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Vehicle Tracking in Large Area Video

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Abstract

The objective of this project is to develop an algorithm using image processing techniques for vehicle tracking in wide area aerial videos. The scope of the work includes developing a fundamental approach for accurately detecting and tracking vehicles in wide area aerial videos and testing the algorithm based on simulation videos. The procedures involved implementing a combination of target indication and track association algorithms, and tuning the parameters for optimal performance. The main results of the project include an accurate vehicle tracking algorithm capable of tracking multiple vehicles in large aerial videos with accomplished accuracy and reliability. The average Multiple Object Tracking Accuracy (MOTA) achieved is 79.1%, with a false positive ratio of 3.8% and a misses ratio of 16.6%. Meanwhile, the algorithm has the capability to detect and track vehicles in different fields of view. The conclusions drawn from this work are that image processing techniques, when combined with multiple target tracking algorithms, can effectively track vehicles in large aerial videos. Moreover, the developed algorithm has potential applications in various fields, such as traffic monitoring, urban planning, disaster response, surveillance, and agriculture. This project contributes to the field of computer vision and provides a fundamental algorithm for further modifications in practical applications.

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1. Introduction

In recent years, the usage of unmanned aerial vehicles (UAVs) has become increasingly popular due to their ability to capture large-scale aerial video footage for various applications. One of the most important applications of UAVs is vehicle tracking, which has numerous practical applications such as traffic monitoring, urban planning, and disaster response [1], [2], [3], [4]. However, tracking vehicles in wide area aerial videos with low frame rate remains a challenging problem due to the complexity of the environment and the fast movement of vehicles.

In this project, a basic approach is proposed for achieving vehicle tracking in wide area aerial videos using image processing. The algorithm is designed to automatically detect and track vehicles in aerial videos, providing accurate vehicle tracking information. The aim of the project is to tackle the challenge of vehicle tracking in large aerial videos by utilizing the combination of image processing and Kalman filter.

The key contribution of this project is the development of a fundamental algorithm for vehicle tracking in large aerial videos. This algorithm is capable of achieving high accuracy and efficiency in handling wide area aerial videos, making it ideal for practical applications. The performance of the algorithm was comprehensively analysed by comparing it with other state-of-the-art vehicle tracking algorithms.

The report is structured as follows: In section two, the literature review of existing approaches related to vehicle tracking is provided. In section three, the industrial relevance of vehicle tracking is discussed. The sections four and five discuss the theory and design of the algorithm, respectively. The section six presents the experimental method used for program simulation and testing. In sections seven and eight the results of the project are presented, and an assessment is provided based on those results. Finally, the report concludes with a summary of accomplishments and suggestions for future research.

2. Project specification

The objective of the project is to develop the algorithm to accomplish vehicle tracking in wide area aerial video. The algorithm should have the ability to track multiple vehicles in the tracking area simultaneously and across multiple sub-areas.

In the original specification report, the objective of the project is to develop the algorithm to track multiple vehicles (more than 5 objects) in the specific field of view using aerial video over a 5-minute period. The project also aimed to calibrate and test the algorithm, ensuring that the tracking error compared to ground truth is within 25%. The ultimate goal of the project is to provide an aerial surveillance system that can assist smart city policy makers in implementing urban management, with a target completion date of April 2023. The original specification report is attached as an appendix.

After gaining a deeper understanding of the project, I realized that to quantify the specification of the report, a method is needed to calculate the corresponding accuracy. In this case, the standard calculation method MOTA (Multi-Object Tracking Accuracy) is selected and applied to evaluate the performance of the multiple vehicle tracking algorithm. MOTA is a metric that quantifies the errors made by a tracking system, including misses, false positives, mismatch errors, and more. It is derived general ratio and the ratios of false positives and misses. MOTA provides a comprehensive assessment of the tracking algorithm's accuracy and effectiveness by considering various types of errors that can occur during the tracking process.

In the evaluation step for the result, the main approach utilized is a sampling survey that involves comparing the results of the algorithm with ground truth data, which is manually labeled. MOTA (Multi-Object Tracking Accuracy) is calculated based on this comparison, and the calculated value is then compared with the specifications to evaluate the accomplishment of the project. The evaluation method allows for an objective assessment of the algorithm's performance in terms of accuracy and effectiveness in tracking multiple objects.

3. literature survey

Multiple-target tracking (MTT) technology was originally developed based on radar technology for tracking manoeuvring targets [5]. As technology advances and tracking requirements become more demanding, the limitations of radar tracking are becoming increasingly apparent. While advanced techniques, such as Cognitive Tracking Radar (CTR) [6] have been developed for radar tracking, they tend to perform poorly in complex terrain and may present challenges for tracking in urban areas. Furthermore, recent advancements in computer vision and aerial imaging technologies have demonstrated promising results for tracking through imageries. Therefore, transitioning MTT technology to computer vision-based approaches is considered a more promising approach for tracking.

multi-object tracking and data association have garnered significant attention in the computer vision field since 1998 [7]. Initially, most vehicle tracking was carried out using low-height cameras, which were only able to capture images for a short period of time before the vehicles moved out of their range. Most of Real-time traffic monitoring systems rely on surveillance cameras to detect vehicles [8]. However, continuous tracking in wide area would require an interwoven surveillance network. In contrast, vehicle tracking through wide field-of-view aerial video is more efficient. Xiao et al. [9] introduces a novel method for detecting and tracking numerous vehicles in low frame rate aerial videos using a joint probabilistic relation graph approach. By using this method, the vehicle tracking system can ensure stability over a prolonged period and achieve the intended outcomes. The algorithm employed in this project shares similarities with a previously proposed algorithm, providing a valuable reference for the ideas presented herein.

The objective of the project is to transition MTT technology towards the computer vision-based approach for detecting and tracking vehicles through aerial videos. In this project, only the location of the vehicle is extracted and used as the sole feature for tracking. Matching the location of the vehicle to obtain corresponding tracks pose a challenge in multiple-target tracking within a wide aerial video area with single feature.

In recent years, with the advancement of machine learning, neural networks have been utilized to extract vehicle features and aid in tracking [10], [11]. Feature-based tracking is considerably more efficient than normal location-based tracking because it can precisely identify the corresponding tracked vehicle, thereby avoiding mis-association in detection and tracking. Moreover, feature tracking can enhance the tracking accuracy of the algorithm in complex environments [7].

The literature survey section delves into the origins of multi-target tracking algorithms and their evolution, along with comprehending the ongoing work on computer vision-based multi-target tracking. Subsequently, the overall development direction of the current project is established by analysing the completed work.

4. Industrial relevance

Aerial video tracking has become a popular research topic in recent years due to the availability of sensors. Meanwhile, aerial video tracking has exhibited its vast technological potential. In this section, the industrial applications of this project would be explored in terms of its industrial relevance, real-world applicability and scientific/social impact.

4.1. Industrial relevance

The industrial relevance lies in its potential to provide vehicle tracking information from wide area aerial videos, which can have numerous practical applications across a variety of industries. The vehicle tracking algorithm based on wide area aerial videos is gaining popularity in various practical applications such as traffic monitoring, urban planning, disaster response, agriculture surveillance, and marine surveillance.

4.1.1. Traffic monitoring

One of the key applications of vehicle tracking in aerial videos is traffic monitoring, which can provide valuable information for transportation planning and management. The algorithm could potentially be used by transportation authorities to monitor traffic flow and identify areas of congestion, helping to optimize traffic flow and reduce travel times. In traffic monitoring, UAVs can identify vehicles without the embedded sensors in cars and can be deployed in a specific area without additional costs [12]. The vehicle tracking algorithm can be employed to assist UAVs in tracking the vehicles.

The proposed vehicle detecting and tracking system by L. Wang [3] utilizes image data collected by unmanned aerial vehicles (UAV) and provides high accuracy in traffic information acquisition at varying altitudes and view scopes. This system can be applied to traffic monitoring and control in metropolitan areas.

4.1.2. Urban planning

The algorithm could also be used in urban planning applications, such as analysing the movement of vehicles within cities to identify areas of high activity or congestion. This information could be used to optimize city planning, such as the placement of new transportation infrastructure or the allocation of public resources.

D. Ilić et al [2] proposes a framework for unmanned aircraft system application in smart cities based on the SWOT-FAHP (Strengths-Weaknesses-Opportunities-Threats analysis and Fuzzy Analytic Hierarchy Process) model, aiming to carry out the urban planning. The project has been proposed in Belgrade, the capital city of the Republic of Serbia, and has helped to build a smart city. Vehicle tracking algorithms can also play a role in helping to build smart cities.

4.1.3. Disaster response

During natural disasters or emergencies, aerial videos can provide valuable information about the movement of people and vehicles, helping to coordinate rescue and relief efforts. With the increased accuracy of remote sensing capabilities in many emergency and disaster management applications [13], the algorithm could be used by emergency services or relief organizations to quickly identify and track vehicles in disaster zones.

4.1.4. Agriculture surveillance

The algorithm could be used to track agricultural vehicles through wide area aerial videos, such as tractors and harvesters, to provide valuable data for precision agriculture. Meanwhile, the tracking algorithm can also be utilized in precision agriculture. Chen et al. [14] proposed a pest identification system utilizing two drones: a detection drone and an agriculture drone. The detection drone captures images and recognizes pests in real-time. The agriculture drone is then used to spray the optimal level of pesticide based on the identified pests.

4.1.5. Marine surveillance

The monitoring of sea areas is a challenging task due to the constantly changing sea surface and the relative scarcity of vessels in certain regions. To tackle this issue, previous research has focused on developing algorithms for tracking shallow sea creatures. H. Kim et al [15], [16] developed the jellyfish removal system , JEROS (Jellyfish Elimination RObotic Swarm) based on UAV surveillance system who can recognize the herd of jellyfish by deep learning algorithm. For marine animal tracking, the marine monitoring algorithm can be utilized as the target indicator and incorporates the vehicle tracking algorithm.

4.2. Real-world applicability

From the perspective of traffic monitoring and management, Barmpounakis and Geroliminis [17] conducted a large-scale experiment using a swarm of 10 Unmanned Aerial Systems (UAS) to monitor road traffic in large urban areas, to explore road traffic phenomena and analyse factors that impact the risk of vehicle collisions in overpass merging zones. The findings can be used to propose safety measures for road users. Similarly, UAS can also be utilized to analyse traffic patterns and identify potential traffic congestions in order to improve traffic management in urban areas [18]. The aerial monitoring can contribute to the creation of a more efficient wide area aerial surveillance (WAAS) system.

However, the use of unmanned aircraft systems (UASs) for civilian surveillance applications raises concerns about privacy and civil liberties. The existing regulatory mechanisms are insufficient in addressing such issues as UASs are complex and involve various technologies and capabilities for surveillance [19].

The usage of vehicle tracking algorithm for traffic management and other functions should be accompanied by appropriate legislation to ensure the protection of the privacy of citizens, and to further enhance the development of Wide Area Aerial Surveillance (WAAS) systems, thereby contributing to the establishment of smart cities.

4.3. Scientific/Social impact

The project has the potential to have significant social and scientific impacts by contributing new techniques and algorithms for vehicle tracking in large aerial videos, which could have a variety of practical applications in transportation, emergency response, security, and more. Additionally, The project may advance the field of image processing and contribute to a better understanding of vehicle movement and behaviour.

From the perspective of the social impacts, the algorithm could potentially improve transportation systems by optimizing traffic flow and reducing travel times, thereby improving the quality of life for people who commute on a daily basis. In disaster situations, your algorithm could help emergency responders quickly identify and track vehicles in disaster zones, potentially saving lives and improving the overall effectiveness of rescue efforts. Meanwhile, the algorithm could have applications in security and surveillance, which could help deter criminal activity and enhance public safety.

From the perspective of the scientific impacts, the algorithm may advance the field of image processing by contributing new algorithm for vehicle tracking in large aerial videos. The algorithm has adaptations for other tracking applications through tuning. The algorithm not only facilitates vehicle tracking but also assists in modeling vehicle movements, and the output of the tracking algorithm can be utilized to construct a dynamic model using deep learning techniques. Furthermore, the algorithm can be fine-tuned to enhance its performance and attain superior results.

5. Theory

The algorithm is theoretically divided into two parts, which are target indication and detection-track association. Collectively, the algorithm utilizes image processing and multiple-target tracking. Firstly, the theory of image processing is applied to process the wide area video and obtain the location of the vehicle. Secondly, existing tracks is used to associate with the detections for further tracks updating. The details of the theory are elaborated below.

5.1. Target Indication

To achieve target indication, the algorithm flow involves detecting the position of the vehicle after motion segmentation. The motion segmentation is primarily differentiate the foreground and background to obtain an approximate position of the motion object. However, the simple inter-frame subtraction or background subtraction may result in an image with a significant error. Therefore, image processing is required to enhance the motion segmentation quality. In this algorithm, the image processing is performed as follows:

5.1.1. Inter-frame subtraction

The first step in motion segmentation is to distinguish the foreground from the background. Various methods are available for this purpose, such as background subtraction and inter-frame subtraction. In this case, the inter-frame subtraction method is utilized. This is because the background of aerial video changes continuously, making it difficult to establish an actually fixed background. Furthermore, the street can cause interference in the background generation due to the high volume of passing vehicles. According to research of Xiao [9], the inter-frame subtraction method is primarily employed, with the background subtraction method serving as an auxiliary method . They also incorporate Geo-referenced images to assist in background generation when using the background subtraction method. For the aforementioned reasons, inter-frame subtraction was ultimately chosen as the method for motion segmentation.

5.1.2. Medium filter

median filter is a type of filter used to reduce noise in an image. It works by replacing each pixel value with the median value of the surrounding pixel values within a defined structure element. To improve the quality of the image and facilitate subsequent processing steps, impulse noise is removed using a median filter, which can effectively remove noise and small variations while preserving edges and other important features in the image. . The second step is necessary to obtain a clearer threshold for the subsequent image binarization.

5.1.3. Binarization

Binarization converts the grayscale image into a binary image, which involves further filtering and differentiation. After the impulse noise is removed using the median filter, threshold is assigned to differentiate the vehicle from the background and impulse noise. The specific thresholds can be obtained through histogram analysis of the grayscale images.

5.1.4. Morphological operation

Morphological operations are used in image processing to manipulate the shapes of objects within an image. In this algorithm, only opening and dilation operations are utilized. The opening operation is a combination of erosion followed by dilation and is used to remove small objects and combine the closed objects together. The dilation operation expands the boundaries of objects in an image. Dilation is used firstly combine two or more objects together as an vehicle. The opening operation is applied later because some vehicles may have non-uniform colours, causing them to appear as two or more separate objects after the previous series of image processing. Therefore, the opening operation is necessary to remove these irregularities and merge the objects into a whole.

5.1.5. Vehicle detection

The 4-connectivity connected-component labeling (CCL) algorithm is utilized for labeling all targets after image processing. Following the detection of the properties of these targets, which essentially include the center of the target as it is a binary image, these properties are considered as detections for further track association.

5.2. Track association

In other algorithms, multiple complex matching algorithms are often used. For example, the SORT algorithm uses the Hungarian algorithm to match detections and tracks [20]. However, in the case of wide aerial video multiple-target tracking, it is often challenging to match detections and tracks. Complex algorithms, such as the Hungarian algorithm, are also not suitable for this task. Instead, basic nearest neighbour data association with Kalman filter is suitable for the algorithm.

5.2.1. Distance based association

The basic nearest neighbour data association is a simple algorithm used in multi-target tracking to associate detections with tracks. It works by finding the closest detection to each track based on the Euclidean distance between their centroids. The detection is associated with the track while the distance is below a certain threshold. This algorithm is simple but effective for tracking objects in a cluttered environment where false detections and missed detections are common.

After completing the association, there may still be redundant detections and tracks that cannot be associated with each other. In the case of redundant detections, the new tracks needs to be created and updated to the existing tracks. In the case of redundant tracks, predictions are made based on the original tracks, and the tracks are either maintained or deleted, eventually updating to the existing trace.

5.2.2. Kalman filter

Ultimately, the Kalman filter is utilized for error reduction to the detections. Meanwhile, the Kalman filter is also utilized for prediction in the tracking association process, which is effective for tracking maintenance. The Theory about the two-dimensional Kalman filter which is used in the tracking algorithm would be explained according to the book written by Ralph [21].

