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Car speed estimation based on cross-ratio using video data of car-mounted camera (black box)

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ABSTRACT

This paper proposes several methods for using footages of car-mounted camera (car black box) to estimate the speed of the car with the camera, or the speed of other cars. This enables estimating car velocities directly from recorded footages without the need of specific physical locations of cars shown in the recorded material. To achieve this, this study collected 96 cases of black box footages and classified them for analysis based on various factors such as travel circumstances and directions. With these data, several case studies relating to speed estimation of camera-mounted car and other cars in recorded footage while the camera-mounted car is stationary, or moving, have been conducted. Additionally, a rough method for estimating the speed of other cars moving through a curvilinear path and its analysis results are described, for practical uses. Speed estimations made using cross-ratio were compared with the results of the traditional footage-analysis method and GPS calculation results for camera-mounted cars, proving its applicability.

1. Introduction

In traffic accident reconstructions, using car black box footages to approximate the speed of cars involved is an important process which is commonly conducted. Traditional method in this process involves recognizing the distance that is clearly visible in the recorded footage, then measuring the time the car of interest passes through that distance to estimate its speed. However, when there are no clear lane markings or landmarks that can specify the location of the car, speed estimation is either impossible or lacks accuracy. To compensate this, images from the black box footage and pictures taken at the site of the accident are compared to deduce the travel distance, then the travel time is used to calculate the car speed [1]. Edelman and Bijhold [2] presented a method for reconstruction of car movements based on the surroundings. There are also reports that claim the change in size of license plates of cars visible in the footage can be used as a reference in accident analysis [3].

For a more accurate speed estimation, alternative methods [4–7] using information other than recorded footage such as acceleration values are suggested, but they require additional equipment such as sensors, so they cannot be a general solution.

Recently, Wong [8] suggested using cross-ratio to estimate the straight traveling speed of cars recorded by a static surveillance camera. This enables estimating car speed from recorded images without specifying the exact location of the car on the road. However, Wong suggested only possibilities on its actual application on car black boxes, and there are limited cases of usage of static surveillance cameras. In this study, using cross ratio, 96 black box footages were collected and various case studies were done on estimation of other cars' speed when the recording car is standing still, and also on estimation of the recording car and other cars' speed while the recording car is moving. Additionally, rough method and analysis result of estimating other curve-traveling cars' speed are included in this study for a more practical application.

2. Footage data (video events) from car mounted camera or black box

In this study, data were collected through a website called Black Box Club [9]. The screen configuration is different between black box manufacturers, resulting in different output information, and footage resolution, Field of View (FOV), and functions differ a lot depending on the black box model. In case of a 4-channel black box, all four points of view – front, back, left, right – can be recorded, minimizing blind spots. It can record in 1080p or 720p, and the range of FOV is 70–170°. It uses 3-axis acceleration sensor to detect

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Table 1
Classification of accident related video footages.

Traveling situation	Number	Camera	Objective
A: Rectilinear other-travel	15	Stationary	Other-travel speed
B: Curvilinear other-travel	12	Stationary	Other-travel speed
C: Rectilinear ego-travel	13	Moving	Ego-travel speed
D: Curvilinear ego-travel	22	Moving	Ego-travel speed
E: Mixed	34	Moving	Other-travel speed

accidents, and separately stores immediate before and after-accident recordings. Many black box models support Global Positioning System (GPS) function, and possible output info includes time and speed, but since the speed info can act as a disadvantage for the driver in case of an accident, it is not included in the output info by default. Several black box models support On-Board Diagnostics (OBD) functions, enabling output of various information regarding the car including brakes and acceleration [10].

Footage data collected through Black Box Club were organized based on traveling situation, then analyzable clips were selected. Traveling situations include daytime and nighttime, and various weathers such as rain, snow, or fog. Traveling situations affect the car and its environment, and may add difficulty in speed analysis.

Analyzable black box footages were organized as shown in Table 1 based on environments of speed estimations based on cross ratio. There were 15 footages for analyzing straight traveling (A) cars' speed from black box of a still car, and 12 footages for analyzing curve-traveling (B) cars. Another group is for analyzing the speed of the car with the camera, mostly related to accidents caused by inattention, of which 13 cases are straight travel (C) and 22 cases are curve travel (D). The remaining 34 cases (E) are when estimating the speed of a moving car from the perspective of a moving camera mounted car. Depending on the group, the cross ratio application method differs, or impossible to apply the cross ratio method.

