TRAFFIC INJURY PREVENTION
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Measurement method for objective cyclist behavior parameters

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ABSTRACT

Objective: The objective of this research is to study the feasibility of measuring behavioral indicators that reflect effects of infrastructure and interaction with other road users.

Methods: An observation study was performed using 6 cameras above a separated cycle path next to a road which included a crossing with both cyclists and cars. A learning method based on Single Shot MultiBox Detector was applied to automatically detect the cyclists, and cyclist tracks were determined. Next, kinematic parameters were calculated from the cyclists' tracks. Amongst others, the cyclists' intensity, speed, position on the cycle path, and the distance to each other were analyzed for a busy period as well as for a quiet period of the day.

Results: With the measurement method developed in this study it is possible to analyze the cyclists' intensity, the space they use at the cycle path, their average velocity, waiting times, the space and velocity amongst each other, and red light negation. However, collisions were not seen in the dataset analyzed, and the data is not sufficiently accurate to analyze sudden braking actions.

Conclusion: It can be concluded that the developed measurement method provides insight of the cyclists' behavior in such a way that it can already be used for obtaining information to make changes to the infrastructure that will improve the comfort and safety of cyclists. The method could be further developed for doing qualitative comfort and safety analyses, and for doing analyses of the interaction between various types of road participants.

Keywords: Cyclist behavior, cyclist detection, cyclist kinematics, cyclist objective behavior parameters.

INTRODUCTION

World-wide cycling is getting more popular, especially in cities. In the Netherlands, cycling has already been a very common means of transport for decades. Due to the dense population and traffic jams in cities, the popularity of cycling in the Netherlands is growing.

Although, in The Netherlands the infrastructure has been made cyclist friendly, 78.400 cyclists were treated at the first aid because of accidents in 2014 [1]. Questionnaires to a representative group revealed that of all accidents almost half was caused by a mistake of the cyclist him/herself, in more than one third another traffic participant was involved, and in one third the road conditions played a role [2]. Almost one third of these accidents happened on a roadway that is shared with vehicles, and one quarter on a cycle path or separated cycle track [2]. Especially with the upcoming of various types of powered bikes, more detailed analyses on the safety critical situations for cyclists is needed in order to adequately adapt and further optimize the infrastructure for cyclists.

Various measurement methods for car-cyclist accident causation have been developed [3, 4], and methods have been developed using naturalistic cyclist data measured at the bike [5]. Recently, a method has been developed for analyzing the safety of infrastructure for cyclist by means of using camera data for objective measures [6]. Previous studies have been performed to investigate cyclist behavior, however the number of measured variables are less (many focusing on cyclists' velocity) and/or the measurement method less advanced compared to this study (for example observation studies) [7][8][9][10]. Currently, the situation at cycle paths is often measured by means of counting the number of cyclists, and sometimes accompanied by surveys. Since participation in surveys is on a voluntary basis, the disadvantage of this method is that the profiles that are participating do not necessary match with the prevalence of each profile at the cycle path, e.g. cyclist that are not in a hurry are more willing to participate.

The objective of this research is to study the feasibility of developing a measurement method, and determine objective cyclist behavior parameters that can be used for judging the situation at the cycle path related to comfort (i.e. comfort related parameters like intensity, usage of space, and waiting times) and safety critical situations. In order to get a complete view on the cycling behavior, and not only measuring occasional situations, the measurement method should also be able to include all cyclists at the cycle path over a representative period (e.g. a week outside vacation periods and holidays). In addition, for practical implementation the measurement method should have the potential to be able to be automated as much as possible.

METHODS

In order to be able to objectively analyze the situation of cyclists on a cycle path over at least one week, a measurement method using cameras was developed. The measurement method is shown in Figure 1 and described in more detail in this section.

An observation study was performed using 6 cameras above a separated one-way cycle path next to a road which included a crossing with traffic lights for both cyclists and cars. The cameras were mounted at 6-meter height and viewing straight down. The cycle path that was selected was the Amstelveenseweg around the crossing with the Zeilstraat in Amsterdam. The camera views of the cycle path at the Amstelveenseweg are shown in the red boxes in Figure 2.