For two-dimensional system, the state vector which is used to represent the state of vehicles contains four states: positions(x and y) and the corresponding velocity ($\dot{x}$ and $\dot{y}$). The measurement can be represent by the following function $H(X)$

$$H(X) = \boldsymbol{H} \cdot \boldsymbol{X}(t_n) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}$$

t_n represent the n[th] time step of the tracks.

To initialize the Kalman filter, the initial state vector $\boldsymbol{X}(t_0)$ and the initial expected errors in the state vector $\boldsymbol{S}(t_0)$ are shown as follow:

$$\boldsymbol{X}(t_0) = \begin{bmatrix} x \\ y \\ 0 \\ 0 \end{bmatrix} \quad \boldsymbol{S}(t_0) = 10^6 \cdot \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Meanwhile, the error covariance matrices are defined for further calculation. The excepted errors in the measurement is given by the covariance matrix $\boldsymbol{R}$. The process noise covariance matrix $\boldsymbol{Q}$ is utilized to make prediction about expected errors in the state vector.

$$\boldsymbol{R} = noise_{measurement} \cdot \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\boldsymbol{Q} = {\sigma_a}^2 \cdot \begin{bmatrix} \frac{1}{4}(\Delta t)^4 & 0 & \frac{1}{2}(\Delta t)^3 & 0 \\ 0 & \frac{1}{4}(\Delta t)^4 & 0 & \frac{1}{2}(\Delta t)^3 \\ \frac{1}{2}(\Delta t)^3 & 0 & (\Delta t)^2 & 0 \\ 0 & \frac{1}{2}(\Delta t)^3 & 0 & (\Delta t)^2 \end{bmatrix}$$

σ_a is the standard deviation of acceleration, used to optimize the performance of tracker.

$noise_{measurement}$ is the error of the measurement for estimation.

Δt is the time interval of the time step, which is 0.2 s because the video is $5\ FPS$.

Then the state estimation is implement by multiplying the state transition matrix $\boldsymbol{F}$ to make prediction about the state of next time step $\boldsymbol{X}_{predict}(t_n)$ and the next expected errors in the state vector $\boldsymbol{S}_{predict}(t_n)$.

$$\boldsymbol{X}_{predict}(t_n) = \boldsymbol{F} \cdot \boldsymbol{X}(t_{n-1}) = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ \dot{x} \\ \dot{y} \end{bmatrix}$$

$$\boldsymbol{S}_{predict}(t_n) = \boldsymbol{F} \cdot \boldsymbol{S}(t_{n-1}) \cdot \boldsymbol{F}^T + \boldsymbol{Q}$$

Δt is the time interval of the time step, which is 0.2 s because the video is 5 FPS.

After make the prediction about the measurement, the estimated measurement need to compare with the actual measurement to update the value of both Kalman gain and the state vector. The Kalman gain matrix $\boldsymbol{K}$ can be calculated by the following equation.

$$\boldsymbol{K} = \boldsymbol{S}(t_n) \cdot \boldsymbol{H}^T \cdot (\boldsymbol{H} \cdot \boldsymbol{S}(t_n) \cdot \boldsymbol{H}^T + \boldsymbol{R})^{-1}$$

Then the state vector and the expected error in the state vector should be updated according to the Kalman gain $\boldsymbol{K}$. Furthermore, the difference ΔY between the expected measurement $Y_{predict}(t_n)$ and actual measurement $Y_{actual}(t_n)$ need to be calculated based on the $H(X)$ function.

$$\Delta \boldsymbol{Y} = \boldsymbol{Y}_{actual}(t_n) - \boldsymbol{Y}_{predict}(t_n) = \boldsymbol{Y}_{actual}(t_n) - \boldsymbol{H} \cdot \boldsymbol{X}(t_n)$$

$$\boldsymbol{X}_{actual}(t_n) = \boldsymbol{X}_{predict}(t_n) + \boldsymbol{K} \cdot \Delta \boldsymbol{Y}$$

$$\boldsymbol{S}_{actual}(t_n) = \boldsymbol{S}_{predict}(t_n) - \boldsymbol{K} \cdot \boldsymbol{H} \cdot \boldsymbol{S}_{predict}(t_n)$$

The $\boldsymbol{X}_{actual}(t_n)$ and $\boldsymbol{S}_{actual}(t_n)$ are the actual state about the object in nth time step. By iteratively applying the aforementioned process, the Kalman filter effectively eliminates errors and makes accurate predictions even in situations where detections are unavailable.

6. Design

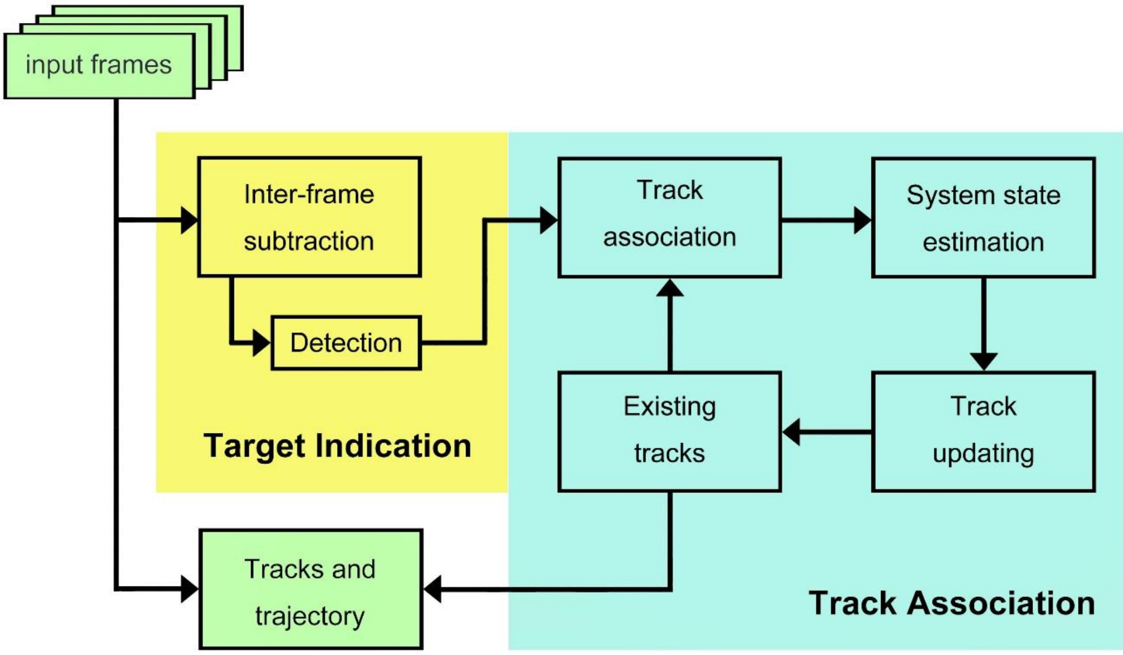

Figure 1: The framework of algorithm about MMT. The first stage is target indication and the second is track association.

The Figure 1 illustrates the framework of the MTT algorithm, which comprises two main stages: (1) Moving Target Indication (MTI) from low frame rate aerial video, and (2) Track Association based on nearest neighbour data association. In the first stage, the inter-frame differencing algorithm is used to detect fast-moving vehicles with their centroids. In the second stage, the target indications are associated to the existing tracks based on the distance. Depending on the situation, the track association algorithm would create new tracks, maintain existing tracks, delete existing track, eventually updating to the existing tracks.

6.1. Moving vehicle detection

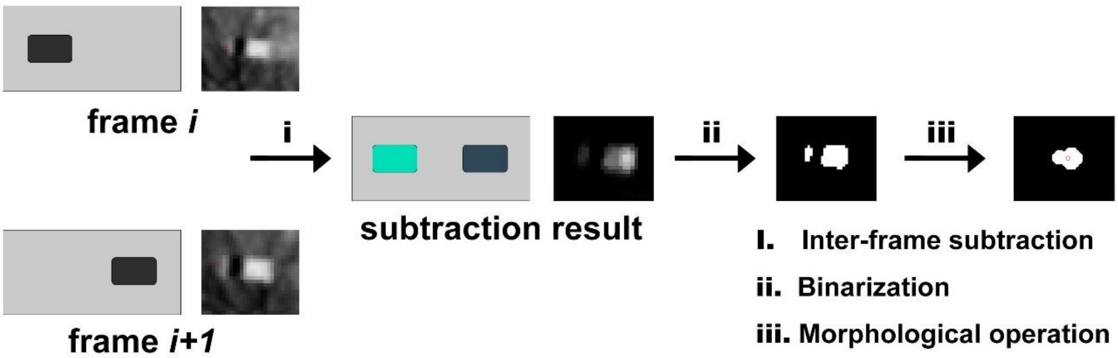

Figure 2: The motion indication scheme. The design of the motion indication algorithm including inter-frame subtraction, impulse noise blur, small objects reduction, binarization, morphological operation, CCL, and properties calculation.

Due to the low frame rate and low spatial resolution of the video, vehicles move relatively fast and there is usually no overlap between consecutive frames of the same vehicle. The traditional two-frame subtraction after stabilization would theoretically produce two speckles, as shown in Figure 2.

At first, I thought this was normal, but upon further investigation, I discovered the underlying issue. Firstly, image subtraction function of MATLAB does not retain the parts of the image with negative grayscale values. The grayscale image in MATLAB typically uses 8-Bytes per pixel, allowing for a range of values from 0 to 255. Therefore, we assume that the value of the background environment is 20. Vehicles with lighter colours appear white in the grayscale image, while vehicles with darker colours appear black. To simplify the distinction, we assume that the vehicles are pure white and pure black, respectively, and their values in the grayscale image are 255 (white) and 0 (black). The resulting image can be displayed by generating an image through the matrices created in MATLAB. The results are shown below.

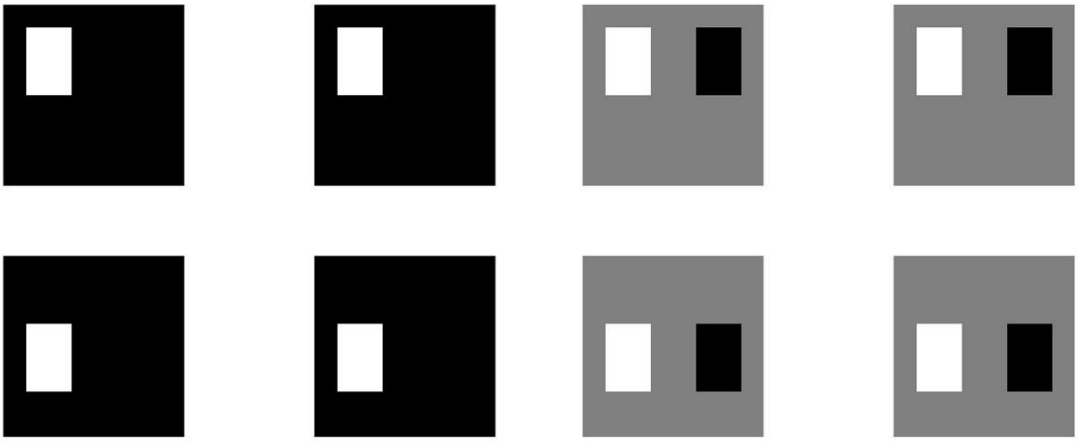

Figure 3: MATLAB image subtraction test. The test generate a series of vehicles with different colour in different environment. It display the influence of the colour of vehicles to the result. Meanwhile, the difference of matrices subtraction and imagery subtraction is displayed

For the set of four images on the left, the subtraction of the matrices are made firstly, then the matrices are converted into image. In the process of transforming the grayscale image, the MATLAB programme autonomously performs histogram equivalization. The positive and negative values of the subtraction of the two frames are represented simultaneously in the grayscale image. For the set of four images on the right, the matrices are firstly convert into images and the images are used to make subtraction. In hence, only the positive value (where the car in the former frame) is displayed. The specificity of MATLAB in performing image subtraction makes the procedure relatively simpler, eliminating the need for an additional procedure to match the object with the frame in which it is located.

To binarize a grayscale image, it is necessary to use histogram analysis to derive the appropriate thresholds. In the initial selection of thresholds, I chose a frame from the video with only one vehicle present, when the number of vehicles was relatively low. The corresponding threshold was obtained by analysing this frame.

6.2. Track association

The tracking algorithm aims to associate the detections of the multi-target indicator to the existing tracks. Therefore, this part of the algorithm introduces two parameters for the auxiliary operation of the tracking algorithm: the number of detections N_d and the number of tracks N_t. The pseudo-code for the tracking algorithm is presented below:

```
if Nd == 0
    if Nt == 0
        Do nothing
    else (Nt ~= 0)
        Update tracking without measurement
        if the track cannot match to the measurement for 10 frames
            stop tracking
        end
    end
else (Nd ~= 0)
    if Nt == 0
        start tracking
    else (Nt ~= 0)
        Ⅰ) use pdist2 to generate the distance matrix => (m1 x m2)
        Ⅱ) Basic association matrix => (n x n)
        Ⅲ) Labelling:
            number of matched centroid => n (1)
            number of tracks without measurement => m1-n (-1)
            number of new tracks => m2-n (0)
        Ⅳ) Complete association matrix
        Ⅴ) Tracking according to label:
            label = 1: match with previous tracks
            label = 0: create new tracks
            label = -1: update track without measurement
            if track not match to measurements for 10 frames
                stop tracking
            end
    end
end
```

The tracking algorithm is divided into four cases, depending on the number of detections and tracks, which are discussed below:

- $N_t = 0, N_d = 0$: In this case, there is neither a detection nor an existing trace. Therefore, no operation is required.

- $N_t \neq 0, N_d = 0$: In this case, there is no detection. However, the existing tracking needs to be updated. In hence, there are predictions without detections based on the Kalman filter.
- $N_t = 0, N_d \neq 0$: In this case, there are detections without existing tracks. Therefore, the tracks about the detections need to be created and updated.
- $\mathrm{N_t} \neq 0, \mathrm{N_d} \neq 0$: In this case, there are detections with existing tracks. The initial step is to establish association between detections and tracks. This is done by calculating the distance between each detection and each track using a distance calculation function, resulting in a matrix whose size is $\mathrm{N_d} * \mathrm{N_t}$. Next, the threshold is set and distances below the threshold are considered as matches and labeled accordingly. The detections and tracks that failed to associate are then processed. Assuming that n detections and tracks have been associated (where n is less than $\mathrm{N_d}$ and $\mathrm{N_t}$), there are $\mathrm{N_t} - n$ tracks that need to be updated without detections using the Kalman filter, and $\mathrm{N_d} - n$ new tracks that need to be created based on the remaining detections.

Meanwhile, the tracking maintenance is vital in the tracking algorithm. During the tracking process, there may be situations where some points in the track are undetectable due to occlusion or other factors. In such cases, it is necessary to predict the trajectory of the object and estimate its future position to connect the preceding and following sections of the track together. This is done using the Kalman filter, which estimates the position and velocity of the object based on its previous motion and predicts its future position.

When a tracked vehicle slows down or comes to a completely stop, the frame subtraction scheme no longer detects the object. This results in difficulties with track association. When the object cannot be tracked any longer, the target indication algorithm assumes that the object has stopped moving and does not associate the vehicle with other objects.

7. Experimental method

The two primary experiments in this project are the selection of image processing thresholds and the evaluation of the tracking algorithm. Threshold selection for image processing involves comparing a series of intermediate images to obtain an appropriate threshold value. The evaluation of the tracking algorithm involves simulating the tracking process and comparing the output with the expected results to draw conclusions. It is challenging to determine if the tracking algorithm is functioning correctly based solely on the detection results from the airspace video, as the tracking results must be overlaid with the original video to visualize the results, which is time-consuming. Therefore, it is more convenient to use a set of known coordinates to generate clear results, and this approach was employed in the tracking program experiments.

7.1. Target indication test

The experiments on threshold selection focus on selecting appropriate thresholds for image processing based on the image performance at each stage. The primary experimental approach is to first adapt the image to a particular frame, typically one with fewer moving vehicles. This is then applied to other frames to evaluate the effectiveness of the target indication algorithm.

