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RESen: Sensing and Evaluating the Riding Experience based on Crowdsourcing by Smart Phones

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***Abstract*—Comfortable travel is an essential issue of Intelligent Transport Systems (ITS). However, the driver's behavior and the road condition affect the comfort of the passenger's riding experience while they are traveling. In this paper, we propose a system named Riding Experience Sensor (RESen) for sensing and evaluating the riding experience, based on crowdsourcing by smart phones. We utilize the acceleration sensor and gravity sensor for sensing with arbitrary orientations of smart phones. We partition the riding experience into horizontal and vertical for evaluation. Thus, based on the driver's historical trajectories, the system can provide feedbacks for improving driving by finding the anomalies along these trajectories. Based on the map, which has evaluated the comfort of each road, the system can provide a comfortable travel plan for query users.**

***Index Terms*—riding experience, participatory sensing, crowdsourcing, motion sensor.**

I. Introduction

Recently, the Intelligent Transport Systems (ITS) are getting increased attention from academic researchers and automotive industries, such as safety [1, 2], fuel-efficiency [3], and convenience (navigation) [4]. The comfort of rides has been identified as one of the top criteria affecting customers' satisfaction with public transportation systems; it has, thus, been shown that comfort is an important consideration for passengers that use public transportation [5]. Especially, some passengers (such as pregnant women, children and sick persons) need more comfortable riding experiences while traveling. The factors affecting the comfort of passenger's riding experience include: (1) individual factors, such as the driver's behavior or the condition of the vehicle; (2) the road conditions, which affect most of the vehicles moving on a given road.

In this paper, we propose a system named Riding Experience Sensor (RESen) for sensing and evaluating the riding experience, based on crowdsourcing by smart phones. With the help of participatory phone sensing, RESen harvests the riding experience while the vehicle is traveling, and it partitions the experience into horizontal and vertical. For adapting various placements for phones, RESen can sense the horizontal and vertical experiences with arbitrary orientation. Based on the participatory sensing data collection, RESen can evaluate the riding experience by three levels (trajectory, road, and driver). For a trajectory, RESen should provide the overall riding experience, including the anomalies along it. For a road, RESen will evaluate its riding experience, based on the trajectories which go through it. RESen can evaluate a driver by comparing the riding experiences of his trajectories, and those of the roads. Based on the evaluations, RESen cannot only improve the driver's behaviors, but also construct a comfort map for providing comfortable travel plans for query users.

The contributions of this work are the following:

1) From the view of passengers, we divide the riding experience into horizontal and vertical experiences. The horizontal experience may be affected by the driving (such as accelerating, braking and turning), and the vertical experience may be affected by the road condition (such as Pothole[7]).
2) Due to the various placements of the phone in the vehicle, RESen can sense the riding experience with arbitrary orientation of a smart phone, and divide the experience into horizontal and vertical.
3) Based on the participatory sensing data collection, RESen can construct a map with the way of crowdsourcing by evaluating the riding experience of each road. Thus, RESen can improve the driver's behavior or provide a comfortable travel plan for query users.

The remainder of this paper is organized as follows. Section II presents the related work. Section III presents the riding experience and the system design. Section IV presents the sensing and reputation in RESen. Section V presents the results from our evaluation study. We conclude in Section VI.

II. Related Work

RESen utilizes the participatory sensing data collection by smart phones for gathering the riding experience while the vehicle is traveling. Then, RESen evaluates the riding experience by way of crowdsourcing, in order to improve the driver's behavior and provide a comfortable travel plan for query users. In this section, we will introduce the related research areas, including participatory sensing data collection and crowdsourcing.

