Video-Based Analysis of Driving Safety of Electric Bicycles at Traffic Intersections

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Abstract. This study presents a method for safety analysis to investigate the safety of electric bicycles at traffic intersections. Based on the development platform Visual Studio 2013, this proposed method uses the image processing functions from OpenCV library to track and detect the moving vehicles in videos of traffic intersections. Meanwhile, this paper puts forward a sieving algorithm based on the area factor to distinguish and recognize electric bicycles at traffic intersections. The traffic data of electric bicycles, such as speed and distance, can be obtained by processing video data. The distribution of electric bicycle’s arrival speed and the rate of traffic interactions between electric bicycles and other vehicles are proposed to measure the severity of the intersections.

1. Introduction

Compared with walking, electric bicycles are more strength-saving and faster. And in contrast to motor vehicles, electric bicycles are emissions-free, less congested and low-cost for their electric-driven systems. Therefore, electric bicycles are gradually accepted by people as a way of travel in urban cities for their fast, clean and low-cost characteristics, and increasingly become the most popular transportation for short-distance travel. In 2015, Electric bicycles, including help-move-vehicle, accounted for 20.2% of all the transportations in Shanghai, and this ratio increased by 3.9% compared with that in 2009 [1].

However, electric bicycles add congestion, security issues, pollution and other issues at the traffic intersections for their rapid development in China. In 2015, non-motor vehicles traffic accidents occurred 15437 times in China, 14068 times of which have connections to electric bicycles, accounting for up to 91% [2]. Accordingly, aiming to analyze the safety riding of electric bicycles at the traffic intersection, we need to effectively track and detect the electric bicycle, and then extract relevant track data and analyze them.

Previous studies have investigated the safety effects of electric bicycles with manual observation of recorded videos since automatic detection and tracking of electric bicycles is a complicated problem at intersections. For instance, Christopher R. Cherry studied the basic data gained by manual investigation of electric bicycles in China, and analyzed the electric bicycles’ driving mobility, accessibility and safety [3]. These characteristics are used to estimate the comparative impacts on the environment brought by electric bikes [4]. Although manual observation can be carried out in a seemingly simpler way, it is time consuming and largely related to investigators’ subjective initiative, which leads to less accurate of the estimated tracking data.

Nowadays, video-based detection and tracking methods have great potential to identify interactions giving rise to collisions. Paul St-Aubin et al. extracted the time to collision as the surrogate safety measure from the video processing software to study the effectiveness of the ban of lane change in
Montreal, a Canadian city[5]. Sohail Zangenehpour et al analyzed the safety of signal intersection based on video detection technology[6]. However, most objects involving in the video detection studies mentioned above are motor vehicles. Automatic detection of electric bicycles at intersections is stills confronted with many problems for their variables and instability.

In this paper, we take electric bicycles at intersections as the research objects, detect and distinguish them with a sieving algorithm according to the area factor. Further efforts are made to calculate the tracking data of the electric bicycles and analyze the riding safety of the electric bicycles at the traffic intersection.

2. Detecting and tracking the electric bicycle at the intersection

2.1. Detection of moving objects
Moving target detection is to check the changes of blobs in videos, and then segment the moving blobs from the picture of each frame. In general, the tracking, counting and motion analysis of objects are carried out after extracting motion blobs from each frame. Therefore, it’s essential to detect and segment the moving objects.

This paper chooses the background segmentation method to segment different parts in each frame as foreground and background. Firstly, the background image $f(x, y)$ of the video is modeled by using the Gaussian Mixture Background Modeling method[7]. The comparison between the original picture and the background picture is shown in Figure 1.

Secondly, subtracting background model from the original picture of each video frame, the foreground moving object $A(x_1, y_1)$ can be extracted. The calculation formula for the foreground object function is:

$$A(x_1, y_1) = f(x_1, y_1) - f(x, y)$$

Finally, using the filtering function in OpenCV library, Gaussian filtering method is carried out on the extracted foreground object to remove the shadow regions of moving blobs, and to obtain clear foreground pictures. The comparison of the picture before and after de-noising is shown in Figure 2.

