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Collision Detection through Optical Flow

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ABSTRACT

In this paper, an analysis of collision detection via optical flow is presented. The main objective of the work is to detect and initiate a warning signal when there is a non-moving object or a moving object (such as a pedestrian) obstructing the path in which a vehicle is moving. The warning signal is given only if there is a risk of a collision. In order to gather the input video streams to the simulation, a camera with a resolution of 1280×720 pixels was used. Since the processing time increases with resolution, the actual processing was carried out at a lower resolution of 160×120 pixels. The colour segmentation was carried out through RGB colour space.

Simulink was used as a platform for the development and testing the simulation. Using the Simulink blocks, video pre-processing, image segmentation, optical flow calculation and thresholding were carried out. The stability of the video is one of the main concerns in this research. For videos taken when the vehicle is moving at high speed, the stability became an issue. The developed system tested successfully at speeds below 10 kmh^{-1} to detect stationary objects and pedestrians crossing the roads.

1. INTRODUCTION

The computer vision is focused on problems that involve interfacing computers with their surrounding environment through visual means. For example, object recognition deals with detecting the presence of an object in an image scene and extracting some features to identify the desired object. In the computer vision applications, basic inputs are images and video streams.

Humans have the ability to identify objects in a highly complex environment. However, when it comes to computers, it is one of the most difficult problems to solve. Given the current state of technology, a successful implementation for object recognition requires one to solve problems with very specific nature.

In this work, the problem is focused on non-moving objects and human in motion obstructing a path of a moving vehicle. We are interested in recognizing objects and humans based on the optical flow [1]. This approach differs from other techniques for human detection, such as those that recognize humans based on shape, colour, texture, or surface features.

For any moving object, the optical flow method can be applied. If an object is moving, the gradient of optical flow is observed everywhere except at the point toward which the object is moving, which, being at the centre of the optical flow pattern, stays constant. Therefore, by analysing the optical flow, not only the motion of the object but also how the object is moving in the particular domain can be analysed [2].

2. METHODOLOGY

2.1 Data Acquisition

Since the project is focused on motion detection with respect to a motion of a vehicle on the road, there are several cases to be considered. First, there are moving and non-moving objects on the road. Second, there are objects blocking the path of the vehicle and there are objects which will be on the sides of the vehicle. When the data collection is considered, there are a few more important parameters. The resolution of the video and the frame rate are two such parameters. Since the optical flow is related to the change of pixels, even for a small change in the video without any change in the scene, there will be change in optical flow vectors which will lead to incorrect results.

In order to maintain the stability of the video, the camera was fixed to the vehicle which was used in the experiment. In addition, the velocity of the vehicle was kept below 10 kmh^{-1}. Table 1 shows the specifications of the camera which was used to capture the video streams.

Table 1: Specifications of the camera

Property	Specification / Value
Video Format	MP4
Video resolution	1280×720 px
Data rate	1524 kbps
Total bit-rate	1524 kbps
Maximum Frame rate	30 frames/second
Recorded Colour space	RGB colour space

The vehicle which was used to capture the videos was a Van. To capture the necessary videos, a road in Kalutara district, located in an isolated area in Horana was selected. Since the selected road was not crowded and situated away from main roads, the experiment could be conducted safely. A plastic container (0.24 meter tall and 0.28 meter diameter) was used as the non-moving object which was quite easy to place at different locations on the road. As the pedestrians, two males of 15 years old and approximately 5 feet and 6 inches tall were selected.

Since the original videos were captured at higher resolution, they increased the processing time and reduce the efficiency of the simulation. Hence, the original videos were converted to reduce resolution (see Table 2) before using in the simulation.

Table 2: Specifications of videos used in the simulation

Property	Specification / Value
Video format	AVI
Video resolution	160×120 px
Data rate	478 kbps
Total bitrate	606 kbps
Frame rate	30 frames/second
Colour space	RGB colour space

2.2 Experiments

Once the frames were extracted from the video, the first step was to detect the road without any obstacle in it (Figure 1). Afterwards, a part of the image was selected as the region of interest (ROI). This was done by colour segmentation. Since the video stream was in RGB colour space, by using threshold values for colours, different regions were identified and the segmentation was done.

Figure 1: A screen shot of the video without any obstacles in it.

Subdividing the image into its constituent parts is known as image segmentation. Depending on the scenario, the segmentation process could differ. In some cases, the objects need to be segmented from its background. After segmenting the objects, the content of that particular section can be further analysed. There are two approaches for this process namely discontinuity detection technique and similarity detection technique. The first approach is based on the abrupt changes in gray-level image while the second is based on thresholds [3].

First, the source video is decomposed into Red, Green and Blue channels. Then each colour channel is subjected to a thresholding mechanism to detect the optimal values that the road can be identified. After thresholding, each of the coloured segments are combined with a bitwise AND operation to improve accuracy.

Since the area of the road is the region of interest, the image file is cropped so that the unnecessary regions are removed before processing the image. This will increase the performance since the processing time is proportional to the image size. After above operations, median filter is used to remove the unwanted noise. The neighbourhood size of the filter is 5×5 pixels.