Participatory sensing data collection: The concept of participatory phone sensing has been implemented in a variety of real-world applications [5]. Authors in [7] investigate an application of mobile sensing: detecting and reporting the surface conditions of roads. They describe a system and

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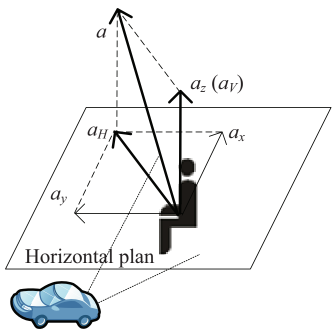


Fig. 1. The coordinate system for the passenger

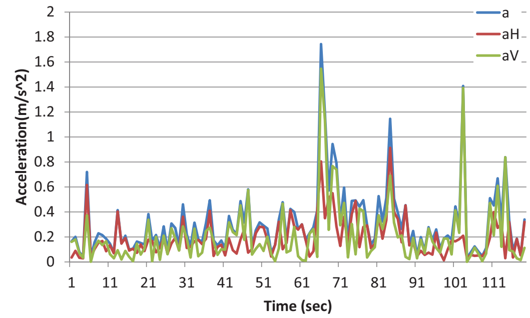


Fig. 2. Partition of acceleration

associated algorithms to monitor this civil infrastructure, using a collection of sensor-equipped vehicles. CenseMe [11] uses the microphone and accelerometer of smart phones to infer users' activities and social context. Meanwhile, SoundSense [12] employs machine learning techniques to classify both general sounds (e.g., music and voices), and to discover novel sound events specific to individual users in their daily lives. In [13], Azizyan and Choudhury propose using ambient information (e.g., camera, accelerometer, microphone and Wi-Fi) to classify the location of a mobile phone. Nericell [14] employs smart phones for rich monitoring of road and traffic conditions, via the sensors (GPS, accelerometer, microphone).

Crowdsourcing: Crowdsourcing is evolving as a distributed problem solving and business production model in recent years [15]. Crowdsourcing was proposed to reduce a company's production costs and make more efficient use of labor and resources [16]. An example of crowdsourcing tasks are seen in creative drawings, such as the Sheep Market [17], which is a web-based artwork implicating thousands of workers in the creation of a massive database of drawings. Authors in [18] design incentive mechanisms for mobile phone sensing. They consider two system models: the platform-centric model, where the platform provides a reward shared by participating users, and the user-centric model, where users have more control over the payment that they will receive. For indoor localization, the system Zee [19] makes the calibration zero-effort, by enabling training data to be crowdsourced without any explicit effort on the part of users.

III. Riding Experience and System Design

In this section, we will first present the riding experience, and then we will discuss the system design for sensing and evaluating the riding experience by a smart phone.

A. Riding Experience

According to ISO 2631-1-1997 [8], the evaluation for the total experience during the time T can be calculated as:

$$e(T) = \frac{1}{T}[\int_0^T a(t)^2\, dt]^{\frac{1}{2}} \tag{1}$$

Here, *a(t)* denotes the overall acceleration of the vehicle at the time *t*. As shown in Fig.1, the acceleration (*a*) can be divided into vertical acceleration (a_V) and horizontal acceleration (a_H).

$$a = \sqrt{a_H^2 + a_V^2} \tag{2}$$

Fig.2 shows an experiment for sensing the acceleration while the vehicle is traveling. We notice that the variations of the horizontal acceleration and the vertical acceleration are different, as are their contributions to the acceleration *a*.

Due to the affects of gravity, the passenger's riding experience can be divided into horizontal experience and vertical experience. The horizontal riding experience may be affected by the driver's behavior (such as avoiding an obstacle). The evaluation for the horizontal experience is:

$$e(T) = \frac{1}{T}[\int_0^T a_H(t)^2\, dt]^{\frac{1}{2}} \tag{3}$$

The vertical riding experience may be affected by the road surface (such as pothole [7]). The evaluation for the vertical experience is:

$$e(T) = \frac{1}{T}[\int_0^T a_V(t)^2\, dt]^{\frac{1}{2}} \tag{4}$$

B. System Design

For sensing and evaluating the riding experience, implement our self-developed system named Riding Experience Sensor (RESen). As shown in the Fig.3, the smart phone in the probe vehicle will gather the acceleration, and divide it into the horizontal and vertical accelerations. Then, it will construct them as the acceleration time series (ATS), and upload it to the back-end server.

For the back-end server, it will partition the ATS into several pieces of roads. Then, it will evaluate the experience of each road. If the experience is not abnormal, it will aggregate it to the comfort map for the query driver. If the majority of the experience is abnormal, it will also aggregate it to the comfort map for the query driver. If the minority of the experience is abnormal, it will build a recommendation of improved driving for the probe driver.