2.2. Modeling the parameters of the electric bicycle
Statistical method is used to model the parameters of the electric bicycle, and analyze the parameters of the electric bicycle blobs in the videos to determine the threshold of electric bicycle areas. The proposed steps are as follows:

First, presupposing the size of the foreground object blobs is taken to remove the oversized or undersized blobs and to count and number the mass.

Second, we calculate and output the area of motion blobs, the length and width of the bounding rectangle of the blobs of electric bicycles in 1000 frames. According to the distribution of these data, we regard the parameter range when distribution probability reaches 80% as the threshold parameters of the electric bicycle. The statistical results are shown in Table 1.

Finally, according to the parameter values obtained in the above steps, the pixels range of area parameter of the electric bicycle selected from the video as an example is [230, 2000] pixels, the width is [20, 80] pixels, and the length is [20, 80] pixels. This parameter is used to screen the foreground moving object in the video. When the area parameter of the moving object blobs satisfies the threshold range, the length and width of the bounding rectangle will be used to further study the blob. When the length and width corresponded with the threshold range of electric bicycles, it is confirmed to an electric bike. Figure 3 is the detecting picture after screening.

2.3. Tracking the electric bicycle object
Tracking the objects of electric bicycles is to compare the blob information of electric bicycles in different frame, and to find the same moving blob. The main steps are as follows:

First, calculate the centroid coordinates and the distance between the centroid pixel of the electric bicycle blob in pictures of the two successional. The mass centroid is as follow:
\[ m_{pq} = \sum_{x=1}^{n} \sum_{y=1}^{n} x^p y^q f(x, y) \]  
\[ x_c = \frac{m_{10}}{m_{00}} \]  
\[ y_c = \frac{m_{01}}{m_{00}} \]  
(2)

Where \( m_{pq} \) is the \( p + q \)th moment matrix, \((x_c, y_c)\) is the centroid of the picture, \( f(x, y) \) is the pixel function of the detected electric bike blobs.

The pixel distance between the two blobs centroid from two successive frames is as follow:
\[ d_{ij} = \sqrt{(x_{ci} - x_{cj})^2 + (y_{ci} - y_{cj})^2} \]  
(4)

Among which, \( d_{ij} \) is the operating range of the electric bicycle in the picture from the ith to the jth frame, \((x_{ci}, y_{ci})\) is the centroid coordinate of the electric bicycle in the ith frame picture, and \((x_{cj}, y_{cj})\) is the jth.

Second, the pixel distance of electric bicycles passed in a flash won’t exceed a extremely small value if the same electric bicycle detected in two successive frames. So the minimum frame difference is set to evaluate the time and the minimum pixel distance is set to evaluate distance. The same electric bicycle is conformed when meeting the frame difference conditions and distance conditions, then tracking the electric bicycle and mapping the trajectories. The cumulative trajectories are shown in Figure 4.

3. Safety analysis of electric bicycles

3.1. Traffic data calculation

The coordinates of the centroids of the electric bicycle blobs can be calculated from the video data. The distance between the two centroids is the pixel distance. The actual distance of the intersection is measured to standardize its corresponding pixel distance. The pixel coordinates are converted to the two-dimensional ground coordinates with the homogeneous coordinate transformation method [8]. The error analysis between the converted distance and the actual distance is shown in Table 2.

The actual riding distance of the same electric bicycle travelling in two adjacent frames can be obtained from the two-dimensional ground coordinates, the formula is as follow:
\[ d = \sqrt{(u_a - u_b)^2 + (v_a - v_b)^2} \]  
(5)

Among the formula, \((u_a, v_a)\) is the two-dimensional ground coordinates of the electric bicycle in the a\(^{th}\) frame, and \((u_b, v_b)\) is the two-dimensional ground coordinates of the electric bicycle in the b\(^{th}\) frame.