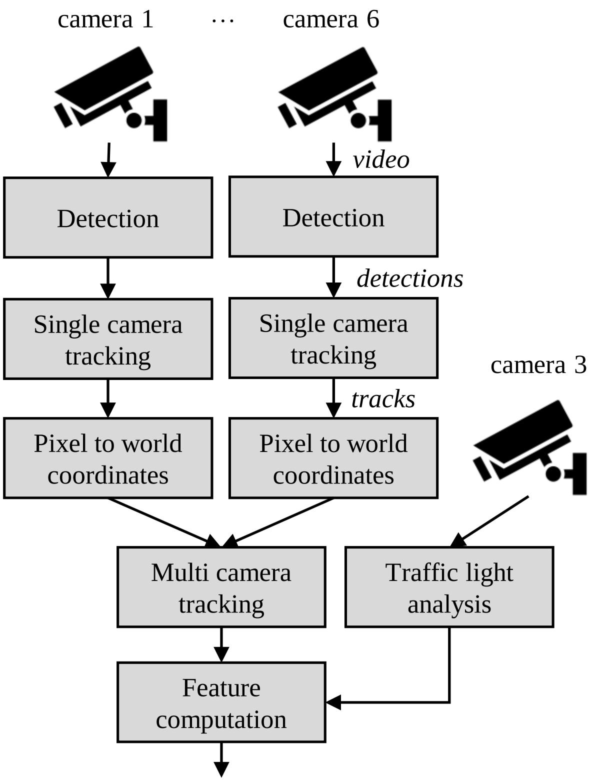

Figure 1. System architecture of the measurement method for objective cyclist behavior parameters

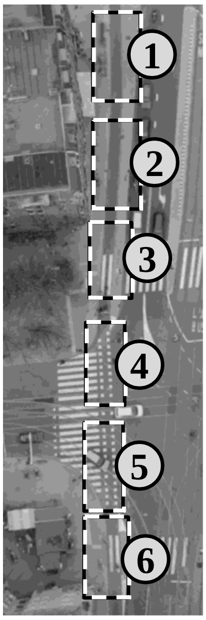

Figure 2. Views of the 6 cameras mounted above the cycle path of the Amstelveenseweg around the crossing with the Zeilstraat in Amsterdam.

The camera data was saved such that the identity of the people could not be recognized. An end-to-end fully Convolutional Neural Network (CNN) approach based on Single Shot MultiBox Detector (SSD) [11] was applied for automatically detecting the cyclists. The cyclists included all road users riding on the cycle path, no classification was performed. Only pedestrians were excluded from the detections. The SSD was retrained [12] on 200-300 examples from each camera. The video has a frame rate of 25 frames per second and the detector was applied at 5 frames per second. Single-camera tracking uses a robust linear fit and a constant velocity assumption to predict the position of the next bounding box and updates are based on the overlap between the predicted and the measured bounding box. Short tracks (less than 1 second) were removed in order to prevent false detections. The cyclists were individually tracked over the 3 cameras before the crossing, and over the 3 cameras after the crossing. Multi-camera tracking uses the following steps; single-camera tracks are not taken into account near the boundaries of the image to prevent incorrect speed estimates, association is based on the Munkres/Hungarian algorithm [13] to minimize acceleration, off-camera U-turns are prohibited and single-camera tracks can only be associated with tracks in the subsequent next camera. The data was calibrated by means of measurements on the road to allow conversion from camera coordinates (in pixels) to world coordinates (in meters). The status of the traffic light was analyzed automatically by measuring the relative intensity of the green and the yellow region of the light.

Next, various kinematic parameters that might be of interest related to comfort (incl. crowdedness) and safety evaluation of a cycle path were defined and calculated from the cyclists' tracks:

For comfort analyses:

- Intensity (number of cyclists in a certain time period)
- Space used at the cycle path
- Average velocity over the cycle path
- Waiting times at the traffic light
- Space and velocity of cyclists compared to its neighboring cyclists

For safety analyses:

- Sudden braking (decelerations)
- Critical speed difference and space
- Collisions
- Red-light negation

RESULTS

Based on a visual evaluation the accuracy of the cyclist detections was larger than 90%. As an example, some results of one day of the two weeks of measurements is shown in the following figures. Figure 3 and Figure 4 show two examples of cyclist intensity (or cyclist flow). Figure 3 shows the intensity of cyclists over the day by showing the number of cyclists passing in camera 1 within 15 minutes. Figure 4 shows the intensity (or flow) of cyclists over the cycle path within 4.5 minutes (7:33:00-7:37:30). Figure 3 shows that the cycle path is most crowded between 8:00 and 9:00. Figure 4 shows that there are high intensity peaks (just) after the traffic light counting up to 17 cyclists (camera 4, 5 and 6), and waiting times can last up to approximately 1.5 minutes.