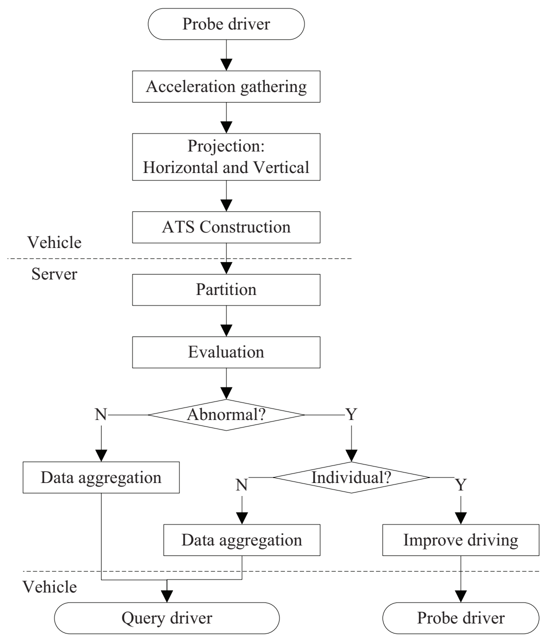


Fig. 3. System architecture

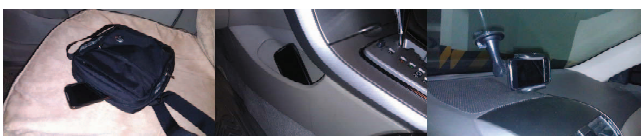


Fig. 4. Various placements for the phones

IV. Sensing and Evaluation

In this section, we will present the approach of sensing riding experience with arbitrary orientation, and then introduce the evaluation for the riding experience.

A. Sensing for the Arbitrary Orientation

As shown in Fig.4, the arbitrary placement of a phone causes its arbitrary orientation.

RESen senses the variation of accelerations by utilizing the gravity and linear acceleration sensors in a smart phone, listed in Table I [10].

TABLE I
Motion sensors used for sensing

Sensor	Sensor event data	Description
Gravity	values[0] (g_x)	Gravity along the x axis
	values[1] (g_y)	Gravity along the y axis
	values[2] (g_z)	Gravity along the z axis
Linear acceleration	values[0] (x_0)	Gravity along the x axis
	values[1] (y_0)	Gravity along the y axis
	values[2] (z_0)	Gravity along the z axis

By utilizing the 3-axis accelerometer and gravity sensors now available in most off-the-shelf smart phones, we obtain the vertical acceleration (a_V) and the horizontal acceleration (a_H). As shown in Fig.5, V denotes the vertical direction,

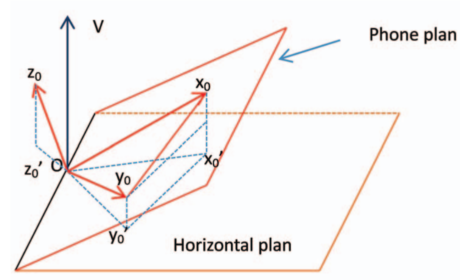


Fig. 5. Coordinate system

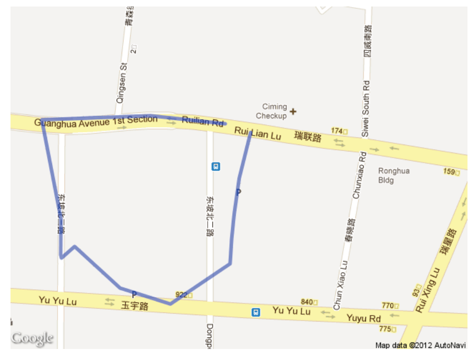


Fig. 6. Trajectory recorded by GPS on Google Map

which is opposite to the direction of gravity. For the acceleration (x_0, y_0, z_0) on the the coordinate of the smart phone, (x'_0, y'_0, z'_0) denote the projections for the three axes on the horizontal plan.

