In vehicle passenger presence detection system

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Abstract— **Public transportation billing systems usually relay on different technologies ranging from mechanical systems, through magnetic cards to contact and contactless smart cards. This paper shows a possible solution that could be used to detect a moment when a passenger leaves a vehicle. The solution relays on data gathered from accelerometers in vehicle and passenger's mobile device, and in that way relieves the passenger from interaction with the billing system. Two approaches for comparison of gathered accelerometer data are considered. The first that compares series of accelerometer vector intensities and the second that compares acceleration gradient. The approaches are evaluated using newly developed system based on Android application.**

Index Terms—**Vehicle, Sensors, Android, Acceleration intensity, Transportation, Passengers**

I. Introduction

With the advancement of technology and especially the development of mobile devices, the ever more intimate connection between users and their devices grows with every new, innovative idea, with every imaginative practical application and through ever-changing diverse ecosystem of applications, services and ways of interaction. Possibilities are truly endless and our reliance on these devices in our daily lives has become undeniable.

Acceptance of new technologies depends on multiple factors such as levels of necessity, usability, and intuitiveness. One of everyday life necessity in large cities is usage of public transportation system. Operational cost of public transportation system is financed partially or in full by the passengers. In cases where payment depends on stations where a passenger entered and/or leaved the public transportation, there is a passenger validation process during which the passenger interacts with the payment system. The interaction can be classified as one of the following: interaction between passenger and driver, interaction between passenger and in-vehicle device, and interaction between passenger's device and in-vehicle device. Only the last class has potential not to require any passenger's action. However, currently, passenger validation process in majority of implemented systems requires passenger's action. This is not really a desirable approach, especially in a system that serves a large number of passengers - as it may be impossible to even get to a ticket validation device, due to e.g. rush hour crowding. The situation is even worse in systems that require two passenger's actions, one during entrance, and the other one during exit.

This paper presents a system for passenger presence detection for the purpose of payment in public transportation. Passenger presence detection could be considered as recognition of the moments when a passenger entered to and exited from a transportation vehicle. The system is based on mobile devices that most of passengers already owns. The idea is to have interaction between passenger's mobile device and in-vehicle device, while the action of the passenger is required only at a moment when the passenger enters, but not at a moment when the passenger exits. Thus, enabling a payment system that would charge a ride depending on both, entry and exit stations. Passenger presence detection is based on data gathered from acceleration sensors from passenger's device and in-vehicle device, and algorithm that compares gathered data in order to estimate similarity between their movements. Comparison is done using normalized values of acceleration vector intensities from both devices and determining whether those two intensities are the same or different at particular moment.

The rest of the paper is organized as follows: Section 2 presents a review of the existing solutions for billing in public transportation vehicles and an overview of possible usages of acceleration sensors in vehicles. Section 3 describes the proposed solution and considers two approaches. Section 4 evaluates the proposed solution by comparing results of both approaches. Section 5 concludes the paper.

II. Existing solutions

Classification of billing systems in public transportation could be done according to three classes of interaction between a passenger and a payment system as explained in the previous section. The first are billing systems based on interaction between passenger and driver that are slowest solutions due to completely manual operations and are not considered in this paper. The second are systems based on interaction between passenger and in-vehicle device that usually relay on mechanical devices for punching paper tickets or on usage of passive magnetic cards. The third are systems based on interaction between passenger's device and in-vehicle device that usually includes smart cards communicating with a device installed in transportation vehicle. The second and the third class of billing systems are considered in subsection A, while subsection B considers existing in-vehicle applications that similarly to the solution presented in this paper relay on data gathered from acceleration sensors.

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A. Billing systems

One of the basic issues in billing systems is a need to accept a large number of payments in short period. Some solutions try to perform the payment process before the ride, so that passengers should only show proof that the payment for the appropriate amount is made. Further optimization of the payment process went in the direction of reducing the number of employees engaged in the process, as well as speeding up and simplifying the process of payment from the perspective of passengers. Reducing the number of employees is achieved by introducing specific dedicated equipment in vehicles. Speeding up and simplifying the process from the perspective of passengers is achieved by the introduction of various forms of passive or active tickets paid in advance by passengers.

The simplest form of ticket is a passive paper ticket that is invalidated upon entering the vehicle, thereby a passenger formally exploits previously paid services. For example, a „Swiss Pass" in Switzerland is a paper ticket that provides a passenger with an option to travel the country using complete transportation system for a limited time. This ticket includes different types of transportation (bus, train, ship, tram) and it also includes numerous discounts for museums, events, cable cars, etc.