7.2. Tracking evaluation

For the tracking program, the first test aims to evaluate the performance of program on associating the continuous data with error generated by the testers and generate the corresponding error-removed trajectory. The error range of the test program is set at ± 7.5 standard deviations and randomly distributed. Although it may be more appropriate to use a normal distribution for the error, a random distribution is considered sufficient for testing purposes. The tracker is expected to generate three trajectories, all of which should be straight lines. The equations of the three trajectories as the time series changes are as follows:

$$\boldsymbol{Trajectory_1} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Trajectory_2} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Trajectory_3} = (\mathbf{600} + \mathbf{0} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$\hat{\boldsymbol{\imath}}$ **: the unit vector in the horizontal direction**

$\hat{\boldsymbol{\jmath}}$ **: the unit vector in the vertical direction**

$\boldsymbol{u}(\boldsymbol{t})$**: the unite step function**

The trace generated by the program should generally agree with the straight line generated by the equation. The successful generation of three straight lines by the tracking program indicates that it is capable of fulfilling its intended purpose and is ready for the next step of simulation testing. The program's ability to fit the traces to the expected curves based on the equations demonstrates its general agreement with the expected results.

The second test aims to verify whether the tracking program can merge two trajectories that correspond to the same vehicle and are uninterrupted by other trajectories. This test evaluates the ability of program to continue tracking a vehicle in the absence of some detections by predicting through Kalman filtering. Two trajectories were used in this test with the following equations:

$$\boldsymbol{Trajectory_1} = (\mathbf{10} * \boldsymbol{u}(\boldsymbol{t} - \mathbf{4})) * \hat{\boldsymbol{i}} + (\mathbf{10} * \boldsymbol{u}(\boldsymbol{t} - \mathbf{4})) * \hat{\boldsymbol{j}}$$

$$\boldsymbol{Trajectory_2} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t} - \mathbf{17})) * \hat{\boldsymbol{i}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{u}(\boldsymbol{t} - \mathbf{17})) * \hat{\boldsymbol{j}}$$

$\hat{\boldsymbol{i}}$ **: the unit vector in the horizontal direction**

$\hat{\boldsymbol{j}}$ **: the unit vector in the vertical direction**

$\boldsymbol{u}(\boldsymbol{t})$**: the unite step function**

In this test, a part of trajectory 1 was intentionally undetected, resulting in a missing section. The aim of the test was to assess the program's ability to track a target despite gaps in the detections, and to improve its overall robustness. The desired outcome was to complete the missing section and generate a total of two trajectory as the result.

7.3. Overall testing

It is necessary to verify whether the program is able to track multiple targets at the same time in a complex environment, and whether the program can accurately detect and track targets even when there are occlusions or when targets cross paths. This is important for evaluating the performance of the program in practical scenarios.

In addition, the program need to be able to handle situations where a target temporarily disappeared from the field of view and then reappeared, by predicting the target's position during the missing period using the Kalman filter.

8. Results and calculations

The results section will first be analysed based on the test results from the previous experimental section. Once the test section results have been analysed, the overall code results will also be analysed.

8.1. Result of target indication

As previously mentioned, the method employed to evaluate the performance of the target indicator is to select a specific frame typically one with fewer moving vehicles, apply the target indicator algorithm to the frame, and subsequently utilize the same algorithm for other frames to assess its efficacy.

As previously mentioned, the target indicator was tested by selecting a frame for testing and applying the target indicator applicable to that frame to other frames to observe its effectiveness. For the actual experiment, I selected the fiftieth frame of the video “2.5_2_4” with a field of view of 2.5 degrees. This sample was chosen because it contains only one moving vehicle that consists of two colours. Thus, the target indicator should theoretically mark only one detection. The debugging process for the specific target indicator involved binarization threshold selection with small object removal, dilation structure element (SE) selection and opening operation structuring elements (SE) selection. The debugging process was similar for the other frames, with no major changes made after the end of the frame

8.1.1. Binarization threshold selection with small object removal

In this section, the size of the small objects to be removed was determined before making the selection of the binarization threshold. The small objects smaller than five pixels are removed. Based on the histogram of inter-frame subtraction, it became evident that some noise remained after applying the median filter to subtracted image with no vehicle movement, with the exception of a large number of pixels that were zero. Therefore, additional steps were necessary to effectively remove the remaining noise.

During the process of removing small objects, I opted to remove objects that consisted of four or fewer pixels. This decision was based on the observation that much of the noise in the inter-frame subtraction histogram appeared as 2x2 squares. By selecting this threshold, we were able to effectively remove these small objects, as well as any smaller objects that may have been present.

As for the choice of binarization thresholds, I selected a series of frames with no car movement and, after removing impulse noise through a median filter, used a histogram to calculate the proportion of pixels for each value. After a series of calculations, it was found that selecting a number between 24/256 (0.09375) and 25/256 (0.0975625) as the threshold for binarization gave better performance. This is because in the subtracted image without moving vehicles, the number of pixels with all values less than or equal to 24 accounted for 99.9999% of the total number of pixels. The result of a series of images are shown in the following table：

Table 1: The histogram based on the results of inter-frame subtraction

The frame number	30	31	32	33	34	35
Pixel value	9	10	24	17	22	32

At 35^{th} fame, the movement of the vehicle is clearly visible and its data has been included in the table for reference. Instead of averaging the pixel values, the maximum value was selected to ensure a consistent threshold for binarization across all images. The complete histogram data has been provided in the appendices.

The value of 0.095 was selected for the binarization threshold, as it met the requirements mentioned below and fell between the two identified values 24/256 and 25/256 .

8.1.2. Structure element (SE) selection

In practice, when a vehicle with heterochromatic colours is detected, it may result in two separate objects after binarization, and morphological processing is required to merge these two objects into one. The specific morphological processing involves first performing an dilation operation, which allows the two objects to be joined together. This is followed by an opening operation to remove small dots and edge burrs.

The structure element (SE) test for the dilation operation is as follows

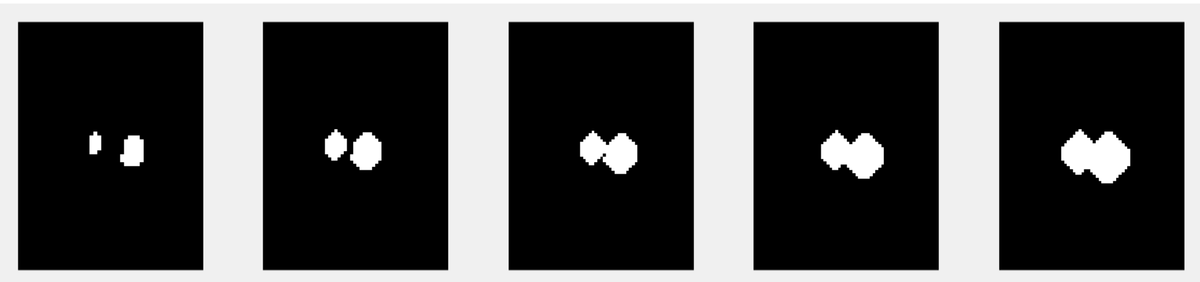

Figure 4: The series of dilation operation with different SE. The image (1) is result of frame subtraction after binarization and small object removal. The images (2) (3) (4) (5) is original image processed by SE of diamond shape which the distance from the structuring element origin to the points of the diamond are 2, 3, 4, and 5 respectively.

As can be observed from the figure, if the radius of the SE is less than 4, the two sections of the head and parking space are not completely connected and contain holes in between, which could be influenced by subsequent opening operations. Therefore, the chosen radius of the SE should be at least 4. Since the vehicle illustrated in the diagram is a small car, which is relatively short, a diamond-shaped SE with a radius of 5 is preferred to achieve a more robust expansion operation. This guarantees that vehicles with relatively longer length (such as pickup trucks) can also be merged without joining adjacent vehicles in front and behind.

The structure element (SE) test for the opening operation is as follows

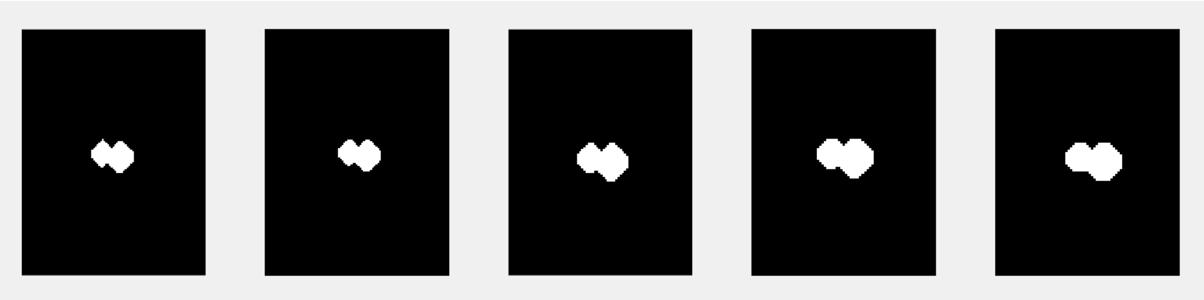

Figure 5: The series of opening operation with different SE. The image(1) is the image after dilation operation with diamond-shaped SE whose radius is 5. The images (2) (3) (4) (5) are the images processed by the opening operation through the square SE whose width are 2, 3, 4, and 5 respectively.

The wider the SE chosen, the closer the resulting shape of the vehicle will be to a rectangle, which is the original shape of the vehicle. In theory, a larger SE would be better. However, in practice, the size of the vehicle needs to be taken into consideration. Since the opening operation was eroded firstly and then dilated, there would be nothing to dilate if the entire vehicle is eroded. Therefore, to ensure that the shape of the vehicle is not removed while also ensuring that the vehicle is not falsely removed, a square SE with a width of 5 was chosen.

8.1.3. Target indicator program results

A series of intermediate results are included in the complete target indicator program, as shown in the figure. These intermediate results include the inter-frame subtraction result, the binarization result, the dilation operation result, and the opening operation result.

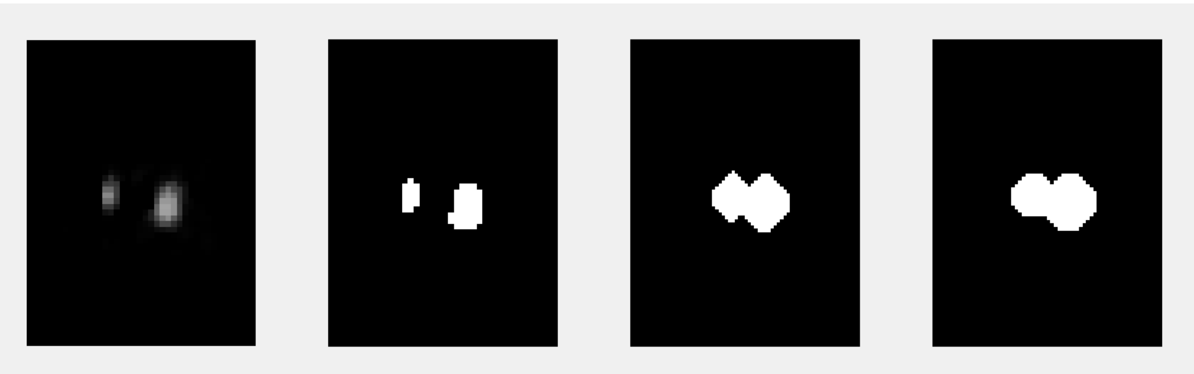

Figure 6: The result of the target indicator programme performance about the single vehicle. The image (1) is inter-frame subtraction result. The image (2) is binarization result. The image (3) is dilation operation result. The image (4) is the opening operation result.

For a single vehicle in a specific frame (the frame 50 of video 2.5_2_4), the target indicator showed accomplished performance. However, when testing it on other frames, poor performance was observed in some specific cases. Another specific frame (the frame 370 of video 2.5_2_4) is utilized to display the drawbacks of the target indicator programme.

The target indicator program has some drawbacks, including multiple indications for large vehicles and mis-combination of vehicles in close proximity. As shown in the following figure, the target indicator detected two separate objects for a heavy truck with a long body, which should actually be combined them into a single object. While it is difficult to merge them by adjusting the target indicator, the solution is to use a track clustering algorithm to merge them accordingly. There is no perfect solution to the problem of false positive detections, but the tracking algorithm can automatically predict and compensate for missing detections in the target indicator, minimizing the impact of this problem on the final tracking results.

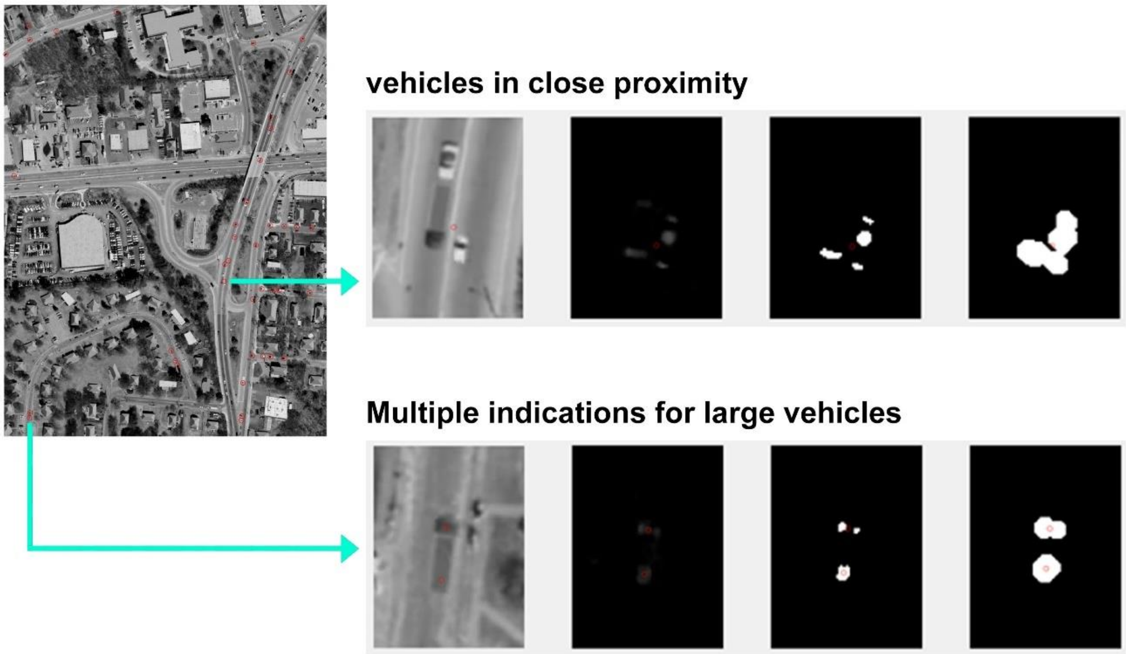

Figure 7: The target indicator with specific drawbacks. The drawbacks of target indicator are multiple indications for large vehicles and mis-combination of vehicles in close proximity.

8.1.4. Target indicator error calculation

The position of the vehicle indicated by the target indicator may contain errors when compared to the actual position of the vehicle, and this error is unavoidable. This problem mainly occurs due to the overlap of the bodywork of a slow-moving vehicle on the front and rear frames. To address this issue, the error needs to be computed and then propagated to the subsequent Kalman filter.

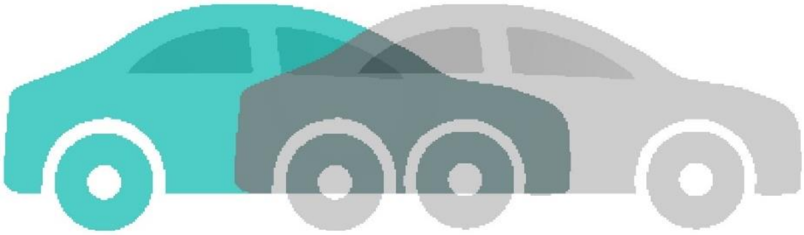

Figure 8: The schematic diagram presented depicts the issue of object overlap in a slow-moving vehicle. As a consequence, the position of the vehicle, as indicated by the target indicator, may deviate from its actual position, leading to errors that cannot be avoided.

By manually marking and recording the actual position of the vehicle and calculating the error between the indicator result and the actual position, the result is shown in the table below:

Table 2: The error and standard deviation about target indicator.

