Opportunistic sensing to improve bike road infrastructure

RWS group

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1. Context

Rijkswaterstaat from the Ministry of Infrastructure and the Environment is interested to investigate how citizens, for instance while cycling, can provide information about the infrastructure they are using without significant involvement and without increasing the risk of accidents. Given the current context of the Netherlands that indicates that 4 million citizens use smartphones while traveling and that 50% of Dutch bikers read social media messages while biking, one may take advantage of the sensing capabilities of smartphones while people are active on their bikes. The challenges are, on the one hand, to understand what is possible to infer about the infrastructure from using the sensing capabilities of a smartphone and, on the other hand, to design an app which is easy to use, doesn't endanger the user while biking, is appealing and engaging to employ and guarantees sufficient privacy to the end-user.

2. State of the art

The pervasiveness of smart devices has open a number of unprecedented opportunities for what falls under the name of *crowdsensing* [4]. Modern smartphones have a wide pletora of sensing interfaces which make interaction with the physical environment easy and information rich, for instance, a modern iPhone has: three-axis gyro, accelerometer, magnetometer, GPS, proximity sensor, ambient light sensor, two high resolution cameras, a microphone and high-frequency networking interfaces. These have been exploited for a number of pattern recognition taks, e.g. [3]. The specific issue of identifying the quality of bike paths using dedicated sensors on board of bicycles has been proposed in [1] while possible social interactions of bikers have been

investigated in [5]. In [2], the authors consider vehicle onboard sensing to measure road quality with dedicated solutions.

3. Problem definition

3.1. Infrastructure quality

One has to first define what are relevant parameters that influence the infrastructure quality, in our case, bike paths. The relevant elements appear to be, in order of relevance,

1. presence of major potholes or other large size obstacles
2. coarseness/smoothness of the biking surface (in relation to the material used to create the infrastructure and its age)
3. weather conditions (wetness, ice, snow, in particular)
4. path traffic
5. neighboring/interfering car traffic
6. quality of air (e.g., CO_2 levels)
7. illumination

3.2. Sensing

To measure the quality of the infrastructure just listed, we plan to consider using a smartphone. Precise design choices can be defined only after experimentation (see Pilot project section). We consider the following relevant assumptions/choices.

Position of the phone. Placing the phone on the frame of the bike or handle appears to make the sensing easier and more consistent across cyclist, though might be harder for the user to accept and will require extra equipment.

Accelerometer. This sensor is essential, but might not provide enough information.

GPS. Necessary for path tracking, reporting problems on specific location, report average speeds on given tracks.

Gyroscope. Very useful, especially if the phone is on the person and not on the bike. It may also help detect hazardous situations, such as the fall of the biker.

Light sensor. Might help in darkness conditions, if the phone is on the bike.

Magnetometer. Might help to detect the amount of surrounding cars.

Camera. Very useful, but putting too much computational and battery stress on the phone, therefore ignored in the following.

3.3. Distribution architecture: data management and privacy

There is an important issue on where the data processing occurs and where raw and inferred data is stored. Another related relevant problem is on when is data transferred from the mobile devices to the data aggregation points. We foresee a solution in which raw data is processed locally on the smartphone, inferred data is transmitted to the RWS servers when the user docks in his base station (e.g., work or home pc), unless a dangerous situation requires immediate data transmission (major infrastructure problem or accident to the cyclist). Also the storage of the data implies important privacy concerns. The sensed data includes highly sensitive information on the location and behaviors of the end user. Storing on the mobile phone is neither feasible nor useful. Storing centrally anonymously seems important, though not giving sufficient privacy guarantees. On the other hand, having user profiles related to sensed data, would highly increase the quality of the acquired data.

A possible high-level architectural overview of the system is presented in Figure 1. The smartphone (on the bottom-right) is responsible for the opportunistic sensing and user interaction, thus acquiring the raw data. The data is then processed on a base station (on the top-right), possibly in the control of the end user. Raw data is transformed into meaningful infrastructure events. The smartphone also has extra components which create added value for the end user and can help foster his adoption and usage of the app, namely, a routeplanner, a biometric "BikeKeeper" component for the tracking of physical activities, and so on. The events acquired by the individuals are then aggregated on the back end servers (on the left of the figure). The event and possibly raw sensor data are also correlated with relevant external information, such as that on the weather, from other sources monitoring the quality of the roads, such as Fietsersbond, etc.