The reciprocal of the video frame rate is the interval time between two adjacent frames, and the average speed can be obtained when divide the actual movement distance of the electric bicycle in the two frames by the corresponding interval time. When the movement time tends to be extremely short, the average velocity of electric bicycles can be regarded as the instantaneous velocity. The formula to calculate instantaneous velocity is as follow:
\[ v_f = r \sqrt{(u_f - u_{f+1})^2 + (v_f - v_{f+1})^2} \]  
(6)

Where \( v_f \) is the instantaneous velocity in the f\(^{th}\) frame, \((u_f, v_f)\) is the two-dimensional ground coordinates of the electric bicycle in the f\(^{th}\) frame, and \((u_{f+1}, v_{f+1})\) is the two-dimensional ground coordinates of the electric bicycle in the (f +1)\(^{th}\) frame, \(r\) is the video frame rate.
Figure 1 Detection area of original image and background image

Figure 2 Foreground image contrast before and after noise reduction

Figure 3 Electric bicycles tracking result

Figure 4 Trajectories of electric bicycles
### Table 1 Statistical table of electric bicycle parameters

| Area    | Num. | Pro. | Width | Num. | Pro. | Height | Num. | Pro. |
|---------|------|------|-------|------|------|--------|------|------|
| <200    | 0    | 0    | <20   | 0    | 0    | <20    | 0    | 0    |
| 200-500 | 20   | 20%  | 20-40 | 38   | 38%  | 20-40  | 46   | 46%  |
| 500-1000| 24   | 24%  | 40-60 | 38   | 38%  | 40-60  | 30   | 30%  |
| 1000-1500| 30  | 30%  | 60-80 | 16   | 16%  | 60-80  | 18   | 19%  |
| 1500-2000| 14 | 14%  | 80-100| 12   | 12%  | 80-100 | 6    | 6%   |
| >2000   | 13   | 12%  | >100  | 0    | 0    | >100   | 0    | 0    |
| Total   | 100  | 100% | Total | 100  | 100% | Total  | 100  | 100% |

### Table 2 Conversion distance and actual distance analysis table

| Original coordinate | Conversed coordinate | Conversed distance(m) | Actual distance(m) | Error rate |
|---------------------|----------------------|-----------------------|--------------------|------------|
| 1 (445.9,347.3)     | (-0.284,0.32)        | 20.615                | 20                 | 3.1%       |
| 2 (1069,327.1)      | (20.33,0.513)        | 13.316                | 14                 | 4.2%       |
| 3 (838,8.297)       | (13.78,-10.86)       | 27.725                | 29                 | 4.3%       |
| 4 (1068,315.8)      | (21.31,0.122)        |                      |                    |            |
| 5 (832,4.7,162)     | (-14.32,-11.72)      |                      |                    |            |
| 6 (8.864,73.130)    | (13.39,-10.80)       |                      |                    |            |
| 7 (7.664,113.6)     | (-15.13,-8.4)        |                      |                    |            |
| 8 (431.3,355.1)     | (-0.802,0.571)       | 16.905                | 17                 | 0.6%       |

#### 3.2. Safe riding speed analysis

According to the calculation method discussed in the previous section, the instantaneous velocity of the electric bicycle in each frame can be calculated. The maximum velocity data of the electric bicycles is counted at the peak time, and divided into the following nine intervals: 0.5~1.5 m/s, 1.5~2.5 m/s, 2.5~3.5 m/s, 3.5~4.5 m/s, 4.5~5.5 m/s, 5.5~6.5 m/s, 6.5~7.5 m/s, 7.5~8.5 m/s and exceed 8.5 m/s.

When the speed of the electric bicycle exceeds the legally required maximum velocity (5.5 m/s) at intersections, the overall distribution and the distribution in the four overspeed interval of the electric bicycle is counted. In this way, the probability of the electric bicycle speeding at the road intersection can be calculated.

