

Parallax Error in Video-Image Systems

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Abstract: Parallax error is a distance-related measurement error when the measurement has to rely on field of view, such as video-image systems. This paper provides a detailed investigation of the geometric elements associated with parallax error in video-image systems. A field-of-view calibration model is presented based on a study of various geometric elements, including camera height, camera location, view of image, and vehicle dimension. The study found that parallax error ranges between 10 and 50% based on normal camera setup. The model presented provides a better understanding of the parallax error; thus the accuracy of distance-related measurements could be improved when video-image systems are deployed. The proposed model has special application values at signalized intersections where video-image systems are deployed. One of the applications is to identify the range of possible blockage by a leading vehicle, which is one of the major causes of missed detections. Another application is to identify the conditions that result in vehicle occlusion, which is a source of false detections.

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Introduction

In recent years, video-image systems have gained popularity in the field of transportation engineering. Speed measurement at transportation facilities is one of the major applications of video-image systems. One aspect of video-image systems is that the measurement relies on field of view, which is a major source of *parallax error* (McShane and Roess 1990). Parallax error represents distance-related measurement error such as speed and headway. All the video-image systems require calibration of field of view based on field measurements of certain geometric elements before the data collection process can be initiated (Econolite 1994; PEEK 1995). Although most video-image systems provide internal algorithms for such a calibration, the algorithms are usually not well documented and are not revealed to the users. To the best of our knowledge, none of the current video-image systems have an algorithm to automatically correct parallax error based on field of view. The purpose of this paper is to provide the results of an investigation of the geometric elements associated with parallax error in video-image systems, so that a better understanding of parallax error can be achieved and the quality of data collection can be improved.

Similar to other measurement tools, speed measurement in video-image systems is obtained knowing the distance and the travel time between two roadway reference locations. The time

that a vehicle passes a reference location is automatically recorded using the embedded tools within the video-image system, such as detectors, speed traps, and speed zones (PEEK 1995; Econolite 1994). However, the distance in the field between the reference locations may not be the same as the distance perceived on the video image; that is, a detector in the video image can be activated even if a vehicle has not yet reached the detector location in the field. The distance used for speed calculation must be properly adjusted. Otherwise, the result would involve parallax error.

Parallax error can be minimized or corrected if the distance measured in the field is appropriately adjusted. The adjusted distance is referred to as *video-image distance* in the following discussions. The video-image distance between two detectors or reference locations in a video-image system is equivalent to the actual distance a vehicle travels in the field when the detectors in a video-image system are activated. For example, the distance between two reference locations is measured as D m in the field. When two detectors are placed in a video-image system at the two corresponding reference locations, and when the two detectors are activated, a vehicle actually travels D' m in the field; D' is referred to as the video-image distance of D , where D' is always less than or equal to D . While D can be measured directly in the field, D' has to be obtained through calibration and used for speed calculation.

Video-image distance is closely related to the field of view. Bonneson and Fitts (1995) defined three types of camera views: an approaching view, a departing view, and an overhead view (Fig. 1). An approaching view is obtained when the vehicles travel toward the camera location; a departing view is obtained when the vehicles travel away from the camera location; and an overhead view consists of both an approaching view and a departing view.

Potential applications of video-image distance calibration can be viewed in the following cases. Under a departing view, the video-image distance should be used for speed calculation to avoid parallax errors. While an approaching view is always desired for speed measurement to avoid parallax errors, it may not always be obtainable. Cases where an approaching view cannot

