Urban Attractors for Uncoordinated Micromobility Riders

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ABSTRACT

This research presents a novel bicycle-to-infrastructure cooperative system that promotes the conversion of a portion of carbon-powered urban trips to assisted two-wheeled vehicles, thereby reducing cities' carbon emissions. The system gathers uncoordinated riders with similar routes around mobile attractors. While the resulting groups receive prioritized traffic from the city's traffic management, the riders have a smoother and safer riding experience. An empirical study with a working prototype examines the extent to which riders on regular and assisted bicycles converge around attractors. Participants riding regular and assisted bicycles followed visual and acoustic cues displayed on the system's user interface and adjusted their speed and acceleration in response to their proximity to a moving attractor. The results show that percussion rhythms suffice to converge around attractors within the first three blocks of a journey, and visual cues are needed to confirm the magnitude and direction of acceleration adjustments. Also, assisted pedaling significantly reduced the cyclist's effort of approaching the attractor's position and keeping up with its speed, minimizing the time to convergence. Widespread adoption of this kind of bicycle-to-infrastructure system could help cities in the United States reduce up to 11% of their daily greenhouse gas emissions, helping to meet the national emissions reduction goal.

KEYWORDS

micromobility, cycling coordination, platooning, user interface

1 INTRODUCTION

In recent years cities in the United States such as Denver, Austin, Santa Monica, and Chicago have expanded their infrastructure to support short- to medium-distance travel on light electric vehicles such as electric bicycles, scooters, and seated scooters, and encourage multimodal trips using high-quality public transportation [16]. This form of mobility, named micromobility, offers significant advantages over conventional non-motorized modes of transportation, like bringing effective commuting alternatives to underserved neighborhoods, enabling low-cost short-distance freight logistics, and reducing the physical load that prevents people with limitations (e.g., aging or some disabilities) from riding conventional bikes.

Studies suggest that assisted bicycles could substitute 35-50% of urban car rides in Europe and 11-46% in the United States for e-bike rides [3, 4]. The impact of such mode substitution on the number of vehicle miles traveled is estimated at 8.5 miles per e-bike trip in Sweden and 9.3 miles in the United States [9]. Given the fast-growing sales of e-bikes in the United States (240% increase between 2020 and 2021 [10]), the reduction in car trips could imply a change in traffic patterns with a significant decrease in greenhouse gas emissions and an increase in healthy physical activity. In the case of Portland, Oregon, a 15% e-bike share of the total number of trips per day could amount to a 10% decrease in miles traveled by car, which would mean 921 metric tons of CO_2 less per day – a reduction of 11% of the city's transportation emissions [11]. For reference, a car emits 274g of CO_2 per person/mile, public transit 140g, and an e-bike 4.9g depending on the efficiency of the power provider [11].

The issue is, however, whether a city can attract sufficient citizens to ride to work or school and contribute to achieving greenhouse gas pollution reduction targets. In the case of the United Stated the target for 2030 is 50-52% less emissions than 2005 levels [6]. Part of the solution is convenient access to owned or rented micromobility vehicles. To that aim, industry-driven initiatives currently ask for subsidy programs and infrastructure improvements. Several transportation network companies (e.g., Veo, Uber, and Lyft) provide affordable mobility solutions in large and intermediate cities of the country. Sun et. al., [16] estimate that such initiatives may have significant impact in reducing the energy used in urban transportation because car riders may switch to micromobility vehicles to do short trips, access transit or convert non-transit to transit trips. An important and unattended part of successful car substitution is to enable a safe and comfortable travel experience for bike riders supported by intelligent infrastructure –e.g., integration of public transportation timetabling with passenger routing [7, 13], and access to services like those available to car drivers –e.g., adaptive control of traffic lights [8].

This research contributes to car substitution by supporting city administrators to elevate cycling infrastructure by prioritizing micromobility with a low disruption of regular car traffic. Our proposal builds on a prototype of a bike-to-infrastructure (B2I) system that congregates riders with similar routes around mobile attractors. The system is designed for micromobility users to delegate the coordination to their vehicles[1], which constantly receive the location and speed of the attractor, compute the appropriate kinematics (acceleration to catch up, distance and time to target). In turn, the vehicles prompt speed adjustments so that the riders react accordingly to converge on the attractor's location, forming an impromptu convoy. Those convoys with a critical mass are given transit privileges over car drivers.