	X-coordinate	Y-coordinate
Mean	$\bar{x} = -1.8358$	$\bar{y} = -0.3101$
Absolute mean	$\overline{\lvert x \rvert} = 3.5218$	$\overline{\lvert y \rvert} = 3.5912$
Standard deviation	$\sigma_x = 4.3848$	$\sigma_y = 6.1923$
Standard deviation for absolute value	$\overline{\sigma_x} = 4.3848$	$\overline{\sigma_y} = 5.0215$

Based on the data in the table, it is recommended to select data that is close to the standard deviation when selecting the measurement noise covariance for the Kalman filter. It is not advisable to select data directly from the table because the actual positions are marked manually and are subject to some error and uncertainty. Therefore, the selection of the measurement noise covariance needs to be determined through certain tests. The detailed data in the table are recorded in the appendices.

7.2. Result of track association

The results section presented herein illustrates the outcomes of the previous experimental simulations, which encompass the Kalman filter noise removal test and the missing detection completion test.

7.2.1. Result of first tracking evaluation test

The tracker is expected to generate three trajectories in the first tracking evaluation test, all of which should be straight lines. The result of the first test is presented below:

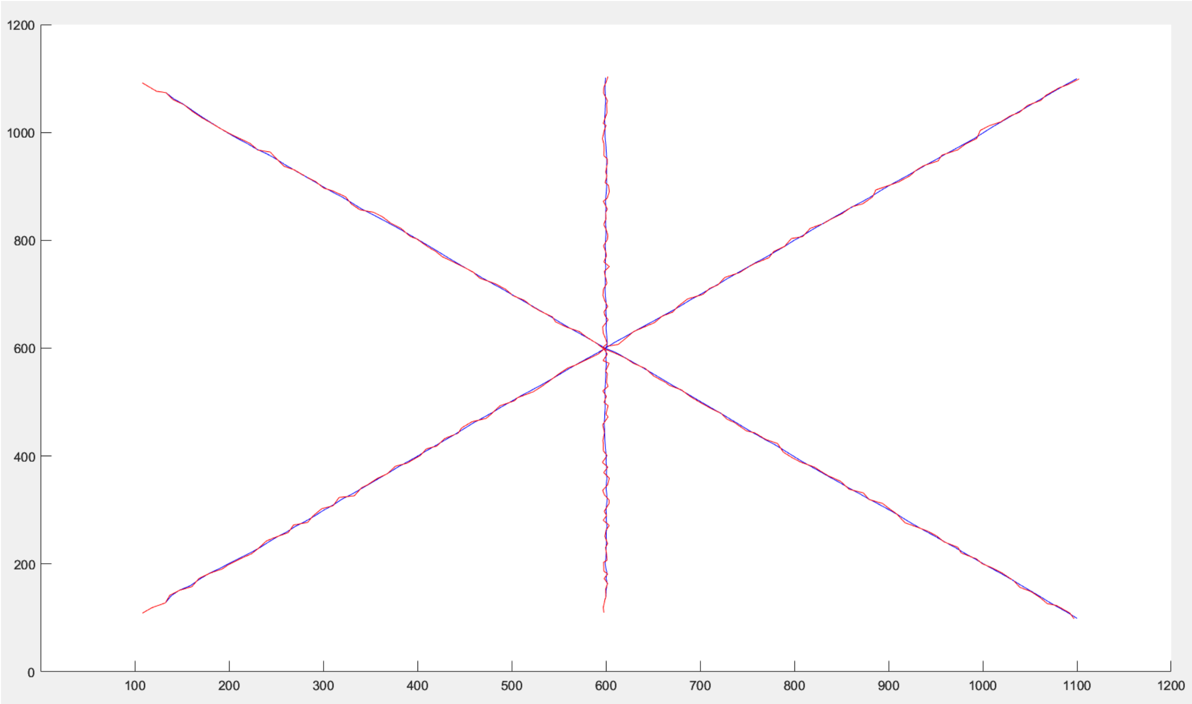

Figure 9: The trajectories of the first test. The red traces in the figure represent the original traces with errors, which were matched manually by researchers. The blue traces were generated by the tracking program and processed by the Kalman filter to remove errors.

As the image represents a two-dimensional plane, three trajectories can be represented by vectors. The equations of the three trajectories with the time sequence changes are as follows:

$$\boldsymbol{Trajectory_1} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Trajectory_2} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Trajectory_3} = (\mathbf{600} + \mathbf{0} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t})) * \hat{\boldsymbol{\jmath}}$$

$\hat{\imath}$ represents the unit vector in the horizontal direction and $\hat{\jmath}$ represents the unit vector in the vertical direction. The detections of the trajectories should be slightly different from the trajectory equations.

$$\boldsymbol{Detection_1} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Detection_2} = (\mathbf{100} + \mathbf{10} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\imath}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\jmath}}$$

$$\boldsymbol{Detection_3} = (\mathbf{600} + \mathbf{0} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\imath}} + (\mathbf{100} + \mathbf{10} * \boldsymbol{u}[\boldsymbol{n}]) * \hat{\boldsymbol{\jmath}}$$

Based on the equation and the image, it can be observed that the blue curve is essentially identical to the expected curve. This indicates that the program meets the requirements of the first test, and that program meets the specified requirements.

7.2.2. Result of second tracking evaluation test

The tracking algorithm is expected to generate a total of two trajectories, one that completes the missing detection in the middle and another that continues to predict the updated trajectory when no detection is available as input.

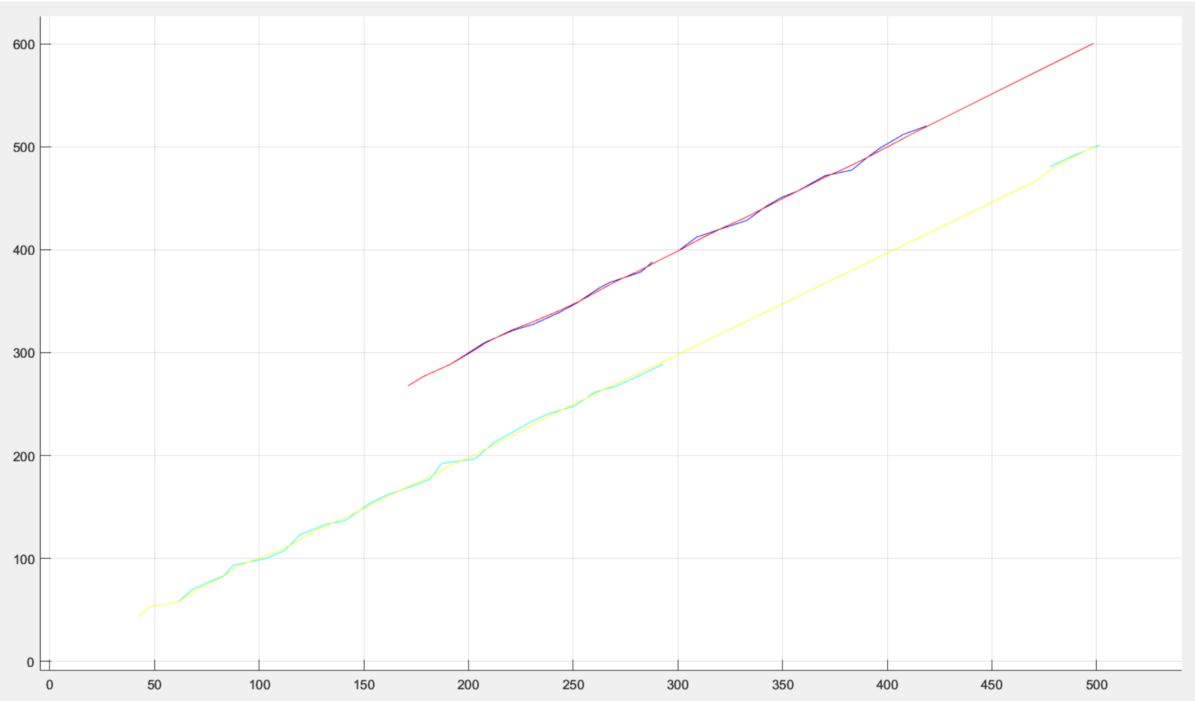

Figure 10: The trajectories of the second test. The cyan and blue tracks represent incomplete tracks given by the target indicator, respectively. The red and yellow trajectories represent the trajectories after the tracking algorithm has associated and completed the missing parts of the incomplete trajectories, respectively.

As the image represents a two-dimensional plane, the trajectories can be represented by vectors. The equations of the two trajectories with the time sequence changes are as follows:

$$\boldsymbol{Trajectory_1} \;=\; (\mathbf{10} * \boldsymbol{u}(\boldsymbol{t}-\mathbf{4})) * \hat{\boldsymbol{i}} + (\mathbf{10} * \boldsymbol{u}(\boldsymbol{t}-\mathbf{4})) * \hat{\boldsymbol{j}}$$

$$\boldsymbol{Trajectory_2} \;=\; (\mathbf{100} + \mathbf{10} * \boldsymbol{u}(\boldsymbol{t}-\mathbf{17})) * \hat{\boldsymbol{i}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{u}(\boldsymbol{t}-\mathbf{17})) * \hat{\boldsymbol{j}}$$

$\hat{\boldsymbol{i}}$: the unit vector in the horizontal direction

$\hat{\boldsymbol{j}}$: the unit vector in the vertical direction

$\boldsymbol{u}(\boldsymbol{t})$: the unite step function

The detections of the trajectories should be slightly different from the trajectory equations.

$$\boldsymbol{f_1}[\boldsymbol{n}] = \boldsymbol{u}[\boldsymbol{n}-\mathbf{4}] - \boldsymbol{u}[\boldsymbol{n}-\mathbf{30}] + \boldsymbol{u}[\boldsymbol{n}-\mathbf{48}] - \boldsymbol{u}[\boldsymbol{n}-\mathbf{51}]$$

$$\boldsymbol{f_2}[\boldsymbol{n}] = \boldsymbol{u}[\boldsymbol{n}-\mathbf{17}] - \boldsymbol{u}[\boldsymbol{n}-\mathbf{28}] + \boldsymbol{u}[\boldsymbol{n}-\mathbf{30}] - \boldsymbol{u}[\boldsymbol{n}-\mathbf{43}]$$

$$\boldsymbol{Trajectory_1} = (\mathbf{10} * \boldsymbol{f_1}[\boldsymbol{n}]) * \hat{\boldsymbol{i}} + (\mathbf{10} * \boldsymbol{f_1}[\boldsymbol{n}]) * \hat{\boldsymbol{j}}$$

$$\boldsymbol{Trajectory_2} = (\mathbf{100} + \mathbf{10} * \boldsymbol{f_2}[\boldsymbol{n}]) * \hat{\boldsymbol{i}} + (\mathbf{1100} - \mathbf{10} * \boldsymbol{f_2}[\boldsymbol{n}]) * \hat{\boldsymbol{j}}$$

$\hat{\boldsymbol{i}}$ **: the unit vector in the horizontal direction**

$\hat{\boldsymbol{j}}$ **: the unit vector in the vertical direction**

$\boldsymbol{u}[\boldsymbol{n}]$**: the unite step function (n = 1, 2, 3, 4…)**

Based on the images, the tracking algorithm utilizes Kalman filtering to mitigate errors in the trajectory while completing it.

7.3. Result of vehicle tracking algorithm

The display of the results will be divided into two parts: the general trajectory display and the individual trajectory display. In the first part, all trajectories will be displayed on a background image and analysed accordingly. In the second part, different specific trajectory maps will be generated and analysed based on the images.

7.3.1. Result of general trajectories

The following map displays all trajectories generated by the multiple vehicle tracking algorithm. The performance of multiple vehicle tracking algorithm is discussed separately according to the respective trajectories.

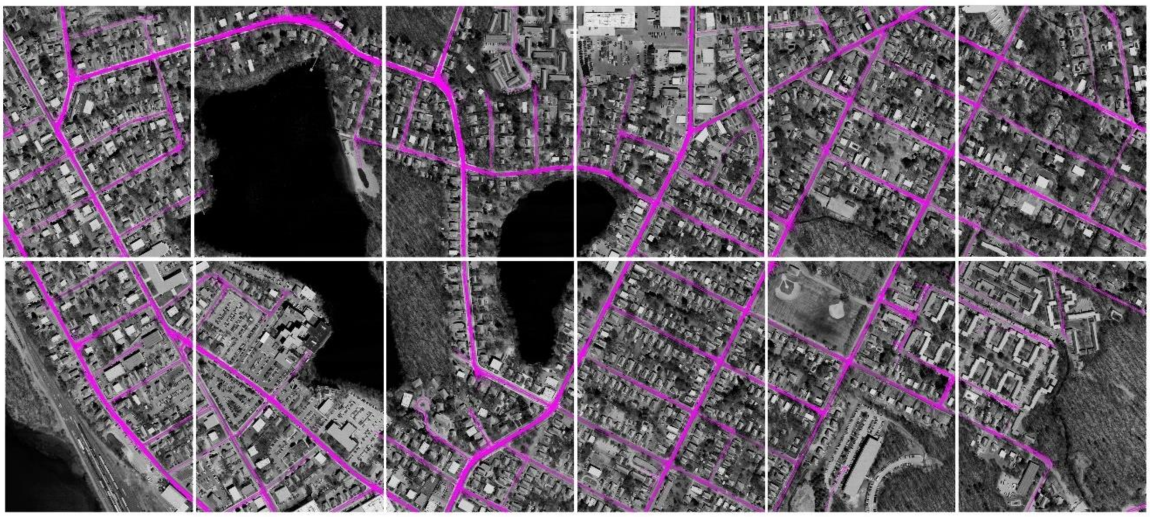

Figure 11: The general trajectories about the series of videos "2.5_1" with the field of view 2.5 degree. All trajectories generated from the video are synchronized to the frames in same time sequence and presented for analysis.

Figure 12: The general trajectories about the series of videos “2.5_2” with the field of view 2.5 degree. All trajectories generated from the video are synchronized to the frames in same time sequence and presented for analysis.

Figure 13: The general trajectories about the series of videos “5_1” with the field of view 5 degree. All trajectories generated from the video are synchronized to the frames in same time sequence and presented for analysis.

Figure 14: The general trajectories about the series of videos "5_2" with the field of view 5 degree. All trajectories generated from the video are synchronized to the frames in same time sequence and presented for analysis.

7.3.2. Result of single trajectory

Taking track 158 in series of videos "2.5_2" as an example, its trajectory is shown below, crossing the areas of videos marked "2.5_2_1", "2.5_2_2", and "2.5_2_3" in sequence.

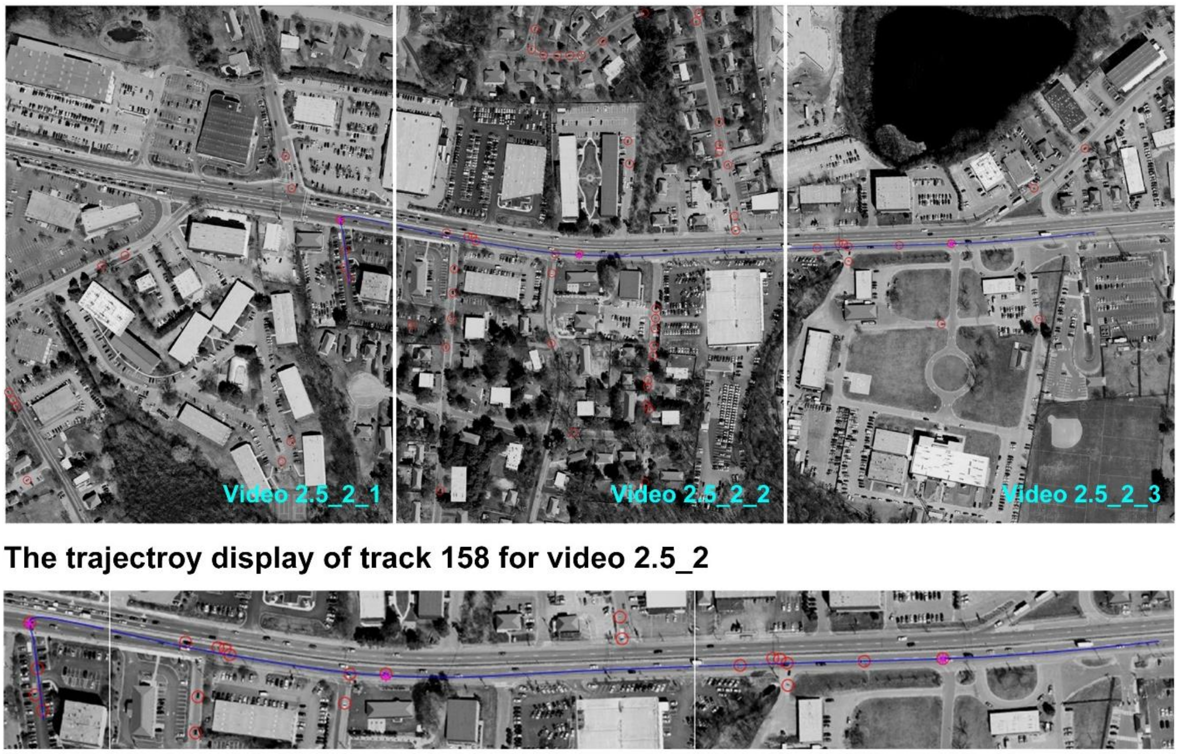

Figure 15: The track 158 in series of videos "2.5_2". The three images presented above were captured from frames 150, 220, and 320 of the video. The image below is the entire trajectory.

