employed techniques. The common steps for object detection are given in Figure 1.

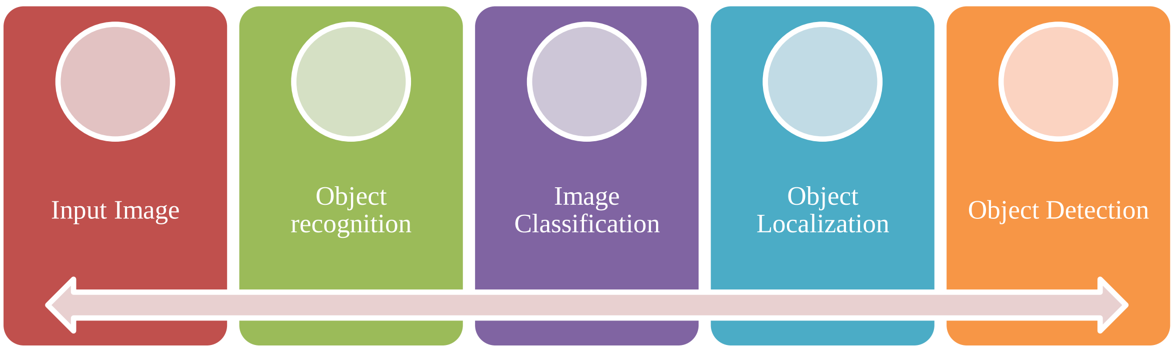

Figure 1. Steps in object detection in image and video

Computer vision can detect objects in video or still images. Preprocessing the image before feeding it to an object detection model is possible. Scaling or normalizing pixel values may be needed to meet model input requirements. Mathematical models help object detection models extract features. These networks learn hierarchical characteristics from photos to distinguish things. Localizing objects in an image is as crucial as categorizing them for object detection. Predicting bounding boxes that securely contain items of interest is common. The model classifies all observable elements after object localization. Post-processing is done after categorization refines results.

3.1. Background subtraction

One of the most used and time-tested methods for finding moving objects in movies or picture sequences is background removal. Separating the moving foreground items from the still background is the fundamental principle of background subtraction [21]. Background statics presupposes that the background is always changing at a slow pace. For example, this could be a static view from a surveillance camera showing a deserted corridor. Changes to the backdrop over time are considered by the dynamic background. Such as in natural settings where the sun, clouds, and shadows all play a role in creating varying degrees of illumination. In this type of model, each pixel in the background is represented by a statistical model. These models can be codebook models or non-parametric models. The initialization of the background model is done using the initial frames of the film or series. For dynamic backgrounds to adjust to small but noticeable changes in the scene, the backdrop model is refreshed periodically. To find areas or pixels that are drastically different from the backdrop, the background model is compared with each new frame. Tuning the background model settings is crucial for optimal performance in diverse scenarios. Examples of these parameters are the threshold for foreground detection and the learning rate for model updates. Real-time processing of high-resolution video feeds can be difficult due to computationally expensive background subtraction procedures. Multi-modal approaches use depth and colored data to improve background models. A common method for detecting moving objects using background subtraction is to compare each pixel in the current frame of the video series with a model of the background. The fundamental ideas and equations of background subtraction are presented here. The initialization of the background model $I_b(x,y,t)$ for pixel (x,y) at time t t is accomplished by utilizing the initial frames of the video series. This can be done with simple averaging as well as more advanced methods like gaussian mixture models (GMM).

$$I_b\ (x,y,t) = \ (1-k)\ I_b\ (x,y,t-1) + k.I_c\ (x,y,t) \tag{1}$$

$I_b\ (x,y,t)$ denotes the background model, $I_c\ (x,y,t)$ denotes the color intensity of the image (x, y) in the 't' frame or current frame, and k is the learning rate ($0 < k < 1$).

The current frame's absolute difference (or other metrics like squared difference) from the previous frame can be used to identify items in the foreground ($I_f\ (x,y,t)$.

$$I_f\ (x,y,t) = |I_c\ (x,y,t) - I_b\ (x,y,t)| \tag{2}$$

The results image after threshold comparison is given as. It is used to classify that image belongs to the background region or foreground region.

$$I_R\ (x,y,t) = \begin{cases} 1 & \text{if } I_f(x,y,t) > T \\ 0 & \text{if } I_f(x,y,t) < T \end{cases} \tag{3}$$

To eliminate noise morphological operations such as erosion and dilation can be applied to get the masked image. The learning rate α is modified via adaptive approaches according to the size of the pixel differences to accommodate different levels of scene dynamics

