A study on the effects of highway and traffic characteristics on cyclist behaviour using an instrumented bicycle

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Introduction

Cycling is an increasingly popular mode of travel in cities due to the great advantages that it offers in terms of space consumption, health and environmental sustainability. Findings from cycling-intensive countries demonstrate that significant savings in terms of congestion and pollution can be achieved with higher modal shares of cycling. For example, it is estimated that the city of Copenhagen saves about 90,000 tonnes of CO_2 per year because of its extensive use of cycles [1]. Cycling is therefore favoured and promoted by many city authorities worldwide. The large number of recently introduced schemes in many cities (such as the Santander Cycle Hire scheme [2] and the Cycle Super-Highways [3] in London) is testimony to this trend.

Despite the intensive efforts of the authorities, however, the take-up of cycling as a viable alternative travel mode in cities remains well below desired levels, with examples like Copenhagen being notable exceptions rather than the norm. Indeed, the average annual total personal cycling distance in the UK is a mere 53 miles [4] – less than 10% of the corresponding figure from Denmark (600 miles) [5]. The main reason is the relatively low perceived safety of cycling from the users' side, which is by no means unjustified: according to the UK Department for Transport's latest official statistical release, there were as many as 102 cyclist fatalities in Britain in 2016 [6], and these were only a small part of a staggering 18,477 casualties, 77% of which occurred on 30 mph (50 km/h) roads in urban areas.

But despite cyclist accidents being widely-acknowledged as a critical issue, attempts to tackle them have so far been rather passive and insufficient. Examples have included both "hard" engineering measures (e.g. mirrors at junctions and "Blaze Laserlights" on Santander Cycles in London), and "softer" technology-based academic and industrial research approaches (e.g. the WATCH-OVER [7] EU-funded project and Volvo's new pedestrian/cyclist detection system [8]). However, they have all had limitations, and so their actual effectiveness has so far remained unproven [9]. This is because there is currently a lack of understanding of the mechanics and behavioural traits of cyclists that would enable the design of suitable interventions.

The aim of the present study is, hence, to shed light into the under-explored topic of cyclist behaviour. The focus is on the specific aspect of the relation between road environment (i.e. different highway features and traffic characteristics) and cyclist behaviour, as expressed by real-world cyclist trajectories in urban areas. This is investigated using trajectory data from a number of road sites in London, collected by means of a field experiment with an instrumented bicycle.

The iBike instrumented bicycle

Previous work by the authors within the context of exploring technological solutions for preventing cyclist accidents in cities has focussed on the issue of accurate (50 cm) cyclist real-time localisation and tracking and has resulted in the development of a prototype instrumented bicycle, called "iBike" (Figure 1) [10]. This is a Santander Cycle Hire cycle supplied by Transport for London, equipped with an absolute encoder and microelectromechanical systems (MEMS) sensors (Hall Effect sensor, gyroscopes and accelerometers). Through these sensors, the iBike is able to take real-time measurements of the distance covered, as well as of the yaw, tilt and steering angles, which are then fetched by a microcontroller board and transmitted to an on-board tablet PC for processing. Using a dead-reckoning technique implemented on the on-board tablet, it is then possible to reconstruct the bicycle's trajectory.

Recent additions to the iBike instruments include a camera, a GPS receiver (smartphone), and an Inertial Navigation System (INS) device, currently used only for validation purposes. Field experimental results have shown that the iBike achieves considerably better positioning accuracy than the GPS and the INS [11]. More recent methodological work has concentrated on the development of a Kalman filter for the iBike with the two-fold objective of further improving the positional accuracy on one hand, and of formulating a cyclist trajectory prediction model with a time horizon of 5 seconds, on the other [12].