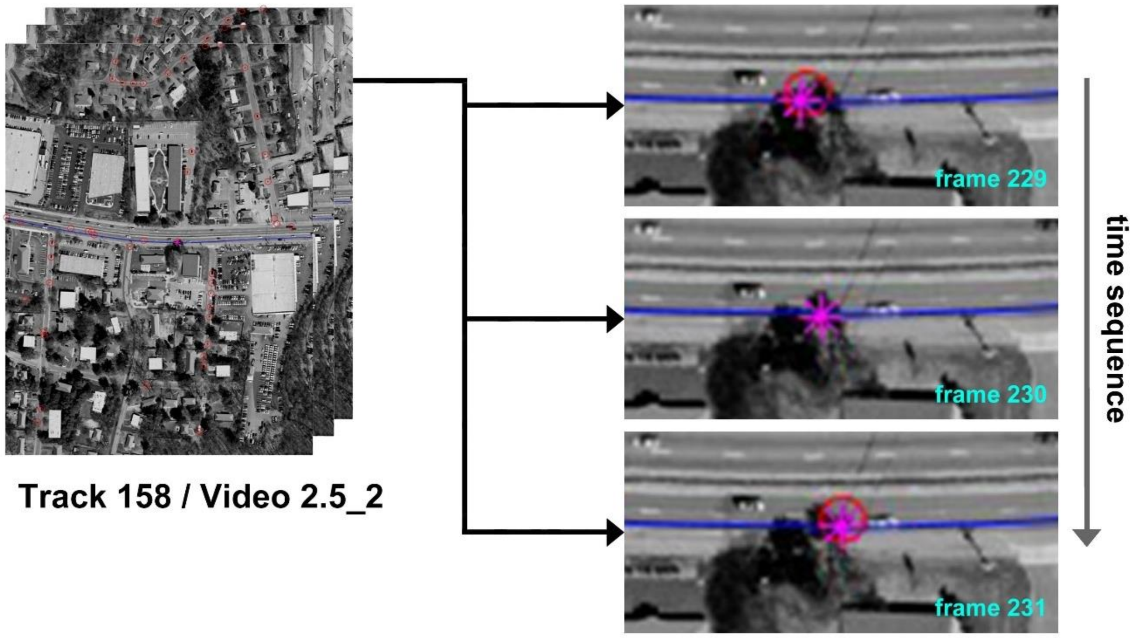

Figure 16: The frame 229-231 of track 158 in series of videos "2.5_2".The target indicator failed to detect the target in frame 230, but the trajectory remained unaffected.

The target indicator failed to detect the target in frame 230, but the trajectory remained unaffected. The target indicator failed to detect the target in frame 230, but the trajectory remained unaffected. This was because the target was too close to the background colour at that point, making it difficult to obtain an accurate vehicle position using frame subtraction. Nevertheless, the tracking algorithm successfully completed the position with a prediction based on the Kalman filter, and no new tracking was created.

The track association algorithm performs well in most cases, but challenges such as missed detection or closed vehicles can result in mis-association. Taking track 4368 in series of videos "2.5_2" as an example, its trajectory is shown below, crossing the areas of videos marked "2.5_2_10" and "2.5_2_4" in sequence.

According to the figure, the program initially tracks the black bus, shown by the cyan symbol in the frame 955. However, in the subsequent frames, the detection is lost as the bus stop in the frame 959, and the Kalman filter automatically make the prediction that the bus still moving forward based on its previous state of the bus. In frame 963, the tracking algorithm then erroneously associate the track whose ID is 4368 to another moving vehicle, marked in green, which is a mis-association.

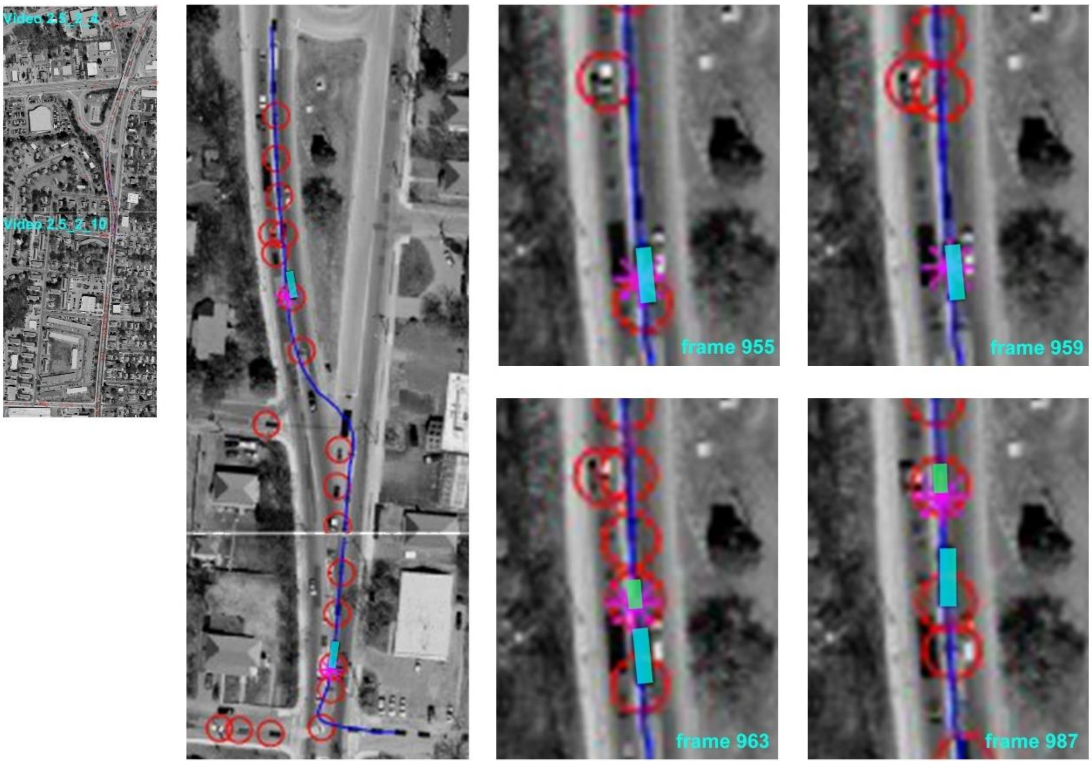

Figure 17: The track 4368 in series of videos "2.5_2". The total trajectory and the separated frames are displayed respectively.

To make further explanation about the mis-association, the schematic diagram is as follow:

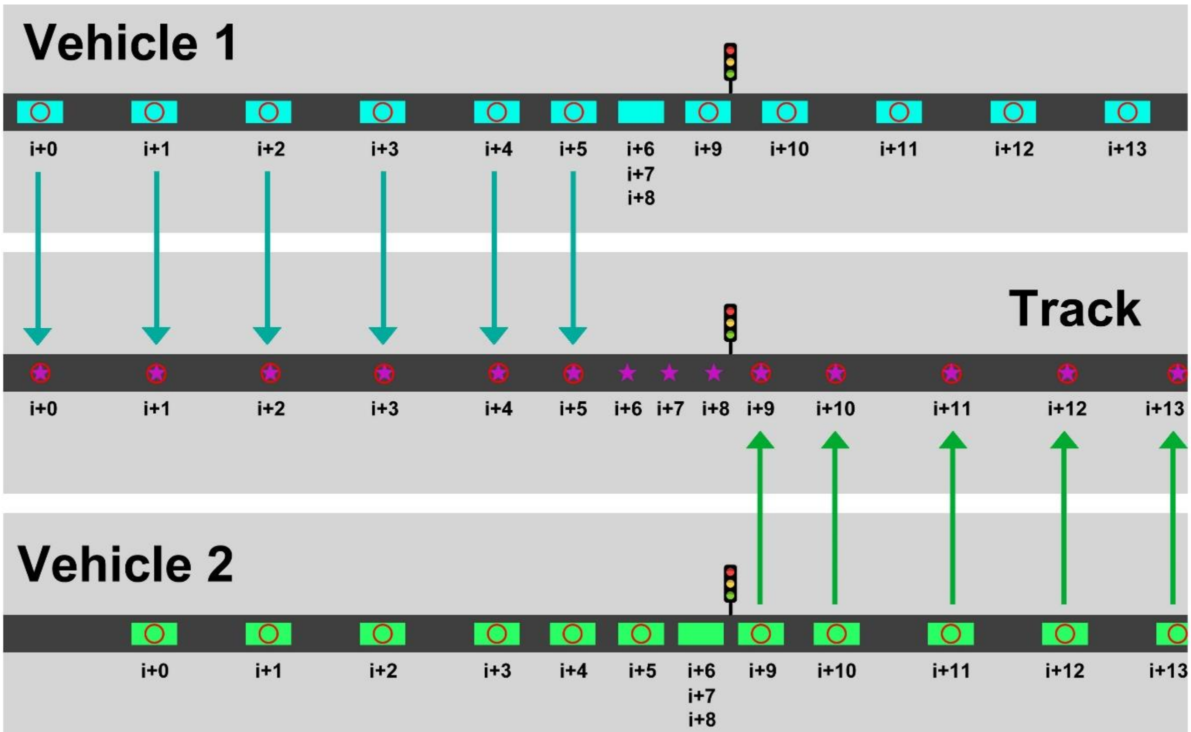

Figure 18: The scheme diagram about the mis-association. This diagram present the simulated situation about the mis-association and demonstrates the performance of the tracking algorithm based on this scenario.

In the above diagram, there are two vehicles traveling from left to right on the same road, with the green vehicle in front and the cyan vehicle behind. Both vehicles stop at the traffic lights. After waiting for the same amount of time, both vehicles start and continue along the road simultaneously. Initially, the tracking algorithm tracks the cyan vehicle, but the mis-association problem occurs at the traffic lights because the algorithm predicts the future state of the vehicle based on its past state even though it has not detected the vehicle. When the green vehicle stops moving, it cannot be detected by inter-frame subtraction, causing detection to be lost, but tracking is maintained. However, after both vehicles start at the same time, the algorithm mistakenly associates the green vehicle and continues tracking based on its detection, as the algorithm predicts a position closer to the position of the green vehicle.

The simple distance-based association is inadequate for determining the accuracy of association, and resolving this issue is difficult. The SORT algorithm [20] addresses this challenge by extracting features from the vehicle and tracking based on these features, which uses neural network related algorithms such as FrRCNN, YOLO, and other algorithms to aid the target indicator. This approach offers greater accuracy but requires higher computing power to support the corresponding calculations.

7.3.3. Programme efficiency

The target indicator algorithm relies on the centroid_finding programme to process the video data and obtain the coordinates of the detected vehicles. Specifically, the programme sequentially analyses 12 videos and applies a series of processing steps to each frame. This pre-processing step greatly enhances the efficiency of the subsequent multi-target tracking algorithm and reduces the memory requirements of the system.

Based on the timing of the programme, the centroid_finding program takes approximately 9,435.4587 seconds. In a single run, the target indicator processed a series of 12 videos, each containing 1496 frames, for a total of 17,952 frames. The efficiency of the target indicator is 1.9026 FPS(frames per second). However, this execution time may vary depending on the size and complexity of the input videos, as well as the hardware specifications of the computer used for running the programme.

The track association algorithm relies on the tracking program to update the tracks by transforming the pre-processed data about detection into tracks. Thanks to the pre-processing of the target indicator, the efficiency of the track association algorithm is much faster than expected. Using the data from the "5_2" video series as an example, a total of 17,099 trajectories were generated from the pre-processed data, which took 1714.7967 seconds. This corresponds to a tracking efficiency of 10.4689 FPS, based on the 12*1496 frames generated from the video data. The following chart illustrates the track generation process and the corresponding time spent for frames in time sequence.

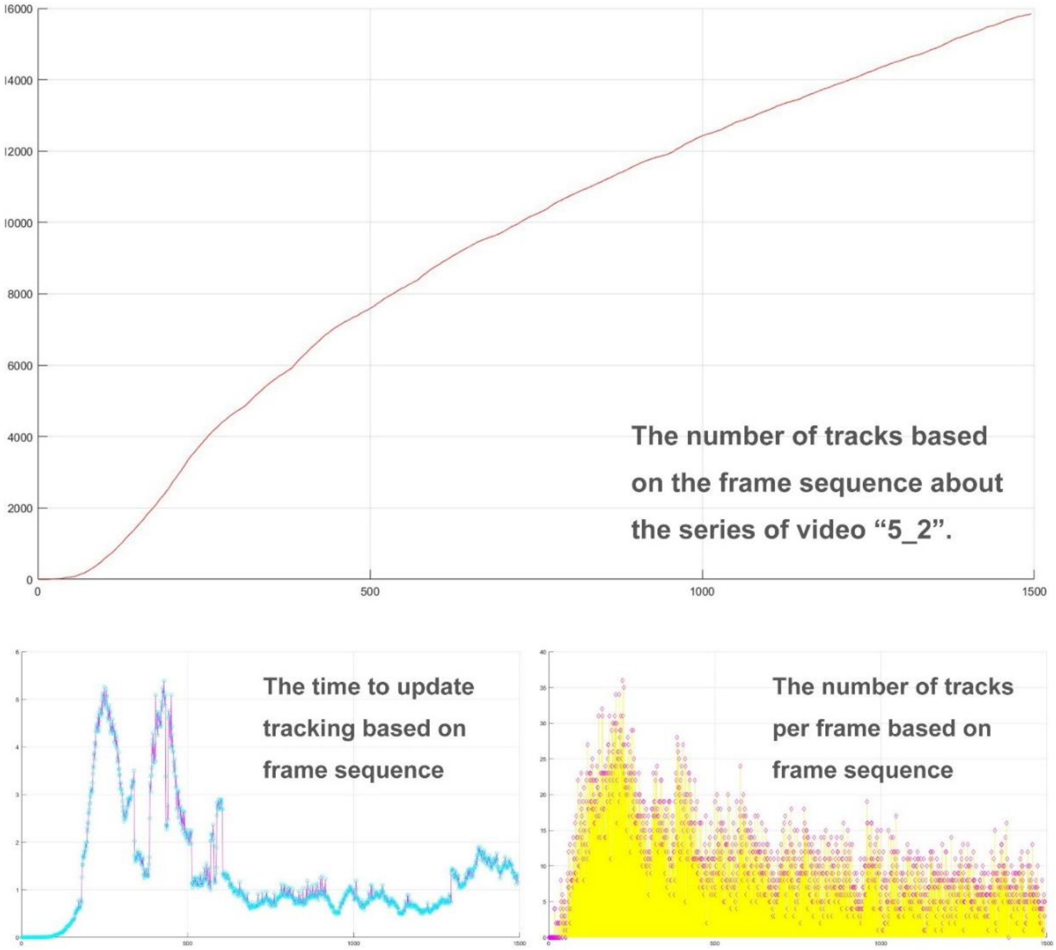

Figure 19: The graphs about the tracking efficiency based on frame sequence about the series of video “5_2”

Based on the graphs about the series of video “5_2”, it is apparent that more vehicles are detected during the processing of the first 500 frames. There is a correlation between the amount of tracking added per frame and the time spent, which is roughly proportional. As a result, tracking increases more quickly. In hence, the time taken to process these frames is correspondingly longer. In subsequent frames, the tracking association procedure can run faster as fewer objects are detected.