The overall acceleration can be calculated as:

$$a = \sqrt{x_0^2 + y_0^2 + z_0^2} \tag{5}$$

G denotes the acceleration of gravity. We denote the angles of the coordinate on the phone to the vertical direction as α_x, α_y, and α_z. The values of the gravity sensor on the three directions are denoted as g_x, g_y, and g_z. Therefore,

$$\alpha_x = arcos(g_x/G) \tag{6}$$

$$\alpha_y = arcos(g_y/G) \tag{7}$$

$$\alpha_z = arcos(g_z/G) \tag{8}$$

Thus, we can calculate the vertical acceleration as:

$$a_V = x_0 \cdot cos(\alpha_x) + y_0 \cdot cos(\alpha_y) + z_0 \cdot cos(\alpha_z) \tag{9}$$

With the help of Eq.6, Eq.7 and Eq.8, we can rewrite it as:

$$a_V = x_0 \cdot \frac{g_x}{G} + y_0 \cdot \frac{g_y}{G} + z_0 \cdot \frac{g_z}{G} \tag{10}$$

Therefore, we can obtain the horizontal acceleration as:

$$a_H = \sqrt{a^2 - a_V^2} \tag{11}$$

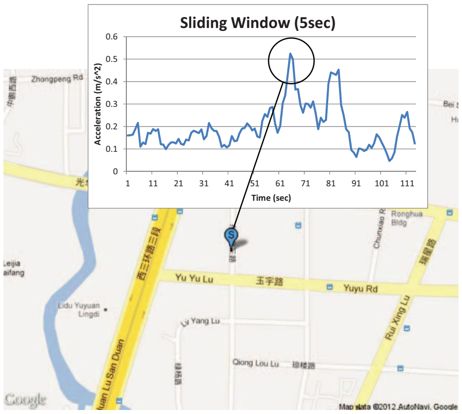


Fig. 7. Localization of the anomaly on Google Map

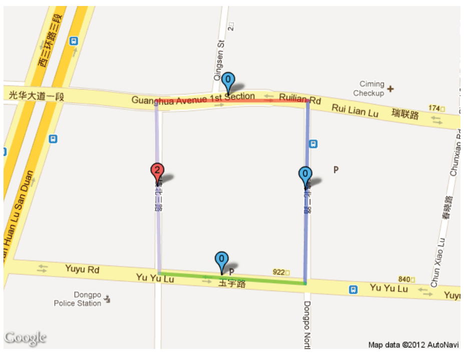


Fig. 8. The partitioned roads of the path

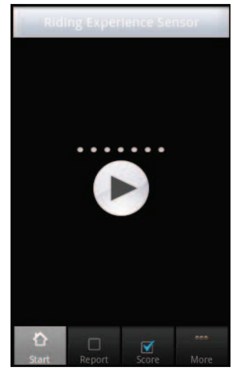


Fig. 9. The snapshot of RESen

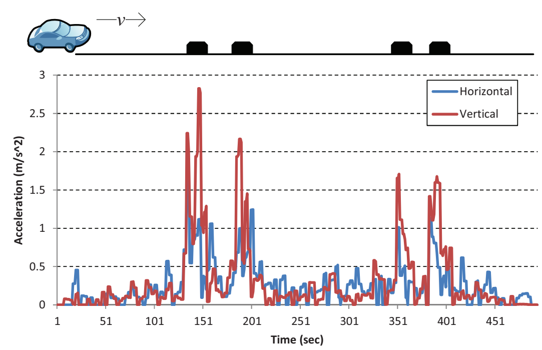


Fig. 10. The variation of acceleration while a vehicle moves on speed bumps

B. Evaluation

The driver's behavior and the road condition affect the passenger's comfort while they are traveling. By evaluating the riding experience, RESen should provide feedback for improving driver behavior, and for providing a comfortable travel plan for query user. RESen can evaluate the riding experience by three levels, including the trajectory, the road, and the driver. For a trajectory, RESen should provide the overall riding experience, as well as the anomalies along it. For a road, RESen will evaluate the riding experience on it, based on the trajectories which go through it. For a driver, RESen can evaluate him by comparison of the riding experiences of his trajectories and the roads.

1) Evaluation for a trajectory: For a trajectory as shown in Fig.6, which is gathered by GPS on a smart phone, we can find the position of the anomaly of a_H as shown in Fig.7; this is done by the way of sliding window with 5s width. The system will send the feedbacks to the driver.