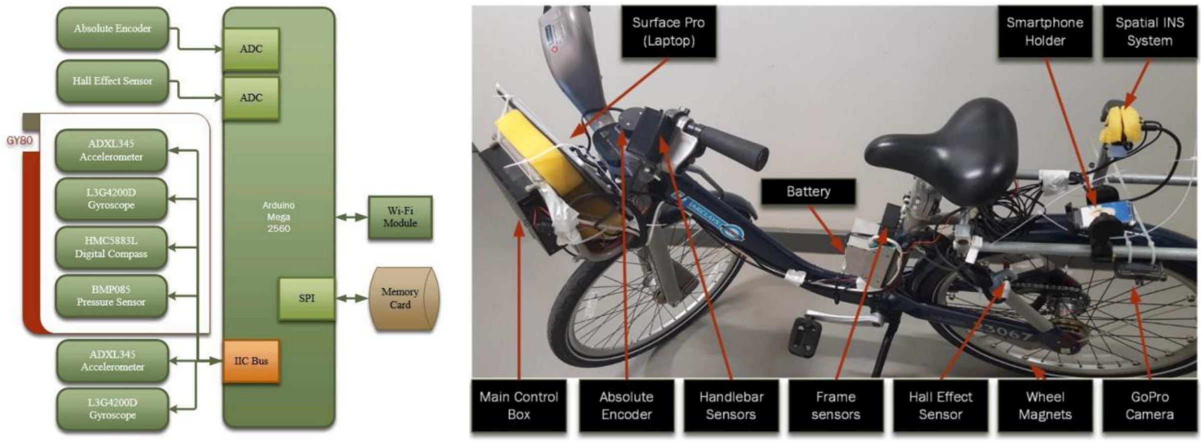

Figure 1: Left: iBike system architecture; Right: the iBike instrumented bicycle

Research design and methodology

The study collects cyclist trajectory data from a number of road sites in London using the iBike and investigates the association between highway/traffic characteristics with trajectory features. This is done by means of a series of linear regression models, where trajectory features are the dependent variables and the road characteristics are the independent ones.

Based on a review of the available literature, a number of parameters relating to highway design features and traffic characteristics are identified as potentially having an influence on cyclist behaviour. Based on these, the following are selected to be analysed in this study, and corresponding categorical variables are defined for use in the regression modelling:

- Road surface condition, classified as “poor”, “adequate” or “good. This reflects the condition of the pavement (i.e. cracks, potholes, rutting etc.) and of the road markings.
- Gradient, classified as “flat”, “uphill” or “downhill”. This reflects the slope of the road in the direction that the cyclist is moving.
- Presence of on-street parking, classified as “present” or “not present”, on the side of the road that the cyclist is moving.
- Road width, classified as “narrow” or “wide”. This reflects the space that the cyclist can use, i.e. the relevant traffic lane, not the total carriageway width.
- Presence of a bus stop, classified as “present” or “not present”, on the side of the road that the cyclist is moving.
- Time of day, classified as “peak” or “off-peak”. This is used as a proxy for the traffic volume on the road in the direction that the cyclist is moving.
- Presence of a cycle lane, classified as “present” or “not present”, on the side of the road that the cyclist is moving.

On the other hand, the cyclist trajectory parameters considered and acting as dependent variables in the resulting regression models are:

- Average distance from the road kerb
- Standard deviation of the distance from the road kerb
- Average speed
- Standard deviation of the speed
- Average yaw angle divergence from the road direction
- Standard deviation of the yaw angle divergence from the road direction.

Data collection and processing

The data collection involves a single cyclist riding the iBike multiple times along a number of urban road sections of different known highway and traffic characteristics and recording the relevant trajectories. 10 road sections, each with an approximate length of 200-300 m and different features, located around City University of London's campus in Central London, have been selected (Figure 2 (top)), and trajectory data has been collected at different times of the day, including afternoon peak (17.00-19.00) and off-peak (10.00-17.00) periods. In total, 112 sets of valid trajectory data have been collected.

The process of trajectory parameter monitoring from the iBike is shown in Figure 2 (bottom). Given the iBike's ability to record 40 sample points per second, the trajectory reconstructed for each of the 112 runs of the survey consists of some 4000 data points, which enables a robust statistical analysis.