[1]The B2I system is a variation of our earlier work [1]

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The system displays the route and points in the direction of the attractor. There is no need to provide navigation instructions because traffic controllers must deploy attractors on marked bike lanes, cycle paths, and bicycle boulevards [12]. Since e-bikes and e-scooters cannot operate autonomously, the interpretation of acceleration and speed suggestions from the B2I system is critical to approach the attractor. This article focuses on the analysis of the user interface and the cyclist's response to visual and acoustic cues. An empirical study with a working prototype examines the extent to which riders on regular and assisted bicycles adjusted their speed and acceleration to converge around attractors.

2 DESCRIPTION OF THE BICYCLE-TO-INFRASTRUCTURE SYSTEM

The B2I system's prototype is a fully functional suite of four web-based applications developed for traffic controllers and riders The city traffic controllers have access to two of them. The *Route maker* serves to define the corner points, stops ad traffic lights of the routes on which attractors run. An attractor is a global position travelling at an adaptive speed on a route of bicycle paths and roads. It's acceleration responds to traffic lights and stops marked on the route. An attractor constitutes the moving leading point which riders are expected to follow. They can 'see' an attractor only through the *Flocking* application (see next paragraph). The second website is the *Attractor tracker* used by traffic controllers to deploy attractors at a designated speed on the routes created with the Route maker. This website pushes the attractor's data to a real-time cloud-based database at 1Hz, but this parameter can be customized to reduce data usage (see Figure 1).

Riders have access to the remaining two web-based applications. The *Flocking* website receives the attractors latest position from the real-time database, computes acceleration to catch up, distance, and time to target based on the e-bike's current's position. Simultaneously, their speed, acceleration, and position are pushed to the same real-time database on the cloud for the analysis of proximity, clustering, and prediction of traffic. Retrieving and pushing data occurs at the same sample rate defined for the attractor (usually at 1Hz). This web application is designed for smartphones, so users can place their portable devices on the handlebar of their vehicles (see Figure 2). The recommendations are displayed visually and acoustically. We envision a future embedding of this application into e-bikes and e-scooters' hardware and software. The fourth website is the *Dashboard* where riders visualize their journeys once they complete them.

Our vision of the B2I system is that a city's traffic controller uses it to deploy a network of attractors traveling on selected bike lanes and protected paths connecting neighborhoods to city hubs. An attractor travelling on a route constitutes a *journey*. The system constantly monitors the size of groups on active journeys, and supplies mobility services to large enough ones. An example of such services is optimized green light speed advisory systems (green waves), a traffic control strategy that synchronizes consecutive green traffic lights to allow efficient traffic flow. Thus, micromobility users could flow smoothly throughout main roads, feel safer when riding with others –especially women [5] and other vulnerable riders, and have a comfortable ride with less physical exertion. Another transit privilege could be the synchronization of mobile attractors with mass transport schedules, such as metro trains and inter-municipal buses, so that users ensure a timely arrival to stations.

2.1 User interface

In this section we will focus on the user interface of the Flocking website (See Figure 2). As mentioned above, the purpose of this tool is twofold: to show the direction in which the attractor is located, and to suggest acceleration adjustments to converge to its location.

2.1.1 Graphic User Interface (GUI). The GUI has two overlapping layers of information: a 3D background and a 2D foreground. The background shows a bird's eye view of a WebGL-based hybrid-reality map using 3D tiles of the surroundings. The map contains the nearby routes and the active attractors. Once the user selects one of them, a *session* is initiated in the respective journey. The camera descends to a first-person view and the interface displays a floating vector field on top of the map pointing to the attractor. The vector field is an effective way to convey the orientation and distance to a point in a 3D map. It is especially useful when the point is behind the viewer's field of view. The 3D map responds to the smartphone's gyroscope so the actual buildings in front of the e-bike are displayed on the map (as in RPG video games). This background layer is dimmed when the cyclists is moving faster than 2.3 m/s to avoid visual distraction while in motion.

The foreground layer, shows the suggested acceleration, the current speed, and the distance to the attractor. Acceleration is represented in three colors of the GUI theme. It is not shown in terms of magnitude, but in terms of direction: positive (green) , negative (red) and no acceleration (blue). Positive acceleration means that the vehicle is behind the attractor and needs to speed up to catch up. Negative acceleration is the opposite. No acceleration means that the vehicle is within the expected scope from the attractor's position. Any other e-bike subscribed to the same journey within this scope will be clustered by the Attractor tracker as a member of that attractor's group. The length of the scope is proportional to speed of the attractor and the duration of the green phase of traffic lights. To clarify, the relative distance between the attractor and the vehicle is not the shortest geodesic distance but the shortest on the route.