More advanced form of ticket is an active paper or plastic smart card with embedded chip that is necessary to put in or to bring close to the dedicated equipment in vehicles for ticket invalidation. In some systems, an active ticket is not a separate physical entity but is stored as appropriate information on a mobile phone, such as RFID (Radio Frequency Identification) or NFC (Near field communication). A brief overview of billing systems that use smart cards would include: Upass Card (Seoul, South Korea) in operation since 1996, that now relies on MiFARE (Philips Electronics) RFID technology; Octopus Card (Hong Kong, China) in operation since 1997, that now relies on NFC FeliCa (Sony) RFID technology; BusPlus Card (Belgrade, Serbia) in operation since 2011, that also relies on MiFARE/RFID technology; Compass Card (Vancouver, Canada) in operation since 2013, that includes an option to re-check the ticket on the way out, in order to be charged only for a section of the road that was being traveled.

B. Detection of user action based on acceleration sensor

From passenger's perspective, active tickets in some form of smart cards are practical and functional, but they require passenger action on enter and possibly on exit. It can happen that some passengers forget to perform some required actions or that are obstructed due to a large crowd in the vehicle. By automatically detecting the presence of passengers in the vehicle a passenger can freed from additional actions. One fact that can be used to detect a passenger presence in a vehicle is that the passenger and the vehicle are moving together synchronously. One possible solution of detecting presence is therefore to analyze movements of both the passenger and the vehicle through the time. Analysis of movements of an entity (e.g. passenger or vehicle) could be performed by using data gathered from acceleration sensor attached to the entity. Acceleration sensors are particularly suitable because of lower power consumption in comparison to the other sensors [1]. Some examples of the acceleration sensor used for the analysis of the passengers' actions are shown in the rest of this section.

The first example is detection of the vehicle type [2]. Vehicle type detection relies on comparison of acceleration sensor data with database samples. Due to usage of acceleration sensor only, the system has low power consumption and solid accuracy. However, system introduces latency in detection because of need to filter out sudden changes in signal introduced by user movement in vehicle and/or device orientation. System uses a mechanism for classifying between walking and other forms of movement. In the event where no movement is detected, the algorithm switches to stationary classification which tries to determine whether a user is in a vehicle or not. If motorized means of transport is detected, classification continues with mechanisms for sorting the type of motor vehicle.

The second example is system for detection of the usage of mobile devices by drivers [3]. System relies on centripetal force between two points in a vehicle - a driver and a passenger. Acceleration sensor is used in combination with gyroscope sensor. In case of a car that turns left, driver on left side of car experiences less centripetal acceleration than a passenger or the center of a vehicle. If the g-force of observable device has lower readings (of two devices/points in the vehicle) when turning left, and higher when turning right, the device belongs to a driver.

The third example is system for detection of traffic accidents [4]. Detection of an accident is achieved by sensing elevated g-forces. The system relies on acceleration sensor, compass and a GPS. Open source application (WreckWatch) records a route, speed, g-force and vehicle acceleration, up until the moment of accident. Because of constant GPS sampling, the power consumption of this application is very high. Moreover, the sensor reading starts only at speeds above 20 km/h to prevent false crash detection when user drops a mobile device during the ride, but can also fail to detect a collision when a parked vehicle get hit by a moving vehicle.

The fourth example is system for detection of driving under the influence of alcohol [5]. Detection of driving under the influence (DUI) of alcohol relies on acceleration and orientation sensors. Upon detection of DUI, by comparing patterns of stored DUI data with sensor readings, the device automatically notifies the driver or contact the police for assistance before an accident could occur. The algorithm relies on detection of abrupt changes in acceleration, sudden braking and turning with a wide radius. Test results show a high degree of precision and relatively low battery consumption.

The fifth example is fall detection system [6]. Fall detection system also relies on the acceleration sensor, and employs a neural network that learns and adapts to specific user's parameters, ie. user's height, weight or speed of movement. The system defines a fall as a force of acceleration above 3g, followed by a time period of 2500ms in which there is no acceleration above defined borders.

III. PROPOSED SOLUTION

New passenger validation solutions should be seamlessly integrated, lowering the time necessary for interaction with the system, limiting the potential abuse of the system, improving the overall service and reducing the financial costs on both sides – the users and service providers alike. By using a mobile device as a validation device and as a ticket at the same time, all previously mentioned goals can be achieved. The main idea is that the validation process, while passengers are entering a vehicle, relies on direct communication between a mobile device and a server, over GPRS/3G/4G network. Passenger - system interaction is still necessary, but the point of contact with a system is shifted to passenger's mobile devices. Validation, in this version of the system, can be carried out by entering an appropriate vehicle identification number, through the use of accompanying mobile application (Android, iOS, or some other platform). To detect the moment when a passenger leaves a vehicle, the system would solely rely on acceleration sensors. With adequate algorithms, after successful detection, system would automatically charge a user for the section traveled (for which a passenger was present in a vehicle). An important requirement for the system is to prevent monitoring of the behavior of passengers in and out of the vehicle, but just detect moment and place of entry and exit from the vehicle.