3.4. User interaction

The user should minimize the interaction with the app. If the app provides extra features (e.g., traffic information, turn by turn routing, biomet-
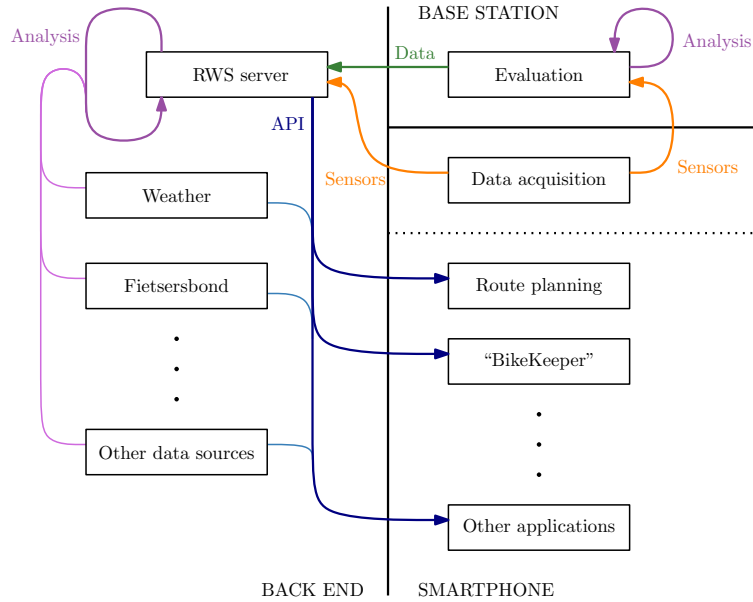
Figure 1: Architectural overview.

rics), these should be presented to the user without distracting him/her from the driving. The opportunistic sensing should be done in the background and user confirmation should occur as an ex post notification. For instance, when docking the user is prompted to confirm that a strong acceleration was related to a major pothole in the pavement.

3.5. Incentive scheme

One has to design an effective incentive scheme for the end user. Some will be willing to help the community independently of any personal advantage. We fear that though these kind of users will be a minority. Other incentives might come from the certainty that reporting infrastructural problems will improve a route that the user frequently follows. More short term high reward incentives, might come from having a free navigation and traffic information system be given "for free" with the infrastructure monitoring app. A quantitative study of what works is necessary to establish an effective marketing strategy for the app.

4. Scenarios of application

5. Pilot project to check feasibility

To come to a first design of a solution, we propose to run a pilot project to acquire evidence of what kind of sensing provides readings that correlate to infrastructure quality. The experiment will be designed in the following way.

Ground truth construction

1. RWS will provide a classification of infrastructure based on its known construction and aging qualities.
2. RWS will also provide a classification of faults that can be present in the infrastructure (e.g., pothole classification)
3. RWS will provide geographical indications of where an instance of each of the types of roads and faults are present in the infrastructure. These should be defined as stretches of about 50-100 meters. These should be geographically close to each
4. The research team will videorecord cyclist pedaling on such identified stretches.
5. The research team will manually annotate the videos indicating quality properties of the infrastructure. The annotations are then related to geographical location with an accuracy of at least 1 meter.

Sensor readings

The research team will perform sensor readings utilizing all sensors of a smartphone by running over the identified road stretches. For each stretch, at least 5 different configurations are used. Each configuration entails a unique type of bicycle and a unique user. Each test is repeated at least 6 times. 3 times with the phone attached in solid to the bike and 3 times with the phone on the user (pants, jacket, backpack).

Data Analysis

The research team will then analyse the acquired sensor data and compared it with the ground truth in order to find correlations between sensor readings and infrastructure qualities.

The end results of the pilot is to come to a preliminary conclusion of what are the possible sensor readings and bike-user configurations that allow an assessment of the infrastructure quality. It also allows to understand the volume and velocity of sensor produced data and types of data analysis necessary to transform raw data into events. This will allow to make a design that answers the first challenge of the project: that is opportunistic sensing. The next problem to then be addressed is the distributed architecture. Finally, having solved the data management issues, one can then move on to the second research question: user engagement and safety.

6. The way ahead

Give us a lot of money and we can solve anything.

References

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