The speed is represented by the height of two bars: one for the speed of the vehicle and the other for the speed of the attractor. This GUI element is very useful to maintain a similar speed in the non-acceleration state by keeping bars of a similar height. Again, the numerical representation of the speed is not relevant. Finally, the distance is shown numerically in metric or imperial units.

2.1.2 Acoustic User Interface. To reduce the dependency of the visual modality and maintain the visual attention on the road, the GUI representation of acceleration and distance is complemented with acoustic signals inspired in Steve Reich's Clapping Music [14]. That master piece of contemporary music is performed by two people. One claps at a basic rhythm with a 12/8 time pattern [15]. The other claps the same pattern but shifts the timing by one eighth note to the right twelve times. The result is a compelling progression of distinctive synchronized rhythms considered the seminal piece of Euclidean music [2]. In the Flocking application, one pattern is

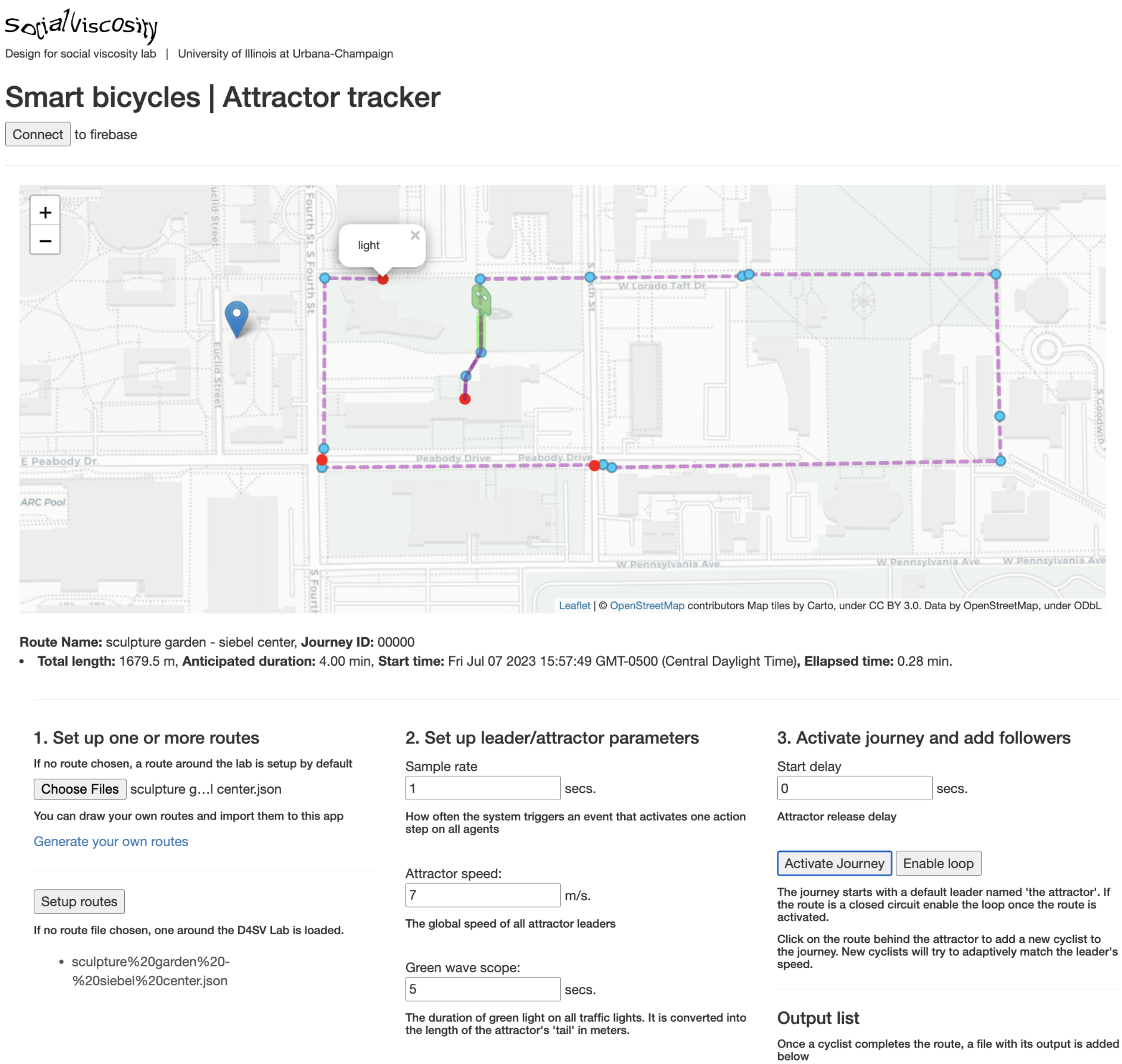

Figure 1: The graphic user interface of the Attractor tracker web tool displaying an attractor moving on a route.

played for positive acceleration, the second pattern is played for no acceleration, and finally there is no sound for negative acceleration. To convey proximity and urgency, the clapping frequency is proportional to the distance between the vehicle and the attractor. The greater the distance the higher the frequency.

3 EMPIRICAL STUDY