8. Discussion

In theory, there exist specific calculations to determine the reliability and performance of an algorithm. In the case of multi-target tracking algorithms, the MOTA (Multi-Object Tracking Accuracy) algorithm evaluates the error of the tracking system based on three main aspects: misses, false positive, and mismatch counts. However, in this particular project, there is no precise dataset of car trajectories, so a sample survey is employed to perform the calculations and make a general comparison with other tracking algorithms. The critical metric of Multiple Object Tracking Accuracy (MOTA) defined as follow:

$$\boldsymbol{MOTA = 1 - (\sum_{t=1}^{N}(c_{fp} + c_m + \log(c_{mm})))/\sum_{t=1}^{N} c_g}$$

$\boldsymbol{c_{fp}}$ **: the false positive counts** $\boldsymbol{c_m}$ **: the misses counts**

$\boldsymbol{c_{mm}}$ **: the mismatch counts** $\boldsymbol{c_g}$ **: the ground truth counts**

Table 3: The MOTA about the different tracks.

$N_{track}^{\#}$	c_{fp}	c_m	c_{mm}	c_g	$MOTA$
135	8	9	11	87	0.792628
158	38	6	0	285	0.845614
241	31	7	12	144	0.728617
367	21	0	0	130	0.838462
3674	43	3	12	188	0.749588

The average MOTA is 79.1% with false positive ratio 3.8% and misses ratio 16.6%.

The measured values of the algorithm's reliability and performance may differ slightly due to the sampling tests carried out during the calculations, but overall indicate a superior performance. Compared with the research of Xiao et al [9], while the accuracy of this algorithm in wide-area vehicle tracking is slightly lower than existing algorithms, the misses ratio is significantly higher. This could be attributed to the process noise covariance utilized in the Kalman filter, resulting in some tracking loss as the tracker fails to detect the indicated target quickly enough. The false positive ratio is relatively low due to the effectiveness and precision of the target indicator used in this algorithm. This allows for better detection of vehicle movements even in complex situations such as partial occlusion by trees. Additionally, the algorithm is able to compensate for some of the missing detections during tracking.

In the vehicle tracking algorithm, a simple dynamic model is utilized solely for estimating the position of objects, based on their past states. However, to enhance the accuracy of the algorithm, a more sophisticated dynamic model can be implemented for more precise predictions that correlate with data. Furthermore, Pellegrini, S. et al [22] introduced a model of social behaviour in addition to the traditional dynamic model, which accounts for social interactions and scene knowledge, leading to improved tracking performance. This research provide the potential improvement for vehicle tracking algorithms to be enhanced by incorporating corresponding models.

Furthermore, the use of neural networks for feature extraction and feature correlation with vehicles is a promising approach to tracking vehicles. The lightweight convolutional neural network architecture can be utilized to complete the feature extraction. However, the feature extraction based on convolutional neural networks is relatively more computationally intensive than conventional image processing techniques, which is not conducive to building real-time systems.

From the perspective of the original specification, this project fulfilled the original requirement of successfully tracking five vehicle volumes with an accuracy rate of over 75%. The algorithm has been able to perform multi-target tracking while performing the task of tracking across video regions. In summary, the algorithm accomplishes the goal of multiple vehicle tracking in wide area aerial video.

9. Reflection on learning.

I would like elaborate on three aspects of reflection on learning based on the project, which are project planning, project skills learning, and professional skills acquisition.

From the perspective of project planning, I have gained an understanding of how engineering management is applied in projects. Through this project, I learned how to set milestones based on deliverables to complete the project in an organized manner. I also developed skills in managing time visually through Gantt charts and organizing the time dimension of the project. These experiences have provided me with a comprehensive understanding of project management, which cannot be obtained through assessments of the courses.

From the perspective of project skills learning, I recognized weaknesses in my project development. For instance, I lacked knowledge of project testing, and as a result, I often encountered difficulties while trying to solve problems during project development. My supervisor helped me understand the importance of testing the project in sections and then synthesizing it to complete the project efficiently. This experience has inspired me to apply proper segmentation to projects to improve efficiency. Additionally, I learned to communicate effectively with my supervisor by addressing issues in a timely manner or using alternative approaches, which accelerated my progress during the second half of the project. I also developed the habit of constantly optimizing and iterating on my code, which led to improved efficiency of the program. For instance, when I first encountered the structure in MATLAB, I added many redundant procedures during the early development stage. However, I subsequently made changes step by step, which improved the program's efficiency

From the perspective of professional skills acquisition, I gained a deeper understanding of the principles and applications of image processing techniques, which are vital in many fields, including computer vision and robotics. I also learned about the use of the Kalman filter in multiple-target tracking algorithms, which has numerous practical applications. Furthermore, I became more familiar with data structures in MATLAB, which is an essential tool in programming and data analysis.

Overall, this project has provided me with valuable experiences and skills that will be useful in future projects and professional settings.

10. Conclusions

In this project, a novel multi-objective tracking approach for detecting and tracking vehicles in wide area aerial video using image processing techniques is proposed. The approach of this project offers several contributions.

Firstly, the algorithm does not rely on complex models, resulting in a small overall computational effort and fast processing speed, while remaining easily modifiable and upgradeable. The relatively simple principle of the algorithm enables its application in a wide variety of situations without requiring excessive qualifications.

Second, the inter-frame subtraction method and image processing techniques allow for accurate detection of moving vehicles with a low false positive ratio, and the algorithm can effectively compensate for mis-detections. Meanwhile, the utilization of the Kalman filter enhances the accuracy of the tracking results by effectively eliminating errors.

Thirdly, the method of the project serves as a strong foundational algorithm with a relative high Multiple Object Tracking Accuracy (MOTA), and can be combined with other techniques to achieve even higher accuracy ratio. Finally, this technology has wide-ranging applications in fields such as traffic monitoring, Wide Area Aerial System (WAAS) construction, smart city management, disaster response, biomonitoring, and has particularly promising potential when used in conjunction with Unmanned Aircraft Systems (UAS).

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Appendices

Appendix of Tables

Table 4: The histogram complete histogram data about the results of inter-frame subtraction based on video “2.5_2_4” with field of view 2.5 degree

#N	frame30	% total	frame31	% total	frame32	% total	frame33	% total	frame34	% total
0	2991773	9.999241	2991598	9.998656	2991686	9.998951	2991554	9.9985094	2991718	9.999057
1	140	9.999709	302	9.999666	193	9.999596	268	9.9994051	143	9.999535
2	33	9.99982	45	9.999816	37	9.999719	66	9.9996257	36	9.999656
3	26	9.999906	19	9.99988	22	9.999793	21	9.9996959	25	9.999739
4	9	9.999936	13	9.999923	17	9.99985	19	9.9997594	8	9.999766
5	3	9.999947	6	9.999943	5	9.999866	9	9.9997894	7	9.999789
6	7	9.99997	10	9.999977	3	9.999876	4	9.9998028	7	9.999813
7	5	9.999987	2	9.999983	0	9.999876	9	9.9998329	4	9.999826
8	0	9.999987	0	9.999983	2	9.999883	1	9.9998362	0	9.999826
9	2	9.999993	1	9.999987	1	9.999886	7	9.9998596	0	9.999826
10	0	9.999993	2	9.999993	5	9.999903	6	9.9998797	4	9.99984
11	2	10	2	10	5	9.99992	2	9.9998864	1	9.999843
12	0	10	0	10	0	9.99992	0	9.9998864	4	9.999856
13	0	10	0	10	2	9.999926	0	9.9998864	3	9.999866
14	0	10	0	10	3	9.999936	2	9.999893	2	9.999873
15	0	10	0	10	2	9.999943	0	9.999893	4	9.999886
16	0	10	0	10	3	9.999953	1	9.9998964	0	9.999886
17	0	10	0	10	3	9.999963	2	9.9999031	1	9.99989
18	0	10	0	10	4	9.999977	1	9.9999064	0	9.99989
19	0	10	0	10	3	9.999987	4	9.9999198	1	9.999893
20	0	10	0	10	0	9.999987	0	9.9999198	1	9.999896
21	0	10	0	10	0	9.999987	0	9.9999198	0	9.999896
22	0	10	0	10	0	9.999987	0	9.9999198	2	9.999903
23	0	10	0	10	0	9.999987	0	9.9999198	0	9.999903
24	0	10	0	10	0	9.999987	1	9.9999231	0	9.999903
25	0	10	0	10	2	9.999993	2	9.9999298	0	9.999903
26	0	10	0	10	0	9.999993	3	9.9999398	0	9.999903
27	0	10	0	10	0	9.999993	0	9.9999398	1	9.999906
28	0	10	0	10	0	9.999993	1	9.9999432	0	9.999906
29	0	10	0	10	0	9.999993	4	9.9999566	2	9.999913
30	0	10	0	10	2	10	2	9.9999632	1	9.999916
31	0	10	0	10	0	10	2	9.9999699	2	9.999923
32	0	10	0	10	0	10	3	9.9999799	0	9.999923
33	0	10	0	10	0	10	0	9.9999799	0	9.999923
34	0	10	0	10	0	10	0	9.9999799	0	9.999923
35	0	10	0	10	0	10	0	9.9999799	0	9.999923
36	0	10	0	10	0	10	0	9.9999799	0	9.999923
37	0	10	0	10	0	10	0	9.9999799	3	9.999933
38	0	10	0	10	0	10	0	9.9999799	3	9.999943
39	0	10	0	10	0	10	2	9.9999866	0	9.999943
40	0	10	0	10	0	10	0	9.9999866	0	9.999943

41	0	10	0	10	0	10	0	9.9999866	2	9.99995
42	0	10	0	10	0	10	0	9.9999866	2	9.999957
43	0	10	0	10	0	10	0	9.9999866	0	9.999957
44	0	10	0	10	0	10	4	10	0	9.999957
45	0	10	0	10	0	10	0	10	0	9.999957
46	0	10	0	10	0	10	0	10	0	9.999957
47	0	10	0	10	0	10	0	10	0	9.999957
48	0	10	0	10	0	10	0	10	3	9.999967
49	0	10	0	10	0	10	0	10	0	9.999967
50	0	10	0	10	0	10	0	10	0	9.999967
51	0	10	0	10	0	10	0	10	0	9.999967
52	0	10	0	10	0	10	0	10	0	9.999967
53	0	10	0	10	0	10	0	10	0	9.999967
54	0	10	0	10	0	10	0	10	0	9.999967
55	0	10	0	10	0	10	0	10	0	9.999967
56	0	10	0	10	0	10	0	10	2	9.999973
57	0	10	0	10	0	10	0	10	0	9.999973
58	0	10	0	10	0	10	0	10	0	9.999973
59	0	10	0	10	0	10	0	10	0	9.999973
60	0	10	0	10	0	10	0	10	0	9.999973
61	0	10	0	10	0	10	0	10	0	9.999973
62	0	10	0	10	0	10	0	10	0	9.999973
63	0	10	0	10	0	10	0	10	4	9.999987
64	0	10	0	10	0	10	0	10	0	9.999987
65	0	10	0	10	0	10	0	10	0	9.999987
66	0	10	0	10	0	10	0	10	0	9.999987
67	0	10	0	10	0	10	0	10	4	10
68	0	10	0	10	0	10	0	10	0	10
69	0	10	0	10	0	10	0	10	0	10
70	0	10	0	10	0	10	0	10	0	10
71	0	10	0	10	0	10	0	10	0	10
72	0	10	0	10	0	10	0	10	0	10
73	0	10	0	10	0	10	0	10	0	10
74	0	10	0	10	0	10	0	10	0	10
75	0	10	0	10	0	10	0	10	0	10
76	0	10	0	10	0	10	0	10	0	10
77	0	10	0	10	0	10	0	10	0	10
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79	0	10	0	10	0	10	0	10	0	10
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82	0	10	0	10	0	10	0	10	0	10
83	0	10	0	10	0	10	0	10	0	10
84	0	10	0	10	0	10	0	10	0	10
85	0	10	0	10	0	10	0	10	0	10
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87	0	10	0	10	0	10	0	10	0	10

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94	0	10	0	10	0	10	0	10	0	10
95	0	10	0	10	0	10	0	10	0	10
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102	0	10	0	10	0	10	0	10	0	10
103	0	10	0	10	0	10	0	10	0	10
104	0	10	0	10	0	10	0	10	0	10
105	0	10	0	10	0	10	0	10	0	10
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229	0	10	0	10	0	10	0	10	0	10
230	0	10	0	10	0	10	0	10	0	10
231	0	10	0	10	0	10	0	10	0	10
232	0	10	0	10	0	10	0	10	0	10
233	0	10	0	10	0	10	0	10	0	10
234	0	10	0	10	0	10	0	10	0	10
235	0	10	0	10	0	10	0	10	0	10
236	0	10	0	10	0	10	0	10	0	10
237	0	10	0	10	0	10	0	10	0	10
238	0	10	0	10	0	10	0	10	0	10
239	0	10	0	10	0	10	0	10	0	10
240	0	10	0	10	0	10	0	10	0	10
241	0	10	0	10	0	10	0	10	0	10
242	0	10	0	10	0	10	0	10	0	10
243	0	10	0	10	0	10	0	10	0	10
244	0	10	0	10	0	10	0	10	0	10
245	0	10	0	10	0	10	0	10	0	10
246	0	10	0	10	0	10	0	10	0	10
247	0	10	0	10	0	10	0	10	0	10
248	0	10	0	10	0	10	0	10	0	10
249	0	10	0	10	0	10	0	10	0	10
250	0	10	0	10	0	10	0	10	0	10
251	0	10	0	10	0	10	0	10	0	10
252	0	10	0	10	0	10	0	10	0	10
253	0	10	0	10	0	10	0	10	0	10
254	0	10	0	10	0	10	0	10	0	10
255	0	10	0	10	0	10	0	10	0	10

Table 5: The positions generate by the target indicator based Video 2.5_2_4 Frame 51 with its actual position and error.

Vehicle	Measurement	Labelled	Error
1	1339.557,1656.663	1331,1656	8.557, 0.663

Table 6: The positions generate by the target indicator based Video 2.5_2_4 Frame 101 with its actual position and error.

Vehicle	Measurement	Labelled	Error
1	482.853, 1887.118	483, 1887	-0.147, 0.118
2	1264.732, 1024.008	1263, 1024	1.732, 0.008

Vehicle	Measurement	Labelled	Error
3	1337.494, 1028.288	1337, 1028	0.494, 0.288
4	1361.405, 1344.415	1347, 1342	14.405, 2.415
5	1377.678, 1043.872	1390, 1045	-12.322, -1.128
6	1480.647, 1037.429	1479.500, 1037.500	1.147, -0.0710

Table 7: The positions generate by the target indicator based Video 2.5_2_4 Frame 370 with its actual position and error.