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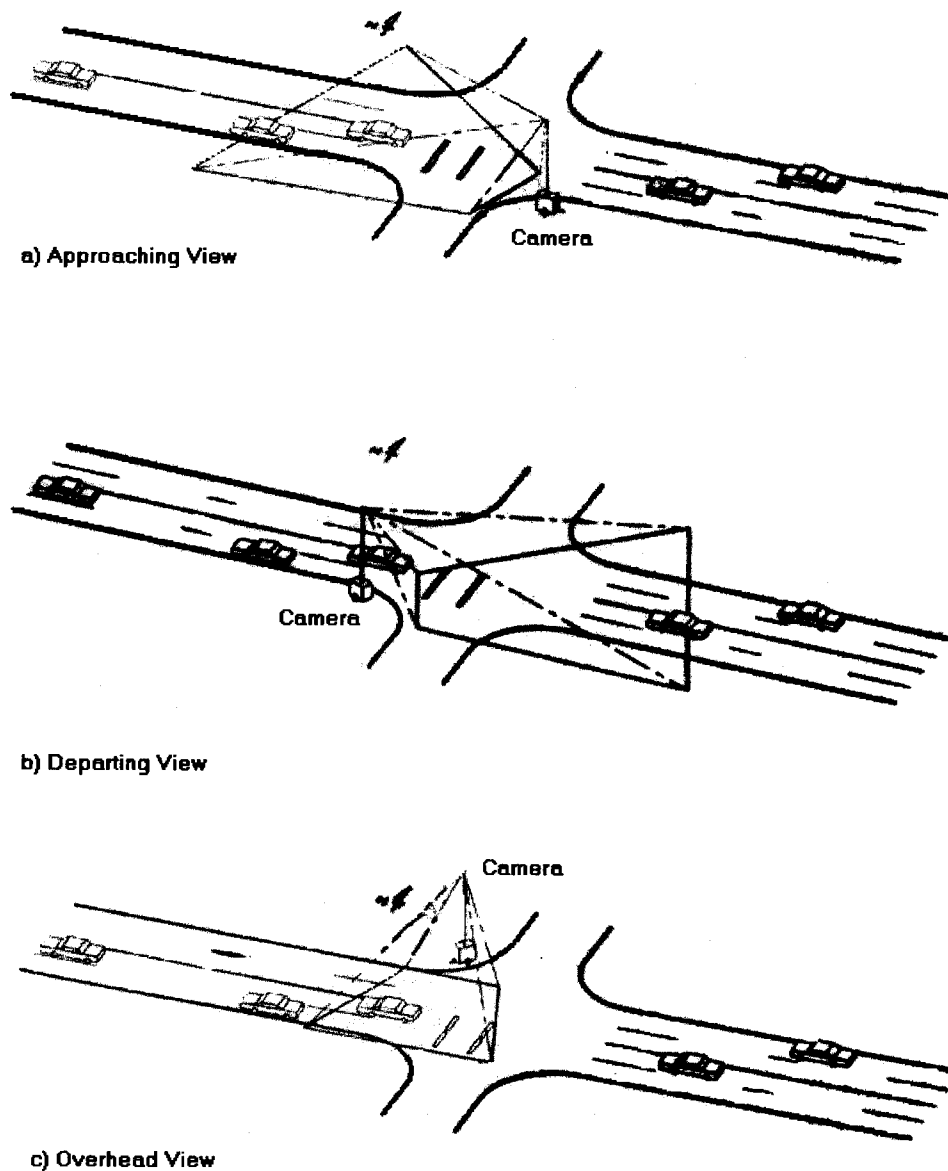


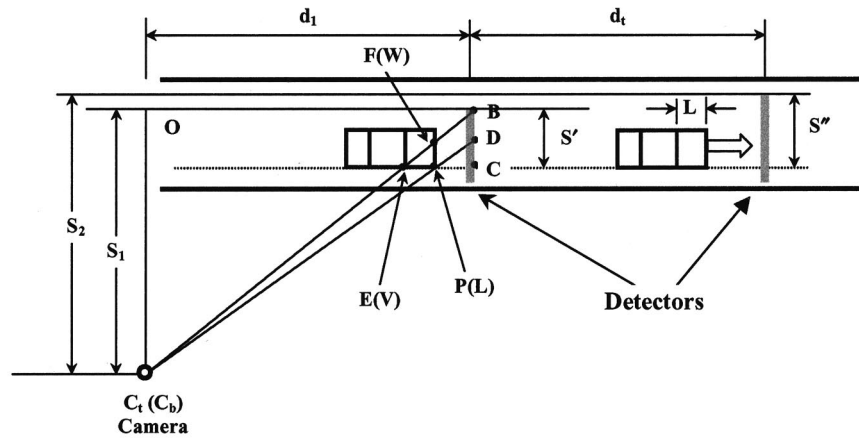
Fig. 1. Types of field of view (Bonneson and Fitts 1995)