3.2. Optical flow method

Recent advancements in computer vision research have enabled robots to sense their surroundings through techniques such as semantic segmentation, which classifies pixels based on their meaning, and object identification, which identifies instances of a certain object class [22]. However, many of these algorithms do not consider the time information (t) when processing real-time video input. Instead, they solely focus on analyzing the relationships between objects inside the same frame (x, y). For each run, they consider each frame as an individual image and reassess it accordingly. To identify areas of motion in a picture, optical flow methods look at the vectors of a moving object's motion across time [23]. The optical flow has been employed by many researchers. In video sequences, objects can be detected using the optical flow method even when the camera is in motion. This theory is derived from the consensus of optical signal processing.

$$I(x,y,t) = \ I(x+\Delta x, y+\Delta y, t+\Delta t) \tag{4}$$

$$I(x+\Delta x, y+\Delta y, t+\Delta t) = I(x,y,t) + \frac{\delta I}{\delta x}\Delta x + \frac{\delta I}{\delta y}\Delta y + \frac{\delta I}{\delta t}\Delta t + \cdots Higher\ Term \quad (5)$$

By excluding higher-order terms, the equation is simplified in forms of (6) to (9).

$$\frac{\delta I}{\delta x}\Delta x + \frac{\delta I}{\delta y}\Delta y + \frac{\delta I}{\delta t}\Delta t = 0 \quad (6)$$

$$\frac{\delta I}{\delta x}\left(\frac{\Delta x}{\Delta t}\right) + \frac{\delta I}{\delta y}\left(\frac{\Delta y}{\Delta t}\right) + \frac{\delta I}{\delta t}\left(\frac{\Delta t}{\Delta t}\right) = 0 \quad (7)$$

$$I_{px}V_{px} + I_{py}V_{py} + I_{pt}V_{pt} = 0 \quad (8)$$

$$I_{px}V_{px} + I_{py}V_{py} = -I_{pt}V_{pt} \quad (9)$$

V_{px}, V_{py}, and V_{pt} denote the velocity or optical flow vectors, I_{px}, $I_{py,}$ and I_{py} show the variants of the image intensities at a coordinate in the form of derivatives for the image I_m(x, y, t). By employing the approach of thresholding to derive the motion vector for object detection. The magnitude of the motion vector is presented as (10).

$$T = \sqrt{V_{px}{}^2 + V_{py}{}^2} \quad (10)$$

Optical flow vectors, in their most fundamental form, provide input to a large variety of higher-level operations that need scene awareness of video sequences. These activities are necessary for proper operation. The optical flow method ensures object velocity across consecutive frames using the apparent motion of brightness patterns in a picture.

3.3. DWT transform

The ability of the DWT to capture signals at many resolutions and accurately localize them in the time-frequency domain makes it a crucial tool for object detection and tracking. When analyzing data at multiple resolutions, the DWT is used to break down an input signal into various frequency bands. Each frequency band corresponds to a specific scale. This enables the simultaneous examination of many levels of signals utilizing object detection techniques. This enables the effective retrieval of characteristics (such as shapes, patterns, and boundaries) at different levels, which is beneficial in the identification and monitoring of objects. The efficient implementation of DWT enables it to handle large amounts of data in real-time applications [24]. It is crucial for tracking and object detection systems to operate in dynamic environments and require rapid decision-making. The DWT is a valuable tool to estimate motion between frames in a video series. Evaluating the wavelet coefficients across frames enables the estimation of motion vectors, which is crucial for object tracking across time. The DWT) is a mathematical technique used to process and analyze data, especially photos [25]. The DWT divides an image into separate frequency components that differ in scale, enabling the examination of several resolutions [26]. The forward 2D DWT of an Image I_m(x,y) is decomposed with dimensions $N \times N$ into low-frequency approximation coefficients and high-frequency detail coefficients at various scales. The image is decomposed in LL, LH, HL, and HH frequency bands [27]. The mathematical equations for the same to present 2D-DWT are given as follows.