Vehicle	Measurement	Labelled	Error
1	8.738, 228.647	7, 229	1.738, -0.353
2	46.942, 792.201	58, 792	-11.058,0.201
3	46.942, 792.201	58, 792	-11.058, 0.201
4	114, 97	116, 100	-2, -3
5	120.012, 161.492	119, 162	1.012, -0.508
6	118.205, 1914.487	119, 1904	-0.795, 10.487
7	120.302, 1891.883	119, 1904	1.302, -12.117
8	242.945,120.869	244,120	-1.055,0.869
9	520.636,31.848	526,30	-5.364,1.848
10	775.5,1603.5	778,1608	-2.5,-4.5
11	794.12,1648.88	794,1647	0.12,1.88
12	804.008,1671.543	810,1686	-5.992,-14.457

Vehicle	Measurement	Labelled	Error
13	1020.447,1281.724	1018.5,1284	1.947,-2.276
14	1024.853,1202.853	1024,1206	0.853,-3.147
15	1041.162,1186.338	1042,1186	-0.838,0.338
16	1069.634,1077.39	1071,1078	-1.366,-0.61
17	1074.398,1018.211	1080,1005	-5.602,13.211
18	1101.203,1926.61	1101,1931	0.203,-4.39
19	1103.154,1906.457	1099,1904	4.154,2.457
20	1108.538,1752.4130	1111,1738	-2.463,14.412
21	1125.66,911.708	1125,921	0.66,-9.292
22	1152.211,1625.022	1161,1626	-8.789,-0.978
23	1157.311,177	1155,177	2.311,0
24	1153.848,1364.1520	1155,1360	-1.152,4.152
25	1169.119,1113.678	1169,1114	0.119,-0.322
26	1187.931,719.478	1188,719	-0.069,0.478
27	1195.462,1316.491	1206,1317.5	-10.538,-1.009
28	1201,1629	1204,1629	-3,0
29	1236.082,572.796	1229,593	7.082,-20.204
30	1235,1022	1245,1022	-10,0

Vehicle	Measurement	Labelled	Error
31	1237.529,524.841	1238,22	-0.471,2.841
32	1236.5,1632.5	1244,1633	-7.5,-0.5
33	1251,1322.5	1246,1321	5 1.5
34	1275.651,1323.172	1285,1323	-9.349,0.172
35	1299.5,1026	1303,1026	-3.5,0
36	1300.5,1639.5	1295,1639	5.5,0.5
37	1325.617,312.617	1328,308	-2.383,4.617
38	1358,1030	1362,103	-4,0
39	1384.754,159.129	1388,154	-3.246,5.129
40	1417.877,1335.637	1422,1336	-4.123,-0.363
41	1426.719,1034.53	1425,1034	1.719,0.53

- <u>Appendix of a listing of source code</u>

Image Processing

The programme `centroid_finding` is used for making image processing about the video. The main function of the programme is find the coordinates of vehicles by frames and save the results in the `centroid` folder in the `data` and `processing` folders separately.
Image processing is performed on the image obtained by subtracting two consecutive frames, and the specific process is as follows：

- *Medium Filter*: apply medium filter to the image
- *Binarization*: convert the grayscale image into binary image, the `threshold` of binarization is quite low to prevent removal of valid information, noise is removed during subsequent image processing
- *Opening Operation*: remove burrs and small noises by opening operation, and get the best results by adjusting structure element (SE).
- *Erosion*: make objects smaller to prevent two objects from sticking together too closely and being judged as one object
- *Connected-component labeling (CCL)*: label the objects by 4-connectivity

Tracking Association

The programme `tracking` would generate track according to the following algorithm and store traced information in a structure variable

Variables

- `Track`
    - `Track.centroid`: The series of centroid of specific vehicle
    - `Track.kalmanX`: The X matrix of Kalman filter
    - `Track.kalmanS`: The S matrix of Kalman filter
    - `Track.delete`: The variable used for tracking deletion
- `Nt`: The number of Tracks that already exist
- `Nd`: The number of Measurement that detected

Algorithm

```
if Nd == 0
    if Nt == 0
        Do nothing
    else (Nt ~= 0)
        Update tracking without measurement
        if the track cannot match to the measurement for 10 frames
            stop tracking
        end
    end
else (Nd ~= 0)
    if Nt == 0
        start tracking
    else (Nt ~= 0)
        Ⅰ) use pdist2 to generate the distance matrix => (m1 x m2)
```

```
        Ⅱ) Basic association matrix => (n x n)
        Ⅲ) Labelling:
            number of matched centroid => n (1)
            number of tracks without measurement => m1-n (-1)
            number of new tracks => m2-n (0)
        Ⅳ) Complete assocaition matrix
        Ⅴ) Tracking according to label:
            label = 1: match with previous tracks
            label = 0: create new tracks
            label = -1: update track without measurement
                if track not match to measurements for 10 frames
                    stop tracking
                end
    end
```

Auxiliary Programmes

- Trajectory Display: The programme `trajectory_display` is used to generate the video and images about the trajectory based on the `Track` data generate in the `tracking` programme. This is an auxiliary program for result visualization.
- Kalman Filter: The programme `F_kalmanfilter` is the MATLAB function which used as Kalman filter in tracking algorithm. The function would update S and X matrices. If the measurement `m` is empty, the Kalman filter would make prediction without measurement. If the measurement `m` is not empty, the Kalman filter would help reduce the noises.

Source Code

The source codes are displayed in the GitHub repository as follow:
https://github.com/yezehao/final-year-project/tree/main/processing

- Appendix of specification report

Specification report for project "Vehicle tracking in large area video"

Author: Ye, Zehao (1928186)
Project Supervisor: Ralph, Jason

Declaration of academic integrity

I confirm that I have read and understood the University's Academic Integrity Policy.
I confirm that I have acted honestly, ethically and professionally in conduct leading to assessment for the programme of study.
I confirm that I have not copied material from another source nor committed plagiarism nor fabricated, falsified or embellished data when completing the attached piece of work. I confirm that I have not copied material from another source, nor colluded with any other student in the preparation and production of this work.
SIGNATURE : Ye, Zehao DATE : 2022/10/13 .

Abstract

This report is proposed as a preliminary report to introduce the global planning about the final year project. Consist of three main sections, which are the introduction of the project content, the allocation of tasks on the time scale, and the criteria to measure the completion of the project, the specification report provides clear instructions on project intent, performance and construction for the project of vehicle tracking in large area. The clarification of the specifications would also help the supervisor and assessor to guide and evaluate the project more efficient to assist student have a clearer understanding about the entire procedure of developing a project.

1. Introduction

As the population of the city proliferates, the challenge about urban managements is coming to the fore. Despite the wide distribution of ground surveillance systems, such as CCTV, the integrated urban managements are not satisfactory. In face of the challenge, the Wide Area Aerial Surveillance (WAAS) system [1] has great promise as the simplest way to provide continuous coverage [2] by replacing ground-based monitoring systems. Therefore, tracking vehicles through aerial photography can be an efficient solution to accomplish urban management. In this context, this project is proposed to accomplish an algorithm to vehicle tracking in large area. The researcher expects to realise the tracking of multiple targets in the city-sized area at the same time ultimately.

This report consists of nine sections, which would describe the introduction, project description, project specification, methodology, project plan, project rationale and industrial relevance, literature review, conclusion, and related appendices in order.

2. Project Description

In this project, the algorithm that tracking vehicles in large areas would be designed. The aim of the project is to achieve tracking of multiple vehicles within the range of the Field of Regard (FOR). The accomplishment of the aim is the ultimate expectation of the project.

To realise the aim of multiple-tracking, series of objectives need to be taken. Firstly, develop the image reading programme to extracting the corresponding frames in the files. Secondly, get the trajectory of all the vehicles in certain area by image processing. Thirdly, utilize template matching method to classify vehicles. Fourthly, realise large area tracking of a single vehicle. Fifthly, revise the feature of target vehicle to change tracking targets. Ultimately, track multiple vehicles at the same time. The specifications and requirements would be discussed in the section of Project Specification/objectives.

3. Project Specifications/objectives

To design and develop an algorithm to accomplish multiple vehicle (more than 5 objects) tracking in Field of Regard, in 5 minutes duration from aerial photography videos, calibrated and tested to within a tolerance of 25% error rate compared to manual tracking, providing an aerial surveillance system to assist the agendas of policy makers in Smart City to implement urban management, by April 2023.

In this specification, the ultimate success criterion is to track five vehicles simultaneously and create their routes accordingly. The accuracy of these routes should overlap with the actual routes (In this project, the human analysts routes are thought to be correct answer.) by at least 75% to ensure the reliability of the program.

4. Methodology

From the perspective of programming language, MATLAB would be used for research in order to avoid spending time on constructing environment, because the functionality of MATLAB would be adequate to accomplish the project. Based on MATLAB, the Kalman Filter and Particle Filter are expected to utilized to realise vehicle tracking in large area from the perspective of algorithm theory.

5. Project Plan

As shown in the Gantt chart in the appendix 2, the project planning is as follow. The entire plan should be arranged based on a series of deadlines accordingly. There are four deadlines in this project, which are specification report, presentation about project, bench inspection report and final report. Despite the urgency of certain deadline, a structured project plan, with the procedure of designing, development, and testing, should be devised to achieve the ultimate success criterion.

After elaborating on the significance of planning and the Gantt chart, another element of the project that cannot be ignored is the preliminary preparation of the project. In hence, literature review of the project is scheduled from 26th September to 28th October. Meanwhile, the completion of preliminary report and forms is arranged from 3rd October to 14th October.

Afterwards, the design and development of the project should be started. The design of the project is scheduled form week 4 to week 8 on semester 1, accompanied with development of the project from week 7 semester 1 to week 2 semester 2. The long period of time, which from week 4 semester 1 to week 2 semester 2 would be spent on developing algorithms to accomplish milestones gradually. At the same time, during week 9 to week 11 on semester 1, the presentation about temporary results is required.

The following procedure of the project would be the testing form week 2 semester 2 to week 6 semester 2. This procedure would provide the opportunity to continue optimizing the algorithm.

Ultimately, the duration from week 5 to week 10 on semester 2 is scheduled to finish the final report and bench inspection, which can analyse and summarize the results of the entire project.

6. Project Rationale and Industrial Relevance

This project is intended to provide an efficient aerial surveillance system to complement and improve the urban monitoring network. Compared with the ground-based monitoring system, the cost of aerial surveillance system is higher. Meanwhile, the obtained data are time-sensitive and research-oriented. According to these premises, the possibility of industrialization and marketization about this project is relatively low.

7. Literature Review

This section is proposed to review the development and significance of technology about vehicle tracking in large area.

From the perspective of the project proposal, this project is mainly utilized to assist the agendas of policy makers in Smart City (SC) [3] as a means to enhance the life quality of citizen. However, the acquire data from sensor, which would be applied in Big Data analysts, far exceed the processing limits of the communication network [4]. The transferred data still complex at the scale of ability and availability of human analysts [2]. In this context, agendas of policy makers desire to develop an simpler way to access data for urban management.

From the perspective of the theory of project, the Kalman filter and Particle filter are used to develop the algorithm of vehicle tracking. Kalman filter is solving linear Gaussian problems in the Bayesian filtering framework. The single target tracking tend to use nearest neighbour association techniques. However, it would be complex while multi-target tracking [5]. To solve this problem, the Multiple hypothesis trackers [5] are expected to be utilized in this algorithm.

8. Conclusion

This report provides the clear instructions on project intent, performance and construction. Firstly, this project is proposed to design and develop an algorithm to accomplish multiple vehicle tracking, whose specifications are simultaneously tracking multiple vehicles in large area with the 75% overlap of manual routes. After the success of the project, it may be added to the aerial surveillance system to help managers make progress in urban management.

Despite of the specification, this report also schedules the tasks on the time scale and creates Gantt chart. Meanwhile, corresponding milestones of the project are set for better completion.

Ultimately, the literature review about the project is discussed for this section is significant for further literature writing and project development. The background of this project is also mentioned in this part. However, there are still some imperfections that need to be further improved in the future.

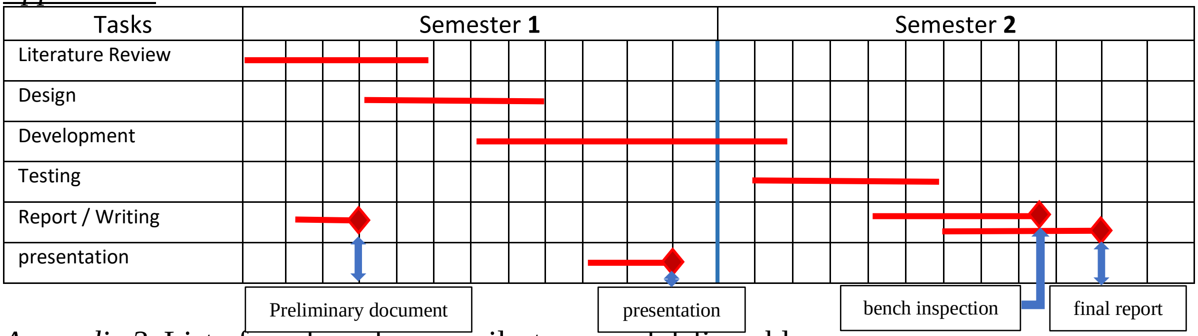
9. Appendices

Appendix 1. Key Specification.
An overview of your key specification/objectives including how you can verify that you achieved them.

Parameter	Verification
Frame handling	Switch files when vehicle approach boundary

Track duration from 0 to 5 minutes	Test by aerial photography video
Track 5 vehicles simultaneously	Test by aerial photography video
Tracking and manual route overlap of 75%	Compared the route with manual tracking route

Appendix 2. The Gantt Chart.



Appendix 3. List of work packages, milestones and deliverables.

Work Packages:

To design and develop an algorithm to accomplish multiple vehicle (more than 5 objects) tracking in Field of Regard, in 5 minutes duration from aerial photography videos, calibrated and tested to within a tolerance of 25% error rate compared to manual tracking, providing an aerial surveillance system to assist the agendas of policy makers in Smart City to implement urban management, by April 2023.

Milestones:

1. develop the image reading programme to extracting corresponding frames in the files.
2. get the trajectory of all the vehicles in certain area by image processing.
3. utilize template matching method to classify vehicles.
4. realise large area tracking of a single vehicle.
5. revise the feature of target vehicle to change tracking targets.
6. track multiple vehicles at the same time. The specifications and requirements would be discussed in the section of Project Specification/objectives.

Deliverables：

1. Track duration from 0 to 5 minutes
2. Track 5 vehicles simultaneously
3. Tracking and manual route overlap of 75%

Appendix 4. The risk assessment form.

SINLGE USER BEng, MEng, MSc GROUP PROJECT RISK ASSESSMENT FORM - REPORT ONLY SIGNIFICANT HAZARDS

Unsafe working methods will lead to a reduction in your final project mark! ALL hardware work must be completed within the laboratory

Students are encouraged to come on site to perform their lab work but are advised that in some circumstances (Adriano, raspberry Pi and micro-controller boards which operate at <20V) equipment is allowed to be brought home. Students removing any other equipment from the lab needs to be authorised in writing by your supervisor - supervisors please confirm with HOD/safety team to confirm.

NAME- Zehao Ye	**LOCATION-**

Student ID Number- 201601167	**Final year Laboratory**
SCHOOL/DEPARTMENT: Electrical Engineering & Electronics Undergraduate year of study : 3	**BUILDING: Electrical Engineering and Electronics, A-Block**
TITLE OF PROJECT: Vehicle tracking in large area video	
Description of Work: This project will be concerned with developing tracking algorithms for detecting and creating a track for specific vehicles through a complex urban environment. This project will use existing video simulations (eg. https://stream.liv.ac.uk/zbj9sswg) showing complex environments where vehicles are occluded as an air vehicle moves through a city.	

Select a category for this project: **Category** **1 / 2 / 3**	**<u>Category 1 – Projects based on specialist equipment:</u>** Projects requiring equipment available in the electronics laboratories (such as power supplies, multimeters, oscilloscopes, etc.) or any other specialist equipment that requires specific health and safety considerations (such as drones, etc.) that students would not normally be allowed to take home.
	<u>Category 2 – Projects based on "home-friendly" equipment:</u> Projects requiring small pieces of equipment that do not require specific health and safety considerations and students can safely use at home (Raspberry Pi's, Arduinos and other similar low-voltage boards with double insulated power supplies).
	<u>Category 3 – Projects based on software only:</u> Projects fully based on software that can be completed using only a computer, without requiring any other equipment.