be obtained include physical constraints such as the camera location and obstructions by physical objects, or a limitation on available resources such as recording speeds at a two-lane highway for both directions using a single camera. Another application for video-image distance calibration is at signalized intersections where video-image systems are deployed for vehicle detection and traffic monitoring. The conditions of blockage by a leading vehicle and occlusion of adjacent lanes can be identified, which are major sources of missed detections and false detections.

Video Image Distance

This section of the paper presents the details of a model for video-image distance calibration. Figs. 2–4 illustrate the various geometric elements for calibration of video-image distance; Fig. 2 is an aerial view of the geometric layout; Fig. 3 is a view from the roadside; and Fig. 4 is a view from the front. In addition to the descriptions included in Figs. 2 and 3, the following definitions are provided and used in the video-image distance model:

- S_1 = perpendicular distance from camera to outer edge of first detector;
- d_1 = distance from first detector to original point (O), the roadway location perpendicular to camera location;
- d_t = actual distance in field between the two detectors;
- S' = distance from first detector's outer edge to inner edge of vehicle;
- S_2 = perpendicular distance from camera to outer edge of second detector;
- S'' = distance from second detector's outer edge to inner edge of vehicle;
- h_c = camera height;
- L = length of vehicle hood;
- h_{v1} = front height of vehicle;
- h_{v2} = height of vehicle cab;
- h', h'' = critical heights for first and second detectors, respectively. Critical height is minimum vehicle height that would trigger detector activation when view between camera and outer edge of detector is blocked. For example, first detector



Note: S_1, S_2 – perpendicular distances from the camera to the outer edge of the detectors
 d_1 – distance from the first detector to the original point (O), perpendicular camera location
 d_2 – distance between two detectors
 S', S'' – distance from detector's outer edge to inner side of the vehicle
 L – length of the vehicle hood
 C_t, C_b – top and bottom of the camera
 $F(W), E(V), P(L)$ – top and bottom points of the vehicle when a detector might be activated
 B, C, D – location points along a detector when a detector might be activated

Fig. 2. Aerial view of geometric elements

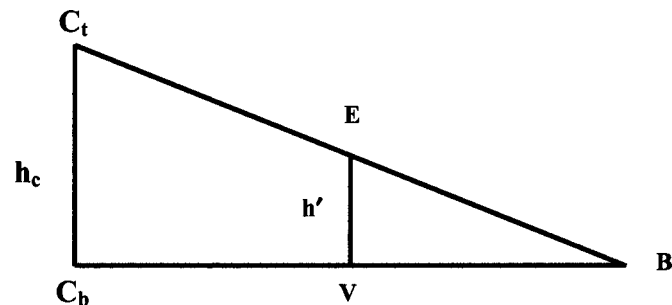
will be activated if a vehicle is higher than h' when entering view between camera and point B (detector's outer edge);

- d', d'' = video-image distances for first detector and second detector, respectively;
- d_1', d_1'' = video-image distances for first detector and second detector, respectively, if front edge of vehicle activates detector;
- d_2', d_2'' = video-image distances for first detector and second detector, respectively, if vehicle cab activates detector; and
- D_v = video-image distance between two detectors.