To understand the extent to which cyclists can converge around attractors, and the effect of the acoustic and visual interface on cyclists' response to acceleration signals we conducted a preliminary study with six participants riding on the same route. The participants were 4 male and 2 female, 24 years old average age, all of them frequent bicycle riders. The dependent variables were the type of bicycle (conventional and assisted). The signaling modality was visual+acoustic in all tests. The initial attractor speed was set to 7m/s but participants had a hard time catching up the attractor. The final speed defined for the test was 5m/s. The independent variables were the time to congregation and the percentage of session duration within the expected scope from the attractor's position.

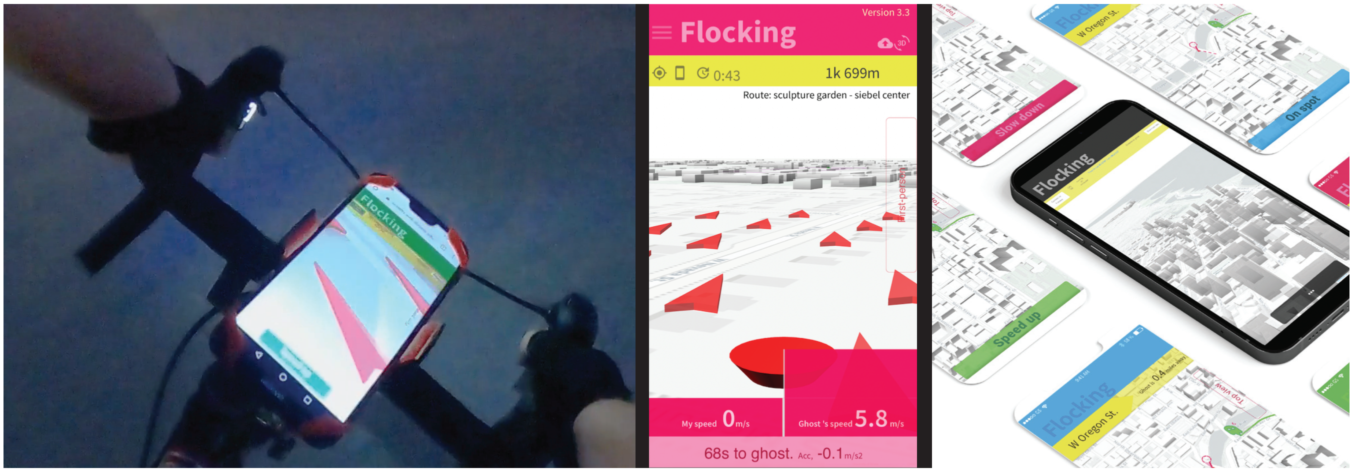

Figure 2: A cyclist chasing an urban attractor, user interface, and color themes to convey acceleration direction for the Flocking web application

Figure 3: Example of the distances between attractor and vehicles in one test.

The route was a circuit with 1645m length on bicycle paths at the University of Illinois. The route included 7 corners, 5 stop signs, and 5 traffic lights. The attractor is programmed to stop at stop intersections and traffic lights. Deceleration and acceleration occur at 0.7 m/s^2. The test were conducted during the summer break at the University of Illinois, thus there were no traffic on the route. Prior to the test the participants learned about the B2I system and the GUI behavior. Preliminary tests were done on vehicles equipped with mobile phones and bone-conducting headsets. Pairs of participant did the test simultaneously, one on a regular bicycle and the other on an e-bike.