2) Evaluation for a road: Reverse geocoding in Google Map provides a way to convert geographical coordinates (longitude, latitude) into street addresses, and forward geocoding provides a means to get geographical coordination from street addresses. With the help of reverse geocoding, we can partition the trajectory into several road sections, as shown in Fig.8.

The overall horizontal and vertical experiences of the vehicle k, moving on the road r_i , are denoted as $e_k(r_i)$, $e_{Hk}(r_i)$, and $e_{Vk}(r_i)$. Thus, we evaluate the experiences of the road r_i with m vehicles as:

$$E(r_i) = \frac{1}{m}\sum_{k=1}^{m} e_k(r_i) \tag{12}$$

$$E_H(r_i) = \frac{1}{m}\sum_{k=1}^{m} e_{Hk}(r_i) \tag{13}$$

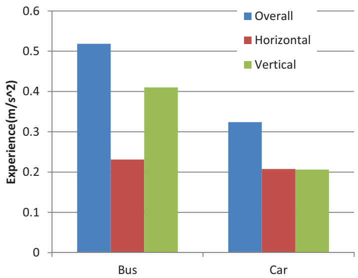
$$E_V(r_i) = \frac{1}{m}\sum_{k=1}^{m} e_{Vk}(r_i) \tag{14}$$

3) Evaluation for a vehicle: The trajectory of a vehicle k includes n roads. The evaluation for the vehicle k can be calculated as:

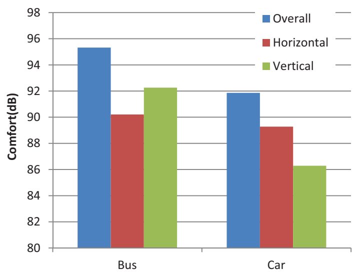
$$E_k = \frac{1}{n}\sum_{r_i \in trajectory} \frac{e_k(r_i)}{E(r_i)} \tag{15}$$

$$E_{Hk} = \frac{1}{n}\sum_{r_i \in trajectory} \frac{e_{Hk}(r_i)}{E_H(r_i)} \tag{16}$$

$$E_{Vk} = \frac{1}{n}\sum_{r_i \in trajectory} \frac{e_{Vk}(r_i)}{E_V(r_i)} \tag{17}$$



(a) Riding experience



(b) Comfort

Fig. 11. Comparison between bus and car

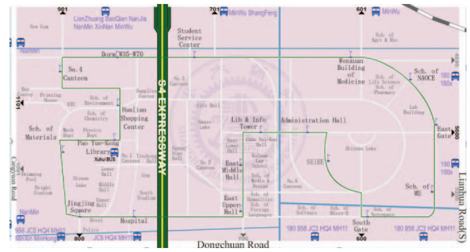


Fig. 12. The route of the campus bus

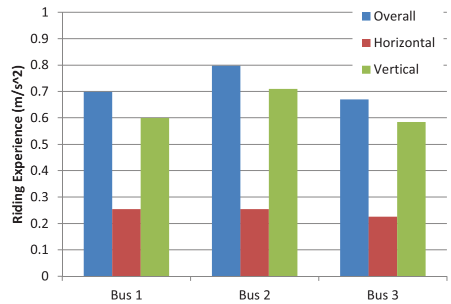


Fig. 13. Riding experiences of campus buses

4) The comfort level: According to ISO2631 [8, 5], we can calculate the weighted rootmean-square acceleration that is obtained by Eq.18 in meters per second squared (m/s^2) for translational vibration, where T is denoted as the duration of the measurement (in seconds).

$$a_w = \frac{1}{T}\{\int_0^T [1.4^2 a_H(t)^2 + a_V(t)^2]\, dt\}^{\frac{1}{2}} \tag{18}$$

$$a_{Hw} = \frac{1}{T}\{\int_0^T 1.4^2 a_H(t)^2\, dt\}^{\frac{1}{2}} \tag{19}$$

$$a_{Vw} = \frac{1}{T}\{\int_0^T a_V(t)^2\, dt\}^{\frac{1}{2}} \tag{20}$$

And we can calculate the acceleration level by [9]:

$$L = 20log\frac{a_w}{a_{ref}} \tag{21}$$

$$L_H = 20log\frac{a_{Hw}}{a_{ref}} \tag{22}$$

$$L_V = 20log\frac{a_{Vw}}{a_{ref}} \tag{23}$$

where a_{ref} is a normalization factor with a constant value equal to $10^{-5} m/sec^2$ [5].