Derivation of Video-Image Distance Model

Step 1: Critical Height (h', h'')

Fig. 3 is a roadside view of the geometric elements. The view between the camera and the detector's outer edge (B) is represented by the straight line $C_t B$. The location of E(V) is the first point a vehicle enters the view line $C_t B$, where V is the perpendicular point of E on the ground level. A vehicle must be higher



Note: h_c – height of camera; h' – critical height

Fig. 3. Roadside view of geometric elements

than the critical height h' in order to activate the detector at this location. The distance between the camera and point B can be calculated by

$$S_3 = BC_b = \sqrt{S_1^2 + d_1^2} \tag{1}$$

As similar triangles of $C_b O B$ and BCV , we have

$$\frac{S'}{S_1} = \frac{BV}{S_3} \tag{2}$$

$$BV = \frac{S'}{S_1} S_3 \tag{3}$$

Since $C_b B C_t$ and VBE are similar triangles, thus

$$\frac{h'}{h_c} = \frac{BV}{S_3} = \frac{S'}{S_1} \tag{4}$$

$$h' = \frac{S'}{S_1} h_c \tag{5}$$

Note that h' is not related to d_1 .

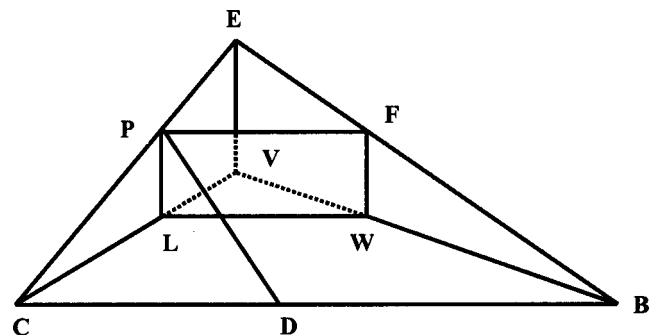


Fig. 4. Front view of geometric elements

Step 2: Video-Distance when Front of Vehicle (h_{v1}) is Higher than Critical Height (h')

In this case, point $E(V)$ is where the detector is activated, and the video-image distance of d_1 is calculated by

$$d' = d_1 - CV = d_1 \left(1 - \frac{h'}{h_c} \right) \quad (6)$$

where

$$CV = \sqrt{BV^2 - S'^2} = \sqrt{\frac{S'^2}{S_1^2} S_3^2 - S'^2} = \frac{S'}{S_1} d_1 = \frac{h'}{h_c} d_1 \quad (7)$$

Step 3: Video-Distance when Front of Vehicle (h_{v1}) is Lower than Critical Height (h')

When a vehicle's height is less than the critical height at point $E(V)$, the vehicle has to move up further before the detector can be activated. In this case, point B is no longer to be blocked first, but rather a portion of the detector (from point D to point B) is to be blocked simultaneously by a front portion of the vehicle (from point P to point F). Again, points W and L are the perpendicular points at the ground level of points F and P , respectively. The length of CL is the distance from the detector to the activation point and can be calculated by letting PL or FW equal to the vehicle height h_{v1} .

$$\frac{CL}{CV} = \frac{h_{v1}}{h'} \quad (8)$$

$$CL = \frac{h_{v1}}{h'} CV = \frac{h_{v1}}{h'} \frac{S'}{S_1} d_1 \quad (9)$$

From Eqs. (5) and (9) we obtain

$$CL = \frac{h_{v1}}{h_c} d_1 \quad (10)$$

Thus, the video-image distance of d_1 is given by

$$d' = d_1 - CL = d_1 \left(1 - \frac{h_{v1}}{h_c} \right) \quad (11)$$

Step 4: Generalized Equation of Video-Image Distance of d_1

A generalized equation of the video-image distance of d_1 can be calculated by

$$d_1' = d_1 \left[1 - \frac{\min(h_{v1}, h')}{h_c} \right] \quad (12)$$

Step 5: Effect of Vehicle Cab

In the case in which the front height of a vehicle is less than the critical height, there is a possibility that the vehicle cab would activate the detector before the front part of a vehicle activates the detector. Using a similar approach, the video distance of d_1 when the vehicle cap activates the detector can be calculated by

$$d_2' = d_1 \left[1 - \frac{\min(h_{v2}, h')}{h_c} \right] + L \quad (13)$$

where L is the length of the vehicle hood.