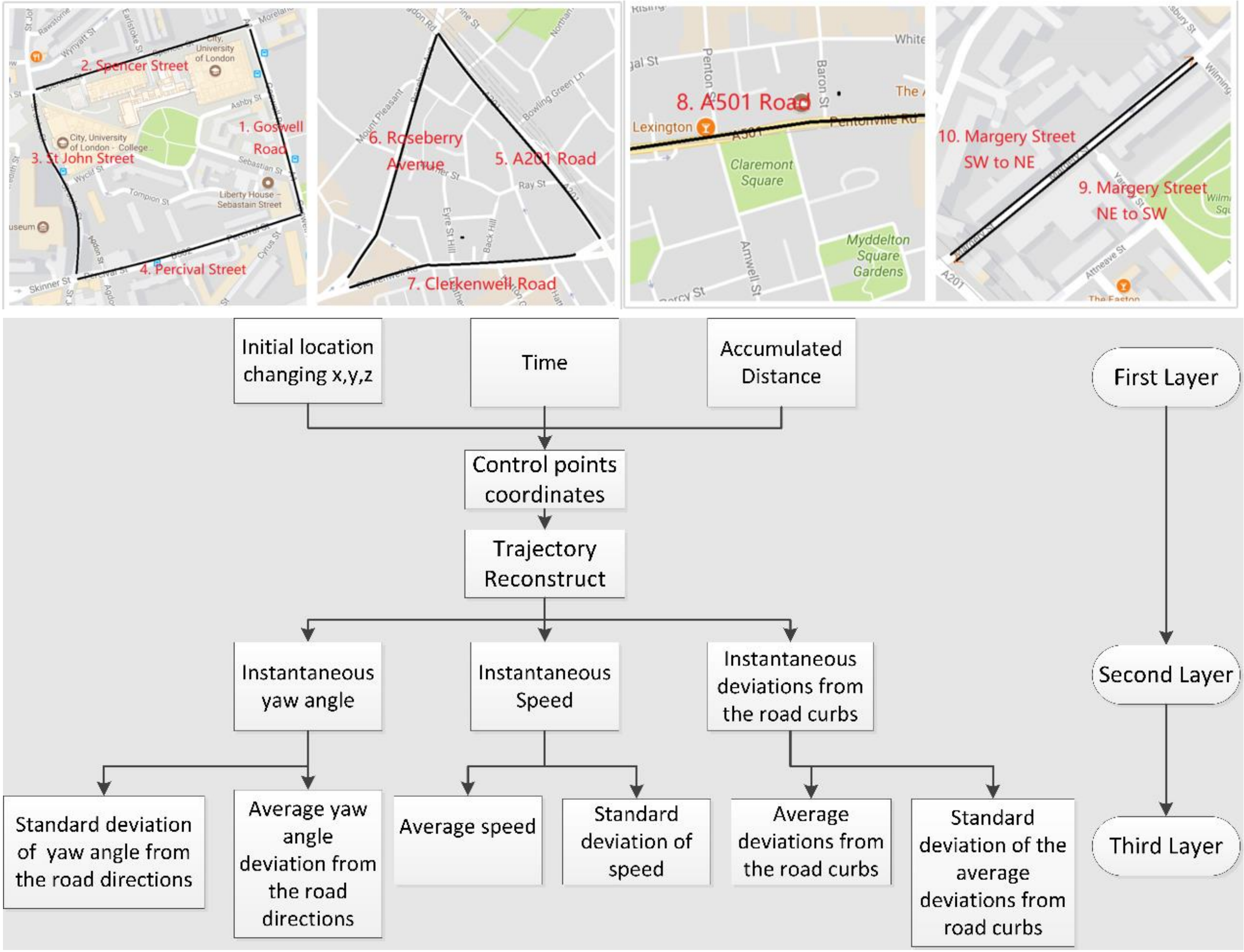

Figure 2: Top: The 10 road sections investigated; Bottom: The trajectory parameter monitoring process

Analysis and results

Six linear regression models are fit to the trajectory data collected, each one having one trajectory parameter as the dependent variable and all of the highway/traffic features as the predictors. In order to ensure comparability between the models and parameters, categorical variables are converted to dummy binary ones.

A summary of the results of the regression is provided in Table 1, whereby each row corresponds to a different regression model and the signs indicate any associations (positive or negative) and their magnitude. All six models are statistically significant as a whole and have R^2 values between 0.5 and 0.98, thus being adequate fits to the data.

Table 1: Summary of regression models, relating trajectory features (down) with highway/traffic parameters (across)

Parameter	**Cycle lane**	**Bus stop**	**Street parking**	**Time of day**	**Road width**	**Road condition**	**Road condition**	**Gradient**	**Gradient**
Level	*Present*	*Present*	*Present*	*Peak*	*Narrow*	*Good*	*Poor*	*Uphill*	*Downhill*
Average distance from kerb	–	+ +	+ + +	–	– – –	– –	+	+ + +	+ +
Distance from kerb standard deviation	.	+	+	–	.	–	–	.	.
Average speed	.	.	.	–	–	+	–	–	+ + +
Speed standard deviation	.	+	+	–	.	–	–	.	.
Average yaw angle diversion	– –	+ + + +	+ + + +	– – –	+ + + +	.	+ +	.	.
Yaw angle diversion standard deviation	–	+ + + +	.	– – –	+ +	– – – –	.	– – – –	– – – –

(+) positive association; (-) negative association; (.) no statistically significant association

The average values reflect the average motion states of the cyclist in response to the various highway and traffic features, while the standard deviation values imply how well the cyclist can keep a relatively steady motion status. From Table 1, it can be observed that:

- The presence of roadside interferences (on-street parking and bus stops) increases the spatial instability of cyclists, causing more agile turns, cycling further away from the kerb, as well as greater speed variability.
- Road condition has a notable impact on cyclist behaviour, as good road condition encourages higher and invariable travel speeds with few turns; poor condition has the opposite effect.
- The provision of a cycle lane provides a clear path for cyclists and increases their riding stability, as portrayed by fewer and less variable deviations from the straight line.
- Cycling during the peak hours, when traffic flows are higher, is generally slower and more agile, with more frequent course changes (possibly due to swerving around congested traffic).
- A gradient (whether uphill or downhill) results in cycling further away from the kerb, but also in few course changes (turns); as expected, an uphill gradient means slower cycling, while a downhill one means faster riding compared to cycling on a flat road.
- Narrower road width means less space, and hence slower and more agile cycling, as expressed by the frequent and variable changes in the yaw angle.

References

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