When electric bicycles drive in the limit speed over the entire process, their maximum velocity will be aggregated. The speed data are arrayed from small to large arrangement. The previous 15% and the posterior 15% of the extracted data are removed to avoid instability situations, and the remaining velocity parameter interval is chosen as the safe riding speed interval at the intersection.

#### 3.3. Traffic conflict judgment

In this paper, the time to collision (TTC) is chosen as a surrogate safety measure of traffic interactions of electric bicycles. TTC refers to the remaining time before the two vehicles collide, from every point in time t until any pair of two road users following their future predicted paths would collide[5]. Traffic interactions of electric bicycles occur in the following three ways at intersections: rear-end interaction, left-turn DC interaction and violation interaction. By definition, the collision time of these three traffic conflicts is calculated as follows:

When a rear-end interaction occurs between two electric bicycles at the intersection, TTC is calculated as follow:

$$TTC = \frac{\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}}{v_2-v_1}$$

(7)

Where \((x_1, y_1)\) is the two-dimensional ground coordinate of the anterior electric bicycle, \((x_2, y_2)\) is the two-dimensional ground coordinate of the posterior one, and \((v_2 - v_1)\) is the speed difference of the two electric vehicles.
When the left-turn DC interaction occurs, TTC is calculated as follow:
\[
TTC = \sqrt{(x_3-x)^2 + (y_3-y)^2} / v_3
\]  
(8)

Where \((x_3, y_3)\) is the two-dimensional ground coordinate of the straight riding electric bicycle, \((x, y)\) is the two-dimensional ground coordinate of the projection overlap point, and \(v_3\) is the speed of the straight riding electric bicycle.

When a violation interaction occurs, the formula of TTC is as follow:
\[
TTC = \min\left(\sqrt{(x_4-x)^2 + (y_4-y)^2}, \sqrt{(x_5-x)^2 + (y_5-y)^2}\right) / v
\]  
(9)

Where \((x_4, y_4)\) and \((x_5, y_5)\) are the two-dimensional ground coordinates of the two electric bikes when a violation conflict occurs, and \((x, y)\) is the two-dimensional ground coordinate of the predicted collision point, and \(v\) is the speed of the electric bike which is closer to the collision point.

In our country, the distance to collision electric bicycles whose weight is less than or equal to 40kg and maximum speed is 20km/h is 3.2m [9], so TTC can be calculated as 1.16s. In other word, a slight interaction happens if the TTC of the electric bicycle greater than 1.16s, otherwise a serious conflict is brought about.

After determine the conflict of the electric bicycle at, the number of conflicts and the traffic volume can be counted, which are used to calculate the collision rate of the electric bicycle at the intersection within a certain period of time. Comparing the collision rate with the ‘Evaluation index for classification of traffic safety city’ [10] in Table 3, the driving safety of electric bicycles at the intersection can be judged. The conflict rate can be calculated by the following formula for the traffic interactions between the electric bicycles researched in this paper:
\[
R = \frac{T}{P}
\]  
(10)

Where \(R\) is the collision rate, \(T\) is the number of interactions per hour, and \(P\) is the traffic volume of the electric bicycle per hour.

| Safety Level      | Interaction Rate |
|-------------------|------------------|
| Particularly safe | <0.01            |
| Security          | 0.01-0.02        |
| Verge of Insecurity | 0.02-0.03       |
| Insecurity        | >0.03            |

4. Case Study
This paper chooses the intersection of Zhongshan East Road and Taiping North Road in Nanjing as the research object. This intersection is a typical four-phase signal control crossroads, the two roads of the intersection are also the urban arterial roads.