The final video distance that will be used for speed calculation should be the smaller of d_1' and d_2' and can be expressed as

$$d' = \min(d_1', d_2') \quad (14)$$

Step 6: Video-Distance Calculation for Second Detector

Similarly, the video distance for the second detector can be calculated using the following equations:

$$d'' = \min(d_1'', d_2'') \quad (15)$$

where

$$d_1'' = (d_1 + d_t) \left[1 - \frac{\min(h_{v1}, h'')}{h_c} \right] \quad (16)$$

$$d_2'' = (d_1 + d_t) \left[1 - \frac{\min(h_{v2}, h'')}{h_c} \right] + L \quad (17)$$

$$h'' = \frac{h_c \cdot S''}{S_2} \quad (18)$$

The video-image distance of d_t can then be obtained from Eq. (19):

$$D_v = d'' - d' \quad (19)$$

where d'' and d' can be obtained from Eqs. (14) and (15), respectively.

A simplified equation can be developed based on the following assumptions:

1. The detectors are always activated by the front of a vehicle (equivalent to having a uniform shape and height); and
2. The two detectors have similar settings, such as detector length and the position relative to the roadway and the camera.

Thus we have $h_{v1} = h_{v2} = h_v$; $S_1 = S_2 = S$, $h' = h''$; and $S' = S''$.

Eq. (19) can be simplified to the following:

$$D_v = (d_1 + d_1) \left[1 - \frac{\min(h_v, h')}{h_c} \right] - d_t \left[1 - \frac{\min(h_v, h')}{h_c} \right] = \alpha d_1 \quad (20)$$

where α can be defined as the adjustment factor and can be derived based on Eqs. (4) and (20):

$$\alpha = 1 - \frac{\min(h_v, h')}{h_c} = 1 - \min\left(\frac{h_v}{h_c}, \frac{S'}{S}\right) \quad (21)$$

Parallax error can be defined by β :

$$\beta = 1 - \alpha = \min\left(\frac{h_v}{h_c}, \frac{S'}{S}\right) \quad (22)$$

Under normal conditions, it is usually the first term (h_v/h_c) that determines the value of β . As can be seen from Eq. (22), parallax error increases as vehicle height increases, but decreases as camera height increases. Fig. 5 illustrates the range of β with various vehicle heights and camera heights. Both camera height and vehicle height can significantly impact parallax error. For typical applications where camera height ranges between 6 and 10 m and vehicle height ranges between 1 and 3 m, the parallax error ranges between 10 and 50%.

Potential Applications

Speed Measurements

The measurement on vehicle's speed using video-image systems is based on the travel time and distance between two detection locations. A video-image system automatically records the time that a vehicle passes a detection location. The field of view needs to be calibrated in the video-image system based on measure-

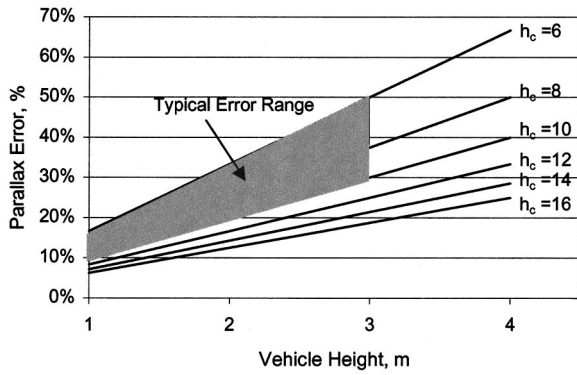


Fig. 5. Parallax errors with respect to vehicle height and camera height

ments of field-referencing locations. The distance between the two detection locations is recognized by the video-image system based on the field-of-view calibration. Most video-image systems do not account for the parallax errors involved with a departing view. The following example illustrates the amount of errors that might be involved in speed measurement.