– Approximation coefficient equation

$$A_{LL} = \sum_{p=0}^{N/2-1}\sum_{q=0}^{N/2-1} h[p].h[q].I_m\,[2p, 2q] \quad (11)$$

– Horizontal element coefficient equation

$$H_{LH} = \sum_{p=0}^{N/2-1}\sum_{q=0}^{N/2-1} h[p].h[q].I_m\,[2p, 2q+1] \quad (12)$$

– Vertical element coefficient equation

$$V_{HL} = \sum_{p=0}^{N/2-1} \sum_{q=0}^{N/2-1} h[p].h[q].I_m\,[2p+1, 2q] \tag{13}$$

– Diagonal element coefficient equation

$$D_{HH} = \sum_{p=0}^{N/2-1} \sum_{q=0}^{N/2-1} h[p].h[q].I_m\,[2p+1, 2q+1] \tag{14}$$

Figure 2 presents the DWT image decomposition and level processing. Applying filters in both the horizontal and vertical axes separates [28] the image into different frequency components in a 2-level DWT decomposition. The decomposition process produces detail coefficients that capture high-frequency information in the horizontal, vertical, and diagonal dimensions, as well as approximation coefficients at various resolutions (levels) [29]. Object detection and tracking, compression, and denoising are just a few of the many image-processing applications that benefit from this multi-resolution representation [30].

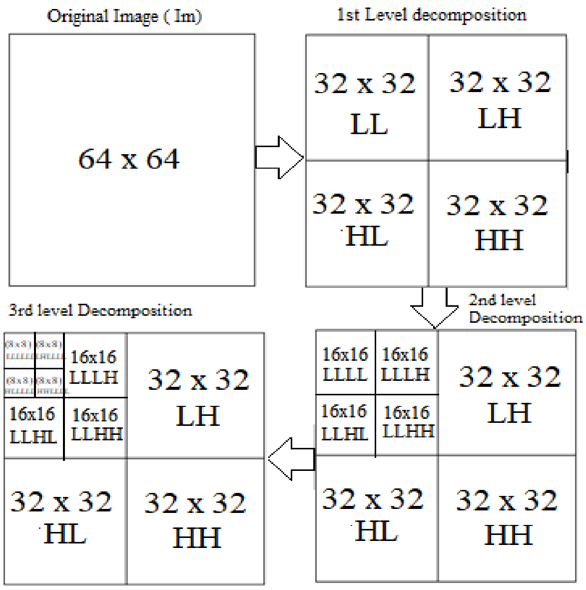

Figure 2. DWT image decomposition and level processing

4. RESULTS AND DISCUSSION

We used MATLAB 2023 to analyze the image's response time. Table 1 provides the specifics of the response times required by these simulations of all algorithms. In Table 2, the outcomes of the algorithm's simulation run on the author's camera's random still images and moving video. MATLAB simplifies the utilization of GPU acceleration for computationally intensive tasks, such as deep learning-based object detection. Utilizing GPUs in processing, as opposed to relying solely on CPUs, can greatly reduce response times, hence enabling faster inference speeds. The response time of MATLAB object detection methods is crucial for achieving real-time performance in various applications, optimizing algorithm selection and implementation, leveraging hardware capabilities, facilitating iterative development, enhancing user experience, and identifying optimization opportunities. Object detection systems can meet the performance requirements of their intended applications when they effectively manage response time. Table 1 presents the simulation response time of the different algorithms used for object detection.

In detecting and tracking moving objects, the three primary metrics that shed light on the system's efficiency, dependability, and resilience in different real-world contexts are specificity, sensitivity, and accuracy. The accuracy with which the system can identify which pixels or regions belong to moving objects or the backdrop is reflected in this metric. The sensitivity, recall, or true positive rate is a measure of how well the system detects real positives or moving objects. A system with a high sensitivity will be able to pick up on most moving items in the scene, reducing the likelihood that anything crucial would go unnoticed. Important fields that rely on it include automated driving and surveillance, where the ability to recognize any moving object is paramount. The sensitivity of a system is defined as the percentage of real negatives (i.e., non-moving background) that are properly detected as negatives.

Table 1. Comparison of the response time for detection

Method description	Response time in MATLAB (seconds)		
	DWT	Optical method	Background subtraction
Object detection Image/Video-1	0.25	0.31	0.45
Object detection Image/Video-2	0.24	0.33	0.44
Object detection Image/Video-3	0.30	0.39	0.47
Object detection Image/Video-4	0.23	0.29	0.35
Object detection Image/Video-5	0.31	0.35	0.40

The importance of a system's ability to accurately detect motion as opposed to non-motion is highlighted by the fact that a high specificity is crucial in reducing the occurrence of false alarms and false positives. It keeps things reliable and cuts down on needless processing or notifications by making sure the system can tell moving objects apart from a stationary background. Table 2 presents the estimated values of all the discussed methods and the corresponding comparative performance curve for the detection algorithms is shown in Figure 3. Table 3 presents the simulated images and results for different images.