3.1 Results

Although the results obtained are not conclusive, it shows that cyclists on e-bikes and bicycles take between 230m and 300m to catch up to the attractor (See Figure 3). This is between 38 and 50 seconds at a speed of at least 6 m/s. Once inside the group scope, both cyclists stayed 93% of the time close to one another, and 88% of the time close to the attractor until the end of the route. This could be evidence of mutual influence between the cyclists once they realized they belonged to a group. Such close proximity is a good indicator that the attractor tracker can accurately group bicycles in a trip and provide special services to that group, but the

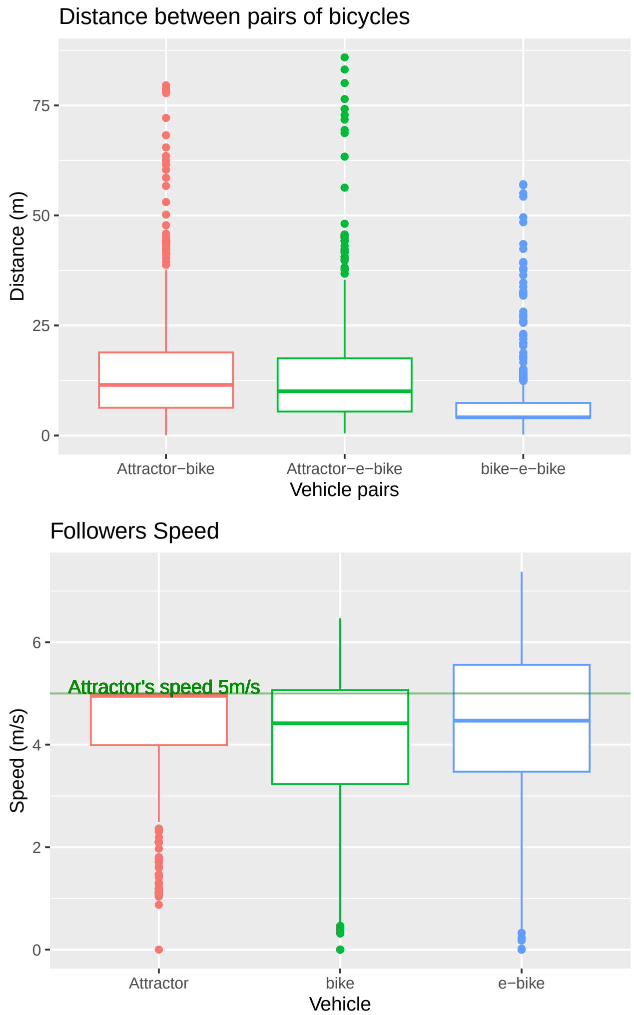

Figure 4: Left: Example of distribution of distance between attractor and vehicles. Right: Example of the distribution of speed of bike, and e-bike in reference to the attractor's speed. Both examples are from one test.

desire keeping a proximity between them may override the need to be close to the attractor.

In terms of the speed variation, conventional bicycles can regulate a constant speed more consistently than e-bikes, but the response of e-bikes to attractors' speed variations is swifter. The right chart in Figure 4 shows how the the speed variation of attractors due to traffic lights and stops is closer to e-bike's speed (Not counting the noise added at the end of the route due to issues in the experimental apparatus).

One participant did a test following only the auditory cues with surprisingly good results (time to attractor 55s and 77% of the time within the group scope). However, the participant reported problems distinguishing between the rhythmic patterns and suggested a change in the timbre of the sound.

4 CONCLUSIONS

This research proposes a B2I collaborative system of micromobility intended to contribute to the reduction of carbon emissions by switching car rides to micromobility rides. The system is based on the principle that *the more I ride with others, the better my riding experience and that of others.*

The preliminary results from this pilot test suggest that the prototype deploys and tracks urban attractors on pre-defined routes, and that cyclist can accurately follow acceleration cues presented on visual and audible displays. As a result cyclists gather around attractors within the first minute of travel and maintain the proximity to the attractor more than 85% of the route. There remains a need to conduct larger experiments in more realistic situations to statistically validate the hypothesis that the B2I system described here can congregate cyclists on urban streets.

The data collected in a larger version of this study will be used in an agent-based simulation to analyze what underlying behavioral dynamics correspond to the formation of convoys large enough to enable green waves of traffic lights and other services in a city scale, and what is the impact of forming these convoys on congestion and emissions.

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