V. Preliminary Results

In this section, we present the preliminary results of the proposed system. Fig.9 shows a snapshot of RESen on the smart phone. The sets of data were collected outdoors using Huawei C8650 with Android 2.3.

A. Horizontal vs. Vertical

Fig.10 shows the variation of accelerations while a vehicle is driven on the road with speed bumps. We notice that both of the horizontal and vertical accelerations are abnormal when the vehicle moved on the speed bumps.

Table II lists the average and standard deviation of accelerations, and the ratio of the vertical acceleration to the horizontal one. We notice that variation of vertical acceleration is more than the horizontal, which is affected by the speed bumps.

TABLE II
The comparison between horizontal and vertical accelerations

	Horizontal	Vertical	Ratio(V/H)
Average (m/s^2)	0.26	0.31	1.18
Standard deviation (m/s^2)	0.28	0.48	1.74

B. Car vs. Bus

Fig.11 shows the riding experience (Fig.11(a)) and the comfort (Fig.11(b)) between a bus and a car (Toyota Corolla) while they travel along the same road. We notice that the horizontal difference between the bus and the car is not obvious. However, the vertical difference between the bus and the car is distinct. This may be caused by the vehicular conditions.

C. Campus bus

We have evaluated the riding experiences with the same type of vehicles (the campus bus in Shanghai, Jiaotong University) which moved along the same route, as shown in Fig.12.

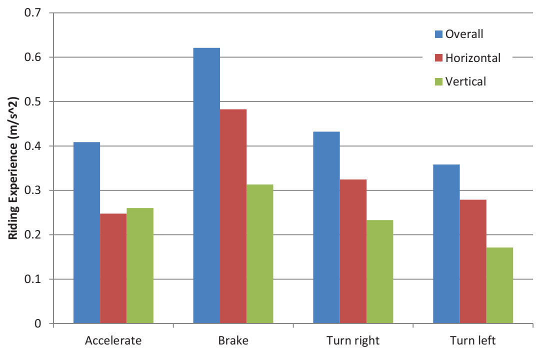


Fig. 14. Comparison among different driving styles

The riding experiences of the three campus buses are shown in Fig.13. We notice that even though the same type of buses move on the same route, their riding experiences are different. This may be caused by the drivers' behaviors.

D. Driving style

We evaluate the riding experiences under different driving styles, including accelerating, braking, turning right and turning left. The results are shown in Fig.14. The horizontal riding experience of braking (from 60km/h to 0km/h) is the highest, the same as the vertical and overall riding experiences. This is related to the safety issues of vehicles, because the braking is more urgent than other driving styles. We notice that the riding experiences of turning right are higher than turning left. This is because the radius of turning right is smaller than that of turning left. Moreover, we notice that higher horizontal riding experience may have higher vertical riding experience. This is because the higher horizontal riding experience may aggravate the vertical shake of the vehicle.

E. Summary

With the results, we notice that the riding experience can be affected by four factors: (1) Road condition, such as the speed bumps or pothole[7]; (2) Type of vehicle, the riding experiences under different types of vehicle may be different; (3) Driver, the behaviors of drivers may affect the riding experience on the vehicles; (4) Driving style, different driving styles may cause different riding experiences. On the other hand, the horizontal and vertical riding experiences affected by the four factors are different. For example, the horizontal experience may be affected by the behaviors of driving, and the vertical experience may be affected by the road surface or the damping system of the vehicle. However, the horizontal and vertical riding experiences influence on each other.

VI. Conclusion

In this paper, we propose a system named Riding Experience Sensor (RESen) for sensing and evaluating the riding experience, based on crowdsourcing by a smart phone. With the help of the acceleration sensor and gravity sensor in the smart phone, RESen can sense and partition the riding experience into horizontal and vertical, with arbitrary orientation of the smart phone. And then, RESen evaluates the riding experience by the way of crowdsourcing, in order to improve the driver's behavior and provide a comfortable travel plan for query users.

Acknowledgment

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