If students are in an observation capacity only when experiment is being performed

- please state this on form as well as risk in being observers - i.e. possible distracting experimentalist,
- State risk if they could be injured in this respect and how. Significant risks only should be stated.
- Class of any laser is required

State voltage & current values of all power sources being used. Any power supplies that have the ability to generate current and voltages > 10mA AND >20V respectively can be regarded as potentially extremely hazardous:

Voltage 0V Current **0mA**

HAZARDS (Location, equipment and substances, activities)	**WHO CAN BE HARMED?**	**CURRENT CONTROLS**	**Likelihood (L) × Consequence (C) = RISK SCORE (R)**		
			L	**C**	**R**
DSE (Design work, programming, producing documentation). RSI, poor posture leading to muscular discomfort etc	Person operating DSE.	DSE assessment, provision of adjustable height monitors, chairs. Updating of DSE assessments, provision of footrests and other adaptations for use of DSE at workbenches where required.	1	1	1
Food and drink spillage and contamination	Any persons in the vicinity	No food or drink allowed In the laboratory at any time. Take refreshment breaks outside the laboratory. Confiscate and dispose of	1	1	1

		food and drink found around the workbenches			

- **For work using only Raspberry Pi and/or Arduino boards or other hardware connected via USB cable the main hazards are Display Screen Equipment (DSE) related, e.g. Repetitive Strain Injury, Carpal Tunnel Syndrome. L=1, C=1, R=1**

Training table - All boxes must be ticked in the following section to indicate either YES or NO.			
	N0	**YES**	**If you have ticked YES please follow the hyperlinks in the attached document, complete and return supplementary paperwork and/or implement and adhere to the guidance given.**
Use of tenon saw/hacksaw	✔		**Read Safe Operating** Procedure and other documentation on hand tools
Will work require the lifting of weights (>15kg)	✔		Manual Handling
Laser – If yes please input class of laser. Laser documents and hazard should be described on page 2 if laser is **NOT** class 1	✔		Please read all documents in the following link README : Laser: information and registration Guidance on the Safe Use of Lasers in Education & Research
Use gas cylinders or compressed gas?	✔		Gas Cylinder safety : Email local safety team to verify if training is required
Use hazardous Chemicals only? If stated on the form, description of hazard is required.	✔		COSHH - Use on-line EEE COSHH system to create COSHH risk assessment. Email local safety team to verify if training is required
Use voltages over 30V DC/AC If hazard has been previously described this	✔		Electrical Safety/Electricity – Includes reading the Sch. of EEE & CS dangers of electricity document
Use Power tools or rotating motors and machines	✔		SCR15-4 PUWER
Use Cryogenic Liquids/gases	✔		Cryogenic liquids and solids – Email local safety team to verify if training is required
Use Vacuum Systems and pressurised vessels	✔		Pressure systems : Email local safety team to verify if training is required
Use Radiation (UV, x-rays, microwaves)	✔		UV radiation (including links to local rules & safety advisor website)

LEVEL of Supervision?	**A** = Work May not be started without direct supervision **B** = Work may not start without Supervisor advice or approval **C** = No specific extra supervision requirements
Other relevant specific assessments (Local rules, Ethic approval forms)-	

Disclaimer

- *The University of Liverpool ensures as far as is reasonably practical the health and safety of its staff and students.*
- *All equipment used by the students for their project must be safety tested and approved by the laboratory technicians before use. This includes but is not limited to, soldering irons, oscilloscopes, power supplies, probes and multimeters.*
- *Students **MUST NOT** undertake hazardous experimental/development work associated with their project outside of their designated laboratory space.*
- *ALL equipment that is used in the laboratory space & project MUST be purchased through the departments purchasing procedures.*
- *No equipment to be plugged into the mains supply unless circuit has been approved by technician or supervisor.*
- *Failure to abide by these conditions can result in the project receiving 0%.*
- ***Submission of this form implies acknowledgement by all the students named below.***

I can confirm that Hazards identified and precautions specified are appropriate for the task :-

Acknowledgement by Student 1 Name: Zehao Ye , Signature: Zehao Ye , Date: 2022.10.7 .

Academic supervisor Name: Jason Ralph , Signature: JFR , Date: 14/10/2022 .

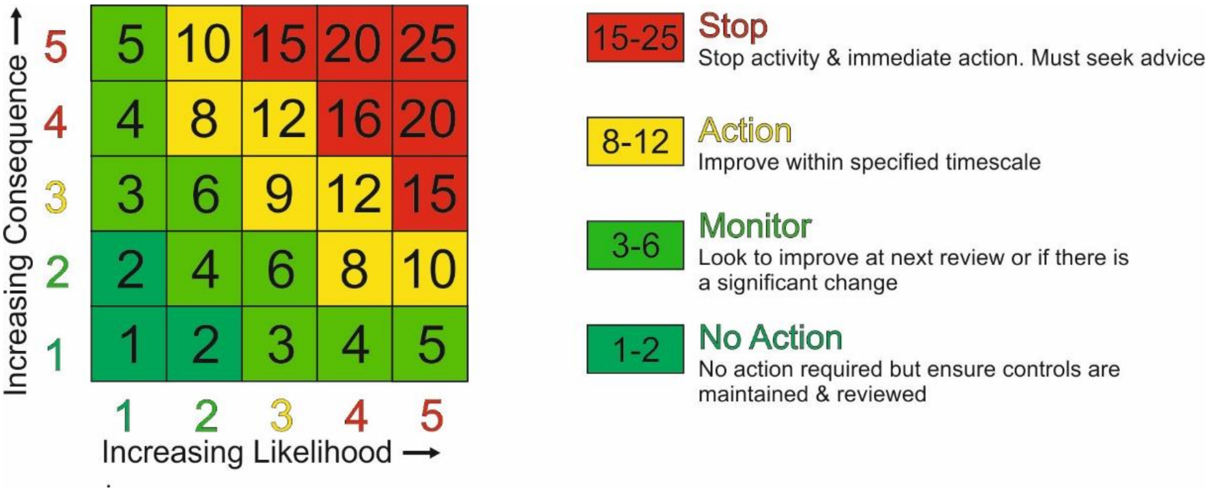
Common reasons for previously rejection of the form

- Project category was not stated on the assessment.
- Contradiction of hazards listed on page 2 compared those identified in training table. Users inserted description of hazards such as chemicals & live working but failed to insert yes in hazard table. Only hazardous chemicals should be described. Only significant hazards observed in experimental process should be described.
- Missing supervisor signature – risk assessment is invalid & students cannot enter the laboratory area
- Additional hazards noted in training table that are not described in hazard section. Lasers were described in training table required but hazard was not described in main assessment. Laser users should refer to risk assessment template document to identify how these should be described.

GUIDANCE TO COMPLETE THIS RISK ASSESSMENT FORM (LIKELIHOOD / CONSEQUENCE / RISK SCORE)

Likelihood		Consequence		Risk score	ACTION TO BE TAKEN
1	Very unlikely	1	Insignificant – no injury	1-2 NO ACTION	No action required but ensure controls are maintained and reviewed.
2	Un likely	2	Minor – minor injuries needing first aid	3-9 MONITOR	Look to improve at next review of if there is a significant change
3	Fairly likely	3	Moderate – up to seven days absence	8-12 ACTION	Reduce risk if possible, within specified timescale
4	Likely	4	Major – more than seven days absence; major injury	15-25 STOP	Stop activity and immediate action
5	Very likely	5	Catastrophic – death; multiple serious injury		

- For work using only Raspberry Pi and/or Arduino boards (i.e. no other hardware connected using additional power supplies) the only hazards are Display Screen Equipment (DSE) related, e.g. Repetitive Strain Injury, Carpal Tunnel Syndrome. L=1, C=1, R=1



Appendix 5. Ethical approval questionnaire.

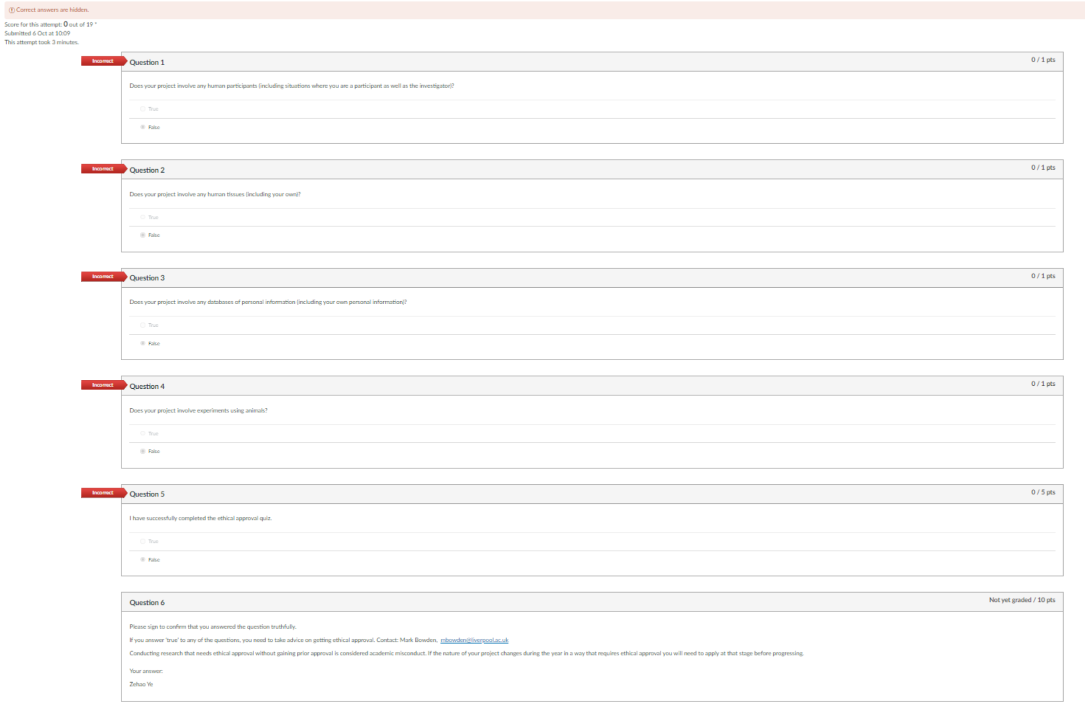


Figure 20: Screenshot of Ethical approval questionnaire

Appendix 6. References.

[1] L. Menthe, A. Cordova, C. Rhodes, R. Costello, J. Sullivan, The Future of Air Force Motion Imagery Exploitation: Lessons from the Commercial World, Technical Report, DTIC Document, 2012.

[2] E. J. Griffith, C. Mishra, J. F. Ralph, and S. Maskell, “A system for the generation of synthetic Wide Area Aerial surveillance imagery,” Simulation Modelling Practice and Theory, vol. 84, pp. 286–308, May 2018, doi: 10.1016/j.simpat.2018.03.003.

[3] P. Neirotti, A. De Marco, A. C. Cagliano, G. Mangano, and F. Scorrano, “Current trends in Smart City initiatives: Some stylised facts,” Cities, vol. 38, pp. 25–36, Jun. 2014, doi: 10.1016/j.cities.2013.12.010.

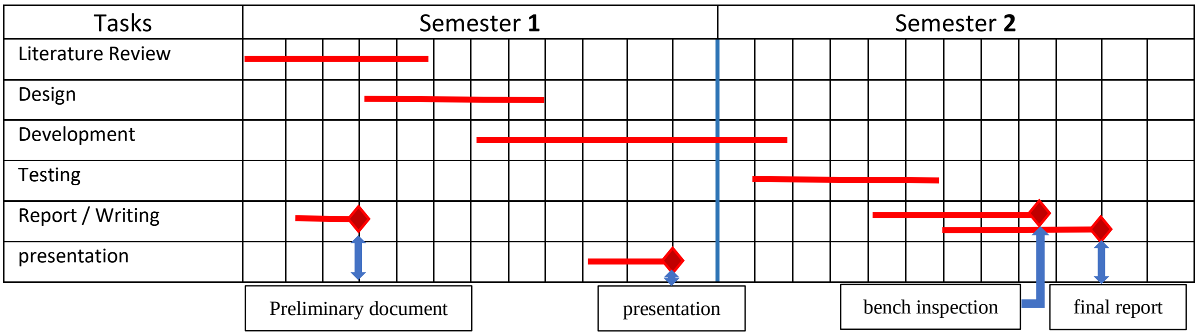
[4] R. G. Baraniuk, “More Is Less: Signal Processing and the Data Deluge,” Science, vol. 331, no. 6018, pp. 717–719, Feb. 2011, doi: 10.1126/science.1197448.

[5] J. F. Ralph, “Target Tracking,” Department of Electrical Engineering and Electronics, The University of Liverpool, Liverpool, UK

● Appendix of Gantt Chart

The original and revised Gantt charts are shown as follow:

Table 8: The original Gantt chart in the specification report.



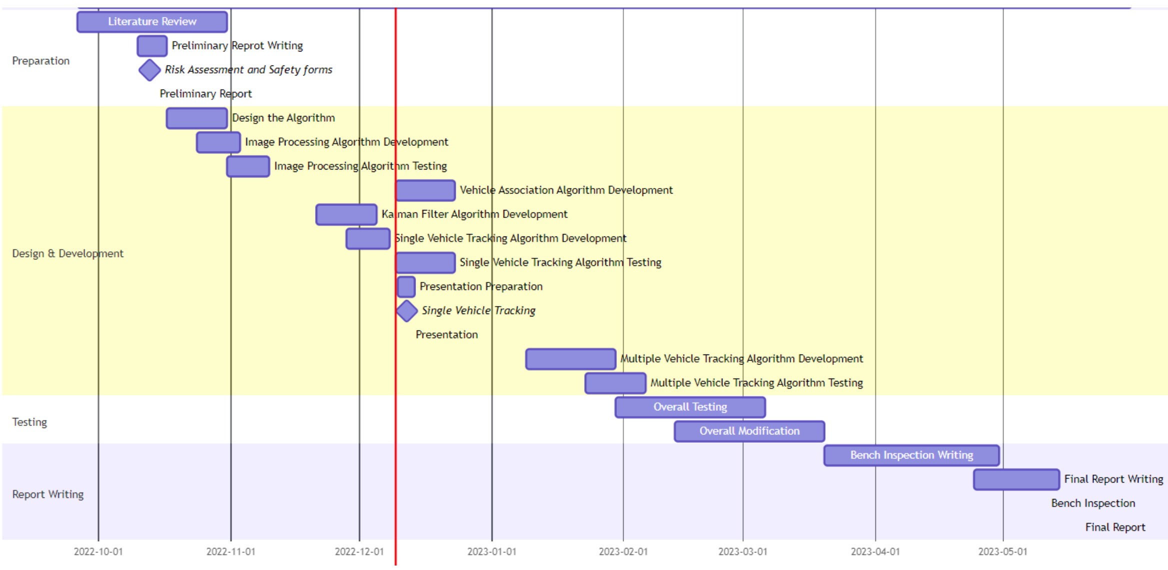


Figure 21: The revised Gantt chart in the presentation.

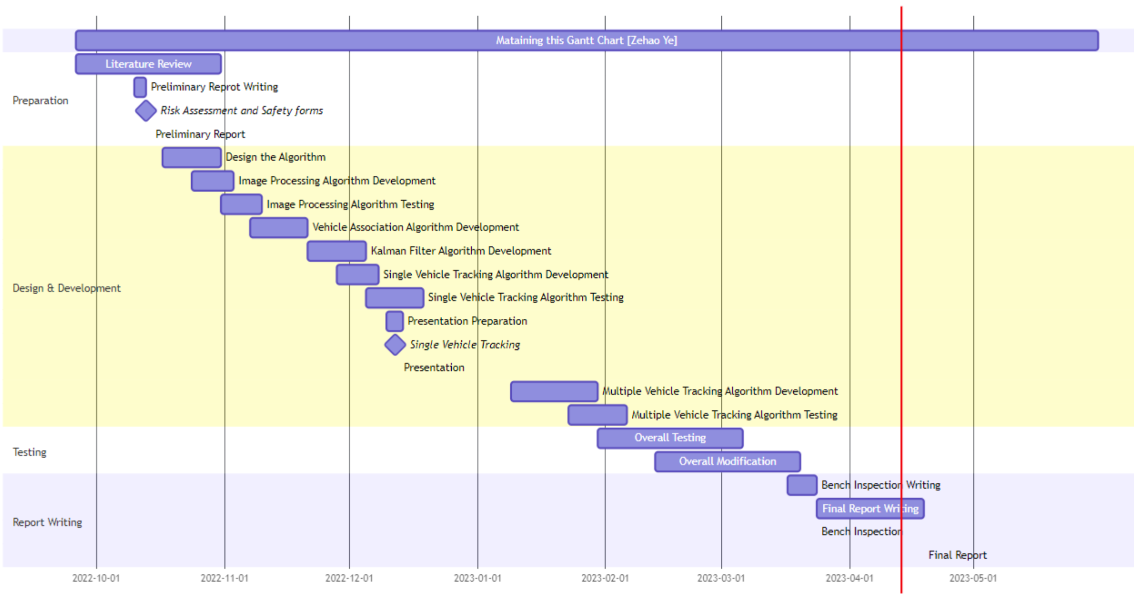


Figure 22: The revised Gantt chart in the final report.