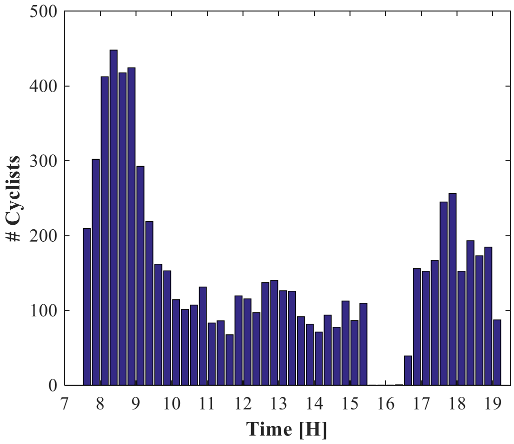

Figure 3. Cyclist intensity at the cycle path over a day (1 bar represents number of cyclist passing in camera 1 within 15 minutes).

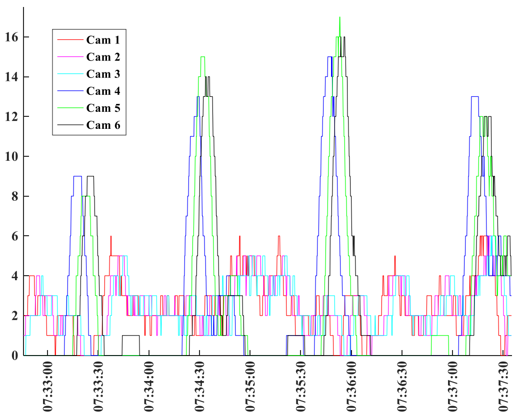

Figure 4. Number of cyclist present in various camera views (in a time period of 4.5 minutes).

The cyclists' spatial distribution of cyclists over the 6 camera's is shown Figure 6 in the appendix. Figure 7 in the appendix shows the velocity distribution in lateral position of the cycle path at the location of camera 1, 2 and 3. Only the data of camera 1, 2 and 3, were selected here in order to get a view on the preferred speed of the cyclists, which is disturbed due to the traffic light (camera 4) and due to the crowdedness after the traffic light (camera 5 and 6). The dotted lines in these figures show the borders of the cycle path. From Figure 6 it can be seen that far before the traffic light, most cyclists ride at the right side, and around the traffic light the cyclists spread over a wider space even beyond the border of the cycle path (on the pavement) and the traffic signs on the road (block marks). From Figure 7 it can be seen that at the right side of the cycle path the cyclists on average have a lower speed than at the left side at the position of camera 1. At the position of camera 2 the average velocity levels more out, probably because of approaching the traffic light and the intersection, faster cyclist on the left side decrease their speed, or they even have to slow down or stop for the traffic light or other stopped cyclists. At the position of camera 3 the overall average velocity of the cyclists decreased from approximately 20 km/h in camera 1 to 10 km/h due to the intersection and the traffic light. On the right side of the lane the average velocity decreases more compared to the left side, since during dense traffic, the first arriving cyclists stop at the right side.

Due to the noise on the positions obtained from the images and the short time period that a cyclist is in a camera view, decelerations from the current data would not be sufficiently accurate. As such, no analyses on sudden braking actions due to cyclist-cyclist interactions could be performed.

Figure 5 shows the relative lateral and longitudinal distance and relative resultant velocity of each cyclist to its left, right and front neighbor in camera 1 during high traffic (8:00h-9:00h). A similar figure for low traffic (13:00h – 14:00h) is shown in Figure 8 in the appendix. Based on the relative position and velocity rough classifications could be provided for each cyclist with respect to its neighboring cyclists, like ‘Cycling together’, ‘Being Overtaken’, ‘Overtaking’, and ‘Following’. This figure clearly shows that it is common to be overtaken on the left side in The Netherlands, since the speed on the left side is higher than on the right side. It must be noted here that the high-speed cyclists also included motor bikes, scooters, and probably e-bikes as well. An “empty” area around the cyclist can be found, where no other cyclists are observed (approximately 0.5m to the left and right, and approximately 2m to the front), which might be the natural personal space that a cyclist induces. When comparing Figure 5 with Figure 8 in the appendix, it can be seen that the personal space is similar during the most crowded period and a quiet period of the day. This might indicate that this cycle path at the position of camera 1 seems not too crowded. Further, it can be seen that in the crowded period there are much more interactions with the other cyclists like following, being overtaken, and overtaking, than in the quiet period. Cycling together seems relatively more often the case in the quiet period than in the crowded period.