Example 1: Speed Measurement

Suppose that $S_1 = S_2 = S = 15$ m; $S' = S'' = 3.6$ m; $h_{v1} = h_{v2} = h_v = 1.2$ m; $h_c = 9$ m; $d_t = 15$ m; and t (recorded travel time between the two detectors) = 1.2 s; then $d' = d'_1$; $d'' = d''_1$; and D_v can be calculated by

$$D_v = d'' - d' = d_t \left[1 - \frac{\min(h_v, h')}{h_c} \right] \quad (23)$$

where

$$h' = \frac{h_c S'}{S} = \frac{9 \times 3.6}{15} = 2.16 \text{ (m)} \quad (24)$$

Thus,

$$D_v = 15 \left[1 - \frac{\min(1.2, 2.16)}{9} \right] = 13.0 \text{ (m)} \quad (25)$$

The accurate speed should be $13.0/1.5 = 8.7$ m/s (or 31.3 k/h). The speed directly reported from video-image systems would be $15.0/1.5 = 10.0$ m/s (or 36.0 k/h).

As pointed out earlier, an approaching view is always desired for speed measurement; however, it may not always be obtainable due to physical constraints or limitation on camera resources. Parallax errors must be corrected to achieve accurate speed measurements under a departing view.

Vehicle Detection at Signalized Intersections

When video-image systems are used at signalized intersections to monitor traffic flow and vehicle detections, the cameras are typically placed on each approach with an approaching view. One common occurrence is that a leading vehicle blocks the view of the following vehicle, resulting in missed detections. Another situation involves vehicle occlusion of adjacent lanes, which would result in false detections. The proposed video-image distance model in this paper could help to better understand such problems.

Example 2: Missed Detections

Let's assume a detector is located $d_t = 25$ m from the camera, which is placed directly above the travel lane at a height of h_c

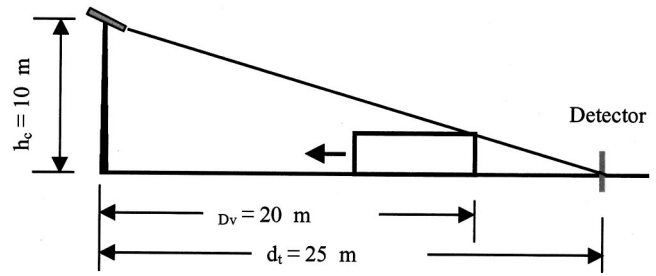


Fig. 6. Range of blockage under approaching view

= 10 m (Fig. 6). An approaching vehicle has a height of $h_v = 2.5$ m. From Eq. (20), the video-image distance of d_t can be obtained as $D_v = 20$ m. This implies that while the tail of a leading vehicle is at 20 m from the camera, the detector at 25 m from the camera is still blocked by the vehicle. It also indicates that any vehicles following closer than 5 m will be viewed by the video-image system as one vehicle, resulting in missed detections.

Example 3: Vehicle Occlusion

Vehicle occlusion refers to the case in which a vehicle on a certain travel lane occludes or gets in the view of the adjacent lanes, resulting in false detections. Vehicle occlusion is common at signalized intersections where the camera is mounted on either an elongated signal pole or a separate luminaire pole, typically located on the far right-hand corner of the intersection. Such a camera mounting is to achieve the required camera height for proper detection purposes.