The video is shot by a perpendicular mounted camera. Based on the OpenCV library, electric bicycles can be detected and tracked, and the traffic volume of each entrance lane at the intersection can be calculated. The detailed data are shown in Table 4. In view of the above calculation method of the time to collision of electric bicycles, this paper chooses to focus on extracting the number of interactions caused by electric bicycles of a 10 minutes video at the peak time, and calculate the rate of interactions, and then convert the formula mode into interactions per hour, shown in Table 5. According to the data in Table 4 and Table 5, the interaction rate between the electric bicycles is calculated as follow:
\[
R = \frac{T}{P} = \frac{54}{1818} = 0.029
\]  
(11)

Comparing the conflict rate \(R\) with the ‘Evaluation index for classification of traffic safety city’, the intersection of Zhongshan East Road and Taiping North Road in Nanjing is on the verge of
insecurity.

Counting the maximum velocity of the electric bicycles that are riding across the intersection at the peak hours, the maximum velocity distribution condition is shown in Table 6, and the maximum velocity distribution diagram is shown in Figure 5.

As shown in Table 6 and Figure 5, the electric bicycles of which the maximum velocity distributed in the four intervals of 5.5~6.5 m/s, 6.5~7.5 m/s, 7.5~8.5 m/s and exceed 8.5m/s is overspeed ones. The distribution probability is 5%, 4%, 2% and 0% of the four intervals mentioned above. The overspeed electric bicycles account for 11% of the overall vehicles.

The speed of the electric bicycles distributed in 2.5~3.5m/s take up the most room in the overall distribution, and the probability is up to 46%. Sorted in a descending order, the previous 15% and the posterior 15% of the velocity is removed, then the safe speed range of 2.5~5.0m/s can be confirmed.

5. Summary and Prospect

Based on the video image technology, the paper establishes the parameter model of the electric bicycle, and preliminarily realizes tracking and detection of electric bicycles at intersections. To further calculate the riding data and the surrogate safety measures between electric bicycles, it is possible to analyze the severity of driving situation at intersections with improved accurate data.

Limited to my finite knowledge, there are still many improvements in coping this method. The improvements are listed as follows. First, the detection efficiency of the electric bicycle needs to be improved. The proposed method can’t distinguish pedestrians and bicycle at present, and can only detect the internal areas of road intersections that do not contain pedestrian crossing areas. Second, in the aspect of video detection, it is difficult to remove the detection effects caused by camera shake and light reflection. Third, for the conflict judgment, the proposed method can’t achieve the goal of automatic judgment completely, a manual and general observation need to be taken to acquire surrogate safety measures, and ultimately determine whether a traffic interaction occurs.

| Table 4 Traffic volume of Zhongshan East Road Taiping North Road intersection (pcu/h) |
|---------------------------------|--------|--------|--------|--------|--------|
| Entrance           | East   | South  | West   | North  | Total  |
| Electric bike      | 534    | 378    | 498    | 408    | 1818   |

| Table 5 Statistics of Zhongshan East Road Taiping North Road electric bicycle interactions |
|--------------------------------------------|--------|--------|
| Num./10min Interaction                  | Rear-end | Left-turn DC |
| Num./h                                    | 4      | 2      |
| %                                         | 44.5%  | 22.2%  |
| Num./h                                    | 12     | 24     |
| %                                         | 44.5%  | 22.2%  |

| Table 6 Statistics of maximum speed distribution |
|---------------------------------|--------|--------|--------|--------|--------|
| Velocity range (m/s)           | Num.   | Pro.   | Velocity range (m/s) | Num.   | Pro.   |
| 0.5-1.5                       | 19     | 1%     | 5.5-6.5                  | 90     | 5%     |
| 1.5-2.5                       | 208    | 11%    | 6.5-7.5                  | 75     | 4%     |
| 2.5-3.5                       | 828    | 46%    | 7.5-8.5                  | 28     | 2%     |
| 3.5-4.5                       | 340    | 19%    | 8.5 以上                 | 3      | 0%     |
| 4.5-5.5                       | 227    | 12%    | Total                     | 1818   | 100%   |
Figure 5 Maximum speed distribution of electric bicycles

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