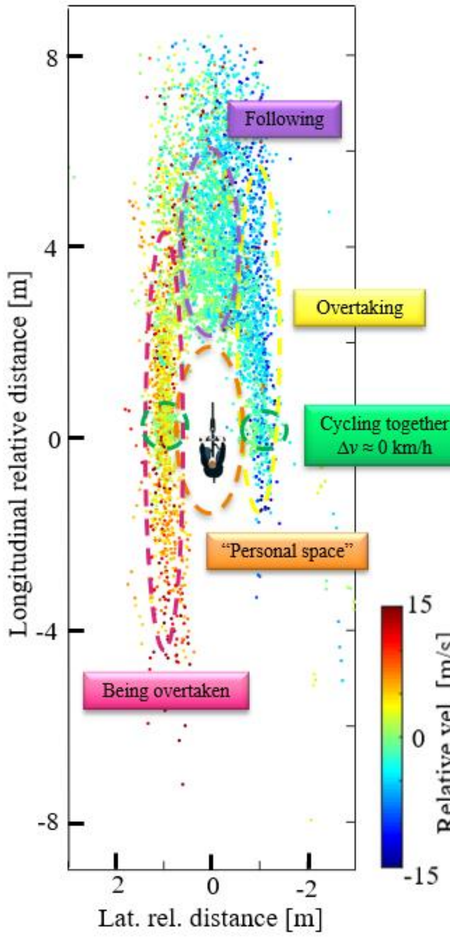

Figure 5. Cyclists' relative distance and velocity to the neighboring cyclists during 7:30-8:30h

For quantitative analysis, three regions were distinguished: not besides (absolute longitudinal distance larger than 2.0 meter), left (besides and lateral position > 0.0 meter) and right (besides and lateral position < 0.0 meter). The results are shown in Table 1. The quantitative analysis shows that the average lateral distance left and right is 1.0 meter and the average speed difference is 4.0 m/s. The quantitative results in the afternoon are similar, but in the busy morning only 34% of the people left and right have the same speed (speed difference smaller than 2.0 m/s) and in the quiet afternoon 50% has the same speed. Apparently, the quiet afternoon allows people more to cycle in pairs without being overtaken than the busy morning. Surprisingly, a clear difference in speed if compensated for the people cycling in pairs was not observed.

Table 1. Lateral position (Y) in meter (mean and standard deviation) and the speed difference in meter per second in the busy morning. There is a distinction between all speeds and only speeds that are different (V > 2.0 m/s).

Morning	Left	Right
Y in m ($\mu \pm \sigma$)	1.0 ± 0.17	-1.0 ± 0.31
V in m/s ($\mu \pm \sigma$): all	4.0 ± 3.79	-3.9 ± 4.25
Same V : $\|V\| < 2.0$ m/s	34%	34%
V in m/s ($\mu \pm \sigma$): $\|V\| > 2.0$ m/s	5.7 ± 3.57	-5.4 ± 4.47

DISCUSSION

With the measurement method developed in this study it is possible to analyze the cyclists' intensity, the space they use at the cycle path, their average velocity, waiting times, the space and velocity amongst each other, and red light negation. However, collisions were not seen in the dataset analyzed, and the data is not sufficiently accurate to analyze sudden braking actions. For sudden braking actions the cameras would need to be mounted higher in order to have a longer time period of each cyclist in one view. Further, red light negations can be extracted from the detections, however these have not been analyzed yet. Therefore, the measurement method is currently mainly limited to be used for comfort (incl. crowdedness), analyses of a cycle path, and can only be used for safety analyses in a limited way (red light negation). However, a smaller personal space compared to quiet periods as well as a high difference in speed could be parameters indicating a higher risk of incidents among cyclists. This would need further research.

The analysis was performed on a small part of the dataset (one day out of two weeks). For using this measurement method and analyses to get more input for improvements on infrastructure, more research is needed to find relationships between cyclist parameters and the layout of a cycle path, e.g. path width, markings, etc.. For this the observation study would also need to be performed at various types of cycle paths. In addition, more research is needed in order to find values for the parameters that reflect comfort and safety for the cyclists.

Collisions between cyclists were not observed in the dataset analyzed. However, red light negations were seen, therefor the red and green light detections were notated with the cyclists' positions. Correlation between red light negation and any other parameter, like speed or waiting time can be analyzed, however this is not performed at this moment.