Using footage from right before the initial impact of the accident has several issues. First, when only the rear-end of the co-impact car before the collision is visible, the cross-ratio suggested in this study cannot be applied to properly estimate the car speed. Second, when the change in speed is extreme, using cross-ratio to calculate the average speed can result in a large error. Also, cross-ratio method cannot be applied when the change in traveling direction is extreme. To resolve these issues, footages from before the driver reacts to the accident by changing the direction and speed, or those from when the directional change is not too great were used.

3. Speed estimation methods

Unlike traditional speed estimation methods, this study used projective transformation and cross-ratio, utilizing the size relationship between projections and actual objects to calculate the travel distance and speed of the car.

3.1. Projective transformation and cross-ratio

With projection transformation, it is assumed that when lines starting from the same point move infinitely away from the point, the lines are parallel to each other. When parallel lines and 2 planes meet vertically, objects on each plane have preserved angle and length, and this is called Euclidean transformation. When the parallel lines and the planes do not meet vertically, the objects on the planes do not have preserved length but the angles are preserved, and this is called affine transformation. When the point from which the lines started is within a finite distance, both the length and angle of the objects are not preserved, but the cross ratio is preserved, and this is termed projection transformation [11].

In projective transformation as shown in Fig. 1, the cross-ratio value is conserved, where its value is determined by the distance ratio between four points on a single line on each surface, and can be expressed as Eq. (1) [12].

$$\{AB, CD\} = (AC)(BD)/(AD)(BC) \tag{1a}$$

$$\{A'B', C'D'\} = (A'C')(B'D')/(A'D')(B'C') \tag{1b}$$

A line $\{A'B', C'D'\}$ in a 2-dimensional image recorded by a black box and a line $\{AB, CD\}$ in the real space can be considered using projective transformation as shown in Fig. 1, and the cross-ratio value calculated by Eqs. (1a) and (1b) should be identical.

When the image of the moment of speed estimation and the image after the car has traveled a distance of $d = (BD) = (AC)$ during time Δt are overlapped, it can be shown as Fig. 2. When assuming the travel pathway of the car as straight, cross ratio of the four points (A, B, C, D) in Fig. 2 can be deduced. Along with the cross ratio value calculated from these images, when the wheelbase length $l = (AB) = (CD)$ is applied, the travel distance d during the time Δt can be deduced to estimate the car speed. From Eqs. (2) and (3), actual travel distance d of the car can be calculated with Eq. (4).

$$\{AB, CD\} = \{A'B', C'D'\} \tag{2}$$

$$\{AB, CD\} = \frac{d^2}{(d+l)(d-l)} = \frac{d^2}{d^2 - l^2} \tag{3}$$

$$d = \sqrt{\frac{\{A'B', C'D'\}}{\{A'B', C'D'\} - 1}} \cdot l \tag{4}$$

Footage time selection should be made when $d > l$, after Δt, and in this case, the cross ratio value is always bigger than 1.

3.2. Traditional method

Usually when estimating car speed from black box footages, visible landmarks or distance between objects are used to calculate the travel time.

The marked location shown in Fig. 3, when using a search portal map (http://map.naver.com), it can be observed that the two sections are both approximately 40 m long. The car speed can be then determined by calculating the time the car took to travel that section. To measure the travel distance, usually lane markings or

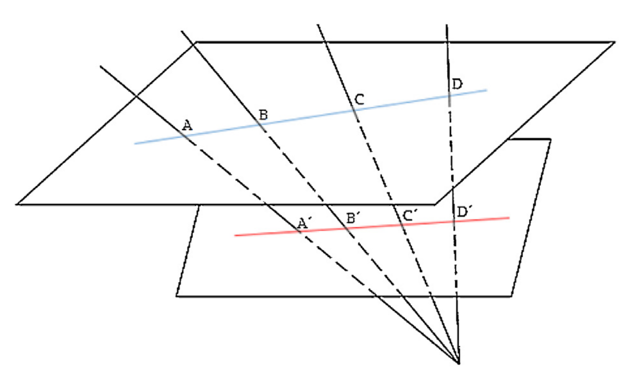

Fig. 1. Projective transformation and cross-ratio.