The obstacle on the road is detected using the optical flow estimation [4]. The first objective is to detect an object which is not moving. Since there is a geometrical difference between the road and the object with respect to the moving vehicle, the calculated optical flow values of the object is different. This difference and the results obtained from the road segmentation process is used in the obstacle detection.

When considering two frames of an image sequence, pixels which represent the object has an optical flow value due to object becoming enlarged. Since the optical flow cannot be used for a colour image, a conversion was performed and the output image is fed into the optical flow calculation. Since the focus is on the object detection, the magnitude of the velocity estimated from the optical flow calculation is used as the output.

When the optical flow output is directly used as an input to the thresholding mechanism, the result is noisy. Therefore the median values are calculated and used. The video frames are concatenated as a 3D matrix and the median is taken along the 3rd dimension of the matrix. As a result, fluctuations due to noise are reduced and the result becomes more stable. A threshold value is used to distinguish the non-moving object which is located within the road margins.

When the colour segmented binary image and the optical flow threshold binary image are obtained, the detection process can be commenced. The isolation of the non-moving object can be done by taking the coincidence (AND) of the two signals.

Then the blob analysis can be performed in order to detect the obstacle on the road after which the classification of the object is done. If the object can cause a collision, the warning is triggered. Otherwise, the object is detected as a safe one which will not trigger any warning.

2.3 Moving Object Detection

As in the non-moving object detection, first the colour segmentation is done. Unlike the non-moving objects, since the pedestrian is moving across the road (in the positive *x*-direction or negative *x*-direction of the image), the optical flow change along a direction perpendicular to the direction of the vehicle movement is considerable. Thus, by analysing the optical flow vectors in the images, the pedestrian detection can be done easily [5].

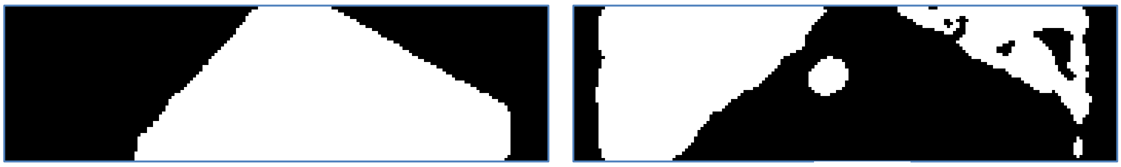
From the optical flow subsystem the velocity vector is taken as an output. The velocity vector is given in the complex form $u + iv$ where, u is the horizontal optical flow component and v is the vertical optical flow component. Since the velocity vector is in the complex form, to get the optical flow along the *x*-direction, despite of the direction of movement, absolute value must be used.

First, an element wise product of the final binary image in which the blob of the pedestrian and the optical flow vector output is taken. The result is the optical flow vector values of the pedestrian. For the moving pedestrian, there is a considerable change in the magnitude of the optical flow vectors in the *x*-direction. Since it is a complex matrix, *x*-direction optical flow value is taken by splitting each complex numbers into the real and imaginary components. Finally, using the absolute value of the optical flow, the detection of a collision is carried out.

3. RESULTS AND DISCUSSION

3.1 Non-Moving Object Detection

Based on the methodology discussed above, a system was developed using the Simulink platform. The original video was used as the input to the developed system. The first process was colour segmentation in order to distinguish the area of the road from the rest of the background (see Figure 2a). Since the motion within a selected area of the road was important, optical flow was calculated only in the selected region.



(a) (b)

Figure 2: (a) Screen shot of the colour segmented video. The road is separated from the background. (b) The optical flow method is applied to the original video. Only the objects which are moving have the optical flow values.

The optical flow calculation was carried out using the same original input video stream. To remove the unnecessary optical flow values, the threshold value was used. After applying the optical flow method with a thresholding, the binary image shown in Figure 2b was obtained. By combining Figure 2a and Figure 2b with an AND operator, the object was isolated.

(a) (b)

Figure 3: (a) The object is tracked using a red boundary box since it has a potential for a collision. (b) The object which does not cause a collision is tracked using a green boundary box

The developed system identified the objects on the road and started tracking the object using the blob analysis. According to the status of the object, it was tracked in different ways. If the object had a potential for collision, it was marked with a red boundary box, otherwise a green boundary box was used (see Figure 3).

In order to detect whether the object was going to cause a collision or not, the size (increase) of the detected object was monitored. From the blob analysis, the centroid which contains the coordinates of the position of the object was taken. With the coordinates, the position of the object was estimated with respect to the relative frame. For a non-moving object, by analysing the area of the blob, a warning signal can be generated.

The difference in the area of two successive object blobs increase when the object was getting closer [6]. The variation of the blob area with time was fitted with a polynomial. By using the rate of change of the area, a warning signal was triggered.