Table 2. Comparative performance values

Method	TP	TN	FP	FN	Accuracy (%)	Sensitivity (%)	Specificity (%)
DWT	95	89	5	4	95.34	95.96	94.68
Optical	92	85	5	6	94.15	93.88	94.44
Background subtraction	90	80	6	10	91.4	90.00	93.02

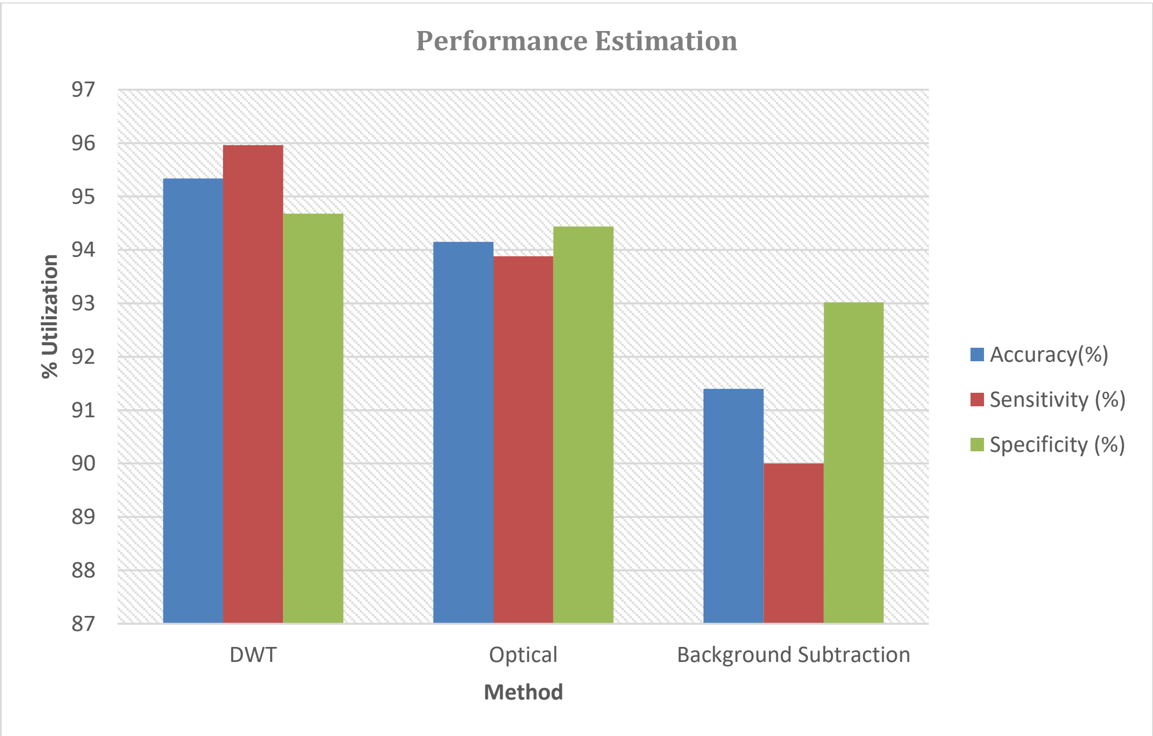

Figure 3. Comparative performance curve for the detection algorithms

Table 3. Simulation outcome of the different sampled image object/video

S. No	Input original	After applying the DWT algorithm
Image object/Video-1		
Image object/Video-2		
Image object/Video-3		
Image object/Video-4		
Image object /Video-5		

5. CONCLUSION

It is possible to compare several methods, tune parameters, and verify that the system satisfies operational requirements with the help of MATLAB's performance evaluation and validation tools. The evaluation is done for the optical flow methods, background subtraction methods, and DWT processing the moving objects detection. The simulation is carried out in several environments including rainy and hazy environments. The primary advantages of the DWT for object detection are its capacity to capture essential information, its robustness against noise, its compact representation, and its multi-resolution analysis. Consequently, it serves as a very effective instrument, particularly when conventional procedures may pose challenges or when obtaining specific attributes is essential. The simulation work of the DWT method has shown a minimum latency of 0.23 seconds then optical flow of 0.29 seconds and 0.35 seconds for background subtraction methods. The same type of behavior is analyzed for other cases also. The accuracy of the DWT, optical, and background subtraction methods is 95.34%, 94.15%, and 91.40%. The sensitivity of the DWT, optical, and background subtraction methods is 95.96%, 93.88%, and 90.00%. The specificity of the DWT, optical, and background subtraction methods is 94.68%, 94.44%, and 93.03%. When it comes to detecting moving objects in images and videos, the DWT method has continuously proven to be the optimal choice in terms of both hardware and software.

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