The measurement method in its current state can already be used for obtaining information to make changes to the cycle path to improve the comfort and safety of cyclists. The measurement method can also be used for analyses of the effect of changes to the cycle path and the effect of interventions, when the data before and after the interventions is compared. Other applications that can be thought of are: Analyses on the interaction of different types of users of the road or cycle path, and the interaction between cyclists and cars for a road without a separated cycle path or at a crossing. For such analyses, further classification of the road participants is needed (e.g., an object classifier to distinguish cyclists and scooters). This is possible with the current measurement method, only sufficient data should be available of each class that needs to be identified to retrain the object classifier, and some types might be more difficult to classify than others.

CONCLUSIONS

From the analyses of a part of the collected data by means of the measurement method developed in this study, it can be concluded that it is possible to determine the cyclists' intensity, the space they use at the cycle path, their average velocity, waiting times, and the space and velocity amongst each other. Also, analyses on red light negation is possible. So, the measurement method in its current state can already be used for obtaining information to make changes to the infrastructure that will improve the comfort and safety of cyclists. The method could be further developed for making qualitative comfort and safety analyses, and for making analyses of the interaction between various types of road participants.

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APPENDIX

The cyclists' spatial distribution of cyclists over the 6 camera's is shown in Figure 6. Figure 7 shows the velocity distribution in lateral position of the cycle path at the location of camera 1, 2 and 3.

Figure 8 shows the relative lateral and longitudinal distance and relative resultant velocity of each cyclist to its left, right and front neighbor in camera 1 during low traffic (13:00h-14:00h).

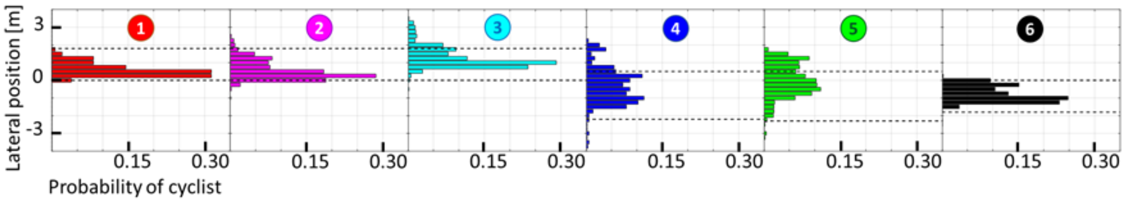

Figure 6. Lateral position of the cyclists on the cyclist path for the 6 camera's. The dotted lines show the borders of the cycle path.

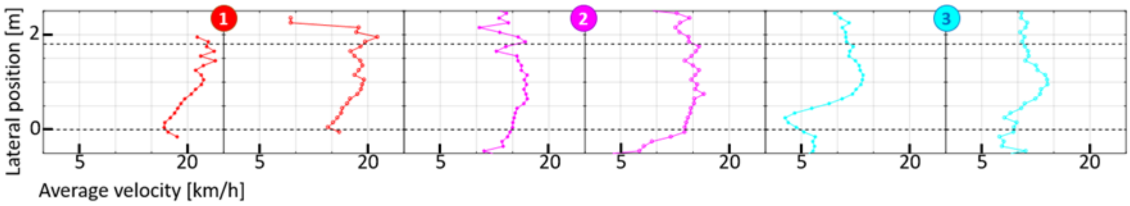

Figure 7. Velocity distribution over lateral position on the cyclist path for camera 1, 2 and 3 (three camera's before the traffic light).

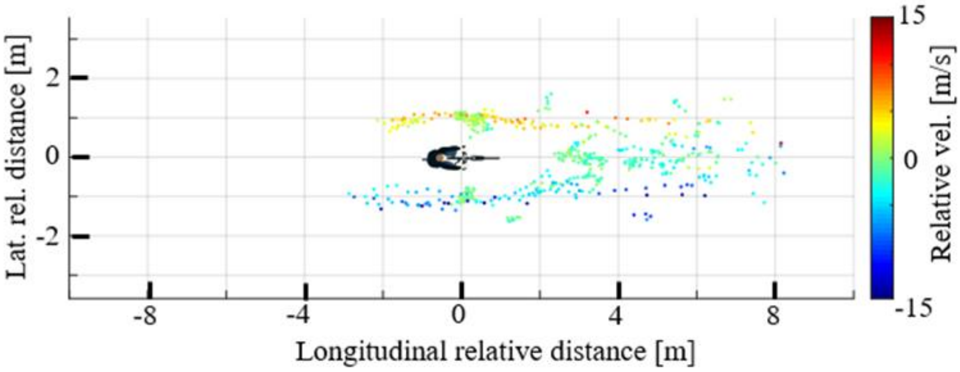

Figure 8. Cyclists' relative distance and velocity to the neighboring cyclists during 13:30-14:30h.