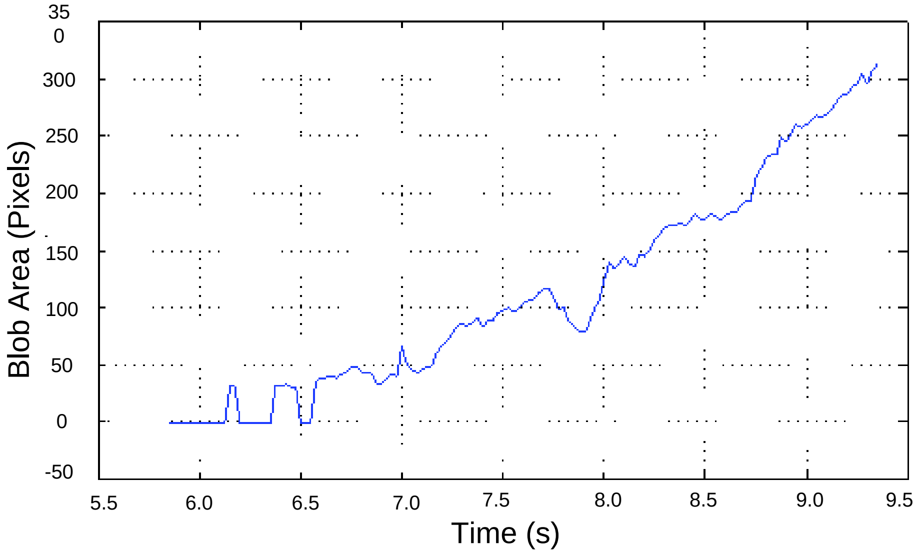


Figure 4: Increasing blob area with time for a non-moving object which may cause a collision.

3.2 Moving Pedestrian Detection

As discussed in the non-moving object detection, there are two cases to consider. The pedestrian may safely cross the road or the pedestrian may not be able to cross the road safely which cause a collision (see Figures 5 and 6). As in the non-moving object, the original image was processed and the pedestrian who was crossing the road was detected. In this case there were further improvements.

- Instead of using speed, the velocity vector was used.
- In order to get an estimate of the change in optical flow, the velocity vector was visually studied.
- Since the pedestrian was moving along the *x*-axis, only the real part of the velocity vector was used.

Figure 5: Two safe scenarios for pedestrian crossing the road; a distant pedestrian and a near pedestrian.

Figure 6: Change in horizontal and vertical optical flow values of a pedestrian moving from right to left; a distant pedestrian and a near pedestrian.

As shown in Figure 6, the optical flow along the *y*-direction is not changing by large amounts. But in the *x*-direction there is a considerable change. When the pedestrian is moving from right to left, the optical flow values are increased negatively while the pedestrian is moving from left to right, the optical flow values are increased positively. Therefore, in order to detect the pedestrian the above criterion can be used.

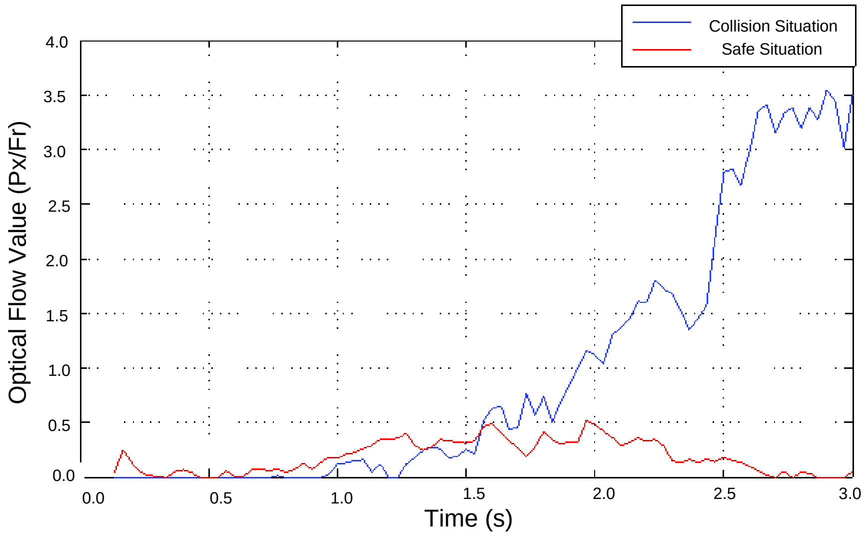


Figure 7: The variation in the optical flow values for collision situation and safe situation when the pedestrian is moving across the road.

As shown in the Figure 7, variation in optical flow values are different for the two cases (distant and near) considered. By using this criterion the system can detect whether the pedestrian is going to collide or not and generate a warning signal.

4. CONCLUSIONS

Optical flow method make it easy to detect the motion of objects using video input. The combination of optical flow with the colour segmentation makes the results more accurate when there are several complex motions. Motion detection based on optical flow can be used in many real world applications such as traffic control, vehicle warning systems without using complex electronic devices and sensors. This work shows that it is possible to detect and predict the collision situation for moving and non-moving objects successfully using optical flow methods.

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