Fig. 7 illustrates a situation where vehicle occlusions may occur of the left turn lane. In this figure, the camera is located on the far right-hand corner of the vehicle's traveling direction. A stop-line detector is assumed for the left-turn lane. The condition in which vehicle occlusion occurs is when the vehicle's height is equal to or greater than the critical heights at either point E or point P. Using similar approach as the video-image distance calibration, the critical height at point E can be obtained by

$$h' = \frac{h_c S'}{S_1} \quad (26)$$

The critical height at point P can be obtained by

$$h'' = \frac{h_c (S' + d_w)}{S} \quad (27)$$

where

d_w = width of stop-line detector

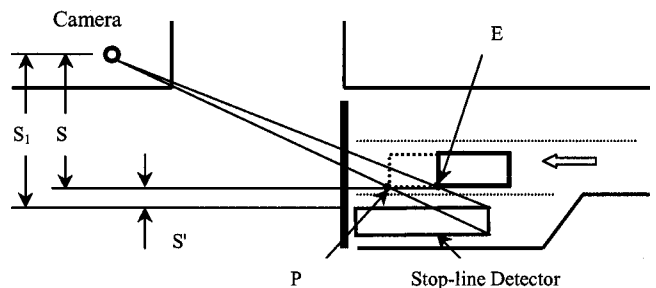


Fig. 7. Vehicle occlusion conditions

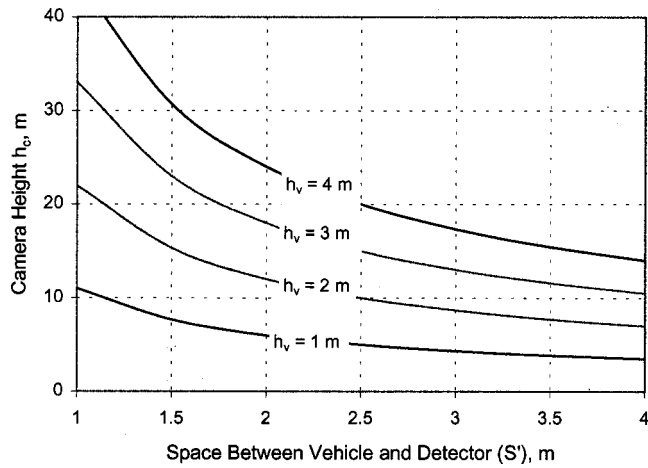


Fig. 8. Vehicle occlusion conditions

As can be seen, h'' is greater than h' ; that is, the occlusion would always occur at point E . Therefore, the critical height at point E can be used to derive the conditions of vehicle occlusion. Substitute the critical height h' with the vehicle height h_v , the following equation can be obtained:

$$h_c = \frac{h_v S_1}{S'} = \frac{h_v (S' + S)}{S'} = h_v \left(1 + \frac{S}{S'} \right) \quad (28)$$

Eq. (28) can be used to calculate the required camera height h_c or the spacing S' to avoid occlusion occurrence based on given geometry and vehicle height information. Fig. 8 illustrates the case for a typical two-lane approach with an exclusive left-turn lane. The camera location S is assumed to be 10 m from the inner edge of the vehicle. As an example, when the spacing between the

detector and the vehicle S' is 2.0 m, the required camera height needs to be at least 12.0 m if the vehicle is 2.0 m high. If the vehicle is 4.0 m high, the required camera height is then at least 24.0 m to avoid occlusion of false detection on the left-turn phase.

Summary and Conclusions

Video-image systems rely on field of view for data collection and traffic surveillance. Speed or other distance-related measurements using video-image systems would involve parallax errors when the camera involves a departing view. Blockage and occlusion may occur at signalized intersections when video-image systems are used for vehicle detection with an approaching view. A video-image distance calibration model is presented and can be used to correct the parallax errors and to identify the conditions of blockage and occlusion. For speed measurements, major elements related to parallax errors include vehicle height, camera height, and camera location. It was found that with normal camera height and vehicle dimension, parallax error ranges between 10 and 50%. Examples are given to illustrate the potential applications of the proposed model in general traffic engineering practices.

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