System use assumes normal passenger behavior in vehicles, such as the movement of passengers while driving, typing SMS messages, possible device drops, etc. Drastic and constant movements of passengers, such as shaking the device, jumping, running and others, are not covered by this solutions. Pocket or belt is assumed to be a default position for a device. To save battery life and to reduce CPU load, the solution considered here is the one that sends all data to a server for analysis and processing. For testing purposes, the algorithm is implemented on the server side application in PHP, which consumes date provided by client side application developed in Java for Android, as shown on Figure 1. The data is transmitted as JSON data-interchange format over GPRS/3G/4G network and stored in MySQL database.

Fig. 1. GUI of testing application

A. Approach 1

Potential approach for passenger presence detection problem is based on simple comparison of acceleration vector intensities for adequate points in time. Vector intensity values are calculated by subtracting measured acceleration vector intensity values (measured values) and offset value. Offset value represents measured value of the device at the time of a standstill. Initial offset is set to 0.35 in order to cancel gravity acceleration (g) and device offset, corresponding to low frequency filtering. Over time, tests proved that the best results are achieved when an offset value is calculated dynamically and when it follows the average measured value of the vehicle, corresponding to high frequency filtering.

Since sensor sensitivity varies widely within different devices (depending on the manufacturer and the model), initial calibration in form of removing offset is required. Moreover, during calculations normalized values are used, for devices used in approaches' evaluation acceleration intensity vector minimum and maximum were 0 and 30, respectively.

$$Normalized\ value = \frac{Current\ value\ -\ (Min.Value)}{(Max.Value) - (Min.Value)}$$

For a successful detection, the number of inputs (samples) per second should be as high as possible. These systems should be implemented with redundancy in mind, especially because of possible delays in communication with the server, data processing or the performance of mobile devices may affect proper functioning of the algorithm. Following algorithm delays were observed and measured in an Android application, sending JSON formated data:

- ~70 ms (Wi-Fi, localhost (XAMPP))
- ~500 ms (Wi-Fi ADSL, WebServer input)
- ~700 ms (GPRS, WebServer input)

Looking at the possible availability of different network connections the application can benefit from using the network connection with the lowest consumption [7]. The algorithm uses fixed and predefined number of acceleration vector intensity values for comparison. Two additional acceleration vector intensity values are also being used, one before and one after observed interval. The four vector intensity values are used to calculate the vector intensity value that will be used in comparison.

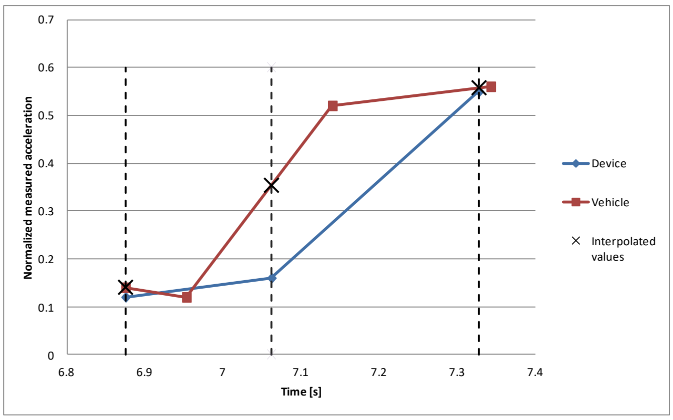

Fig. 2. Vehicle and device normalized accelerometer vector intensities values used for approach 1

Figure 2. represents chart of randomly selected segments of vehicle and device normalized measured acceleration vector intensity values. Comparison should be done for values with identical sampling times. It is assumed that clocks on device and vehicle are synchronized. As sampling moments on device and vehicle can differ, the interpolation can be used to calculate value of vehicle acceleration intensity corresponding to sampling time of device acceleration intensity. Table I shows calculation example related to vehicle's normalized measured acceleration vector intensity at the moment 7.062 (7 sec. 62 ms), related to the acceleration vector intensity of the device. Vehicle's interpolated measured normalized acceleration vector intensity at the moment is 0.35. Offset value corresponds to average vehicle normalized measured vector intensity is 0.33, (0.14+0.12+0.52+0.56)/4. Comparing vehicle and device vector intensity values at the moment 7.062, it is clearly a mismatch and device could be considered as outside of the vehicle. Number of mismatches during observation interval is stored in mismatch counter. In order to account for user's movement during a ride, certain number of value deviations from the exact match are allowed by defining a fixed number of permitted mismatches. The mismatch counter will be reset every time comparison result is not mismatch or exact match is encountered and the cycle repeats again.

TABLE I
INTERPOLATION EXAMPLE

	Value	Calculation
Increase value:	0.40	0.52 – 0.12
Total time:	187 ms	7.140 s – 6.953 s
Until the monitored point:	109 ms	7.062 s – 6.953 s
Percent:	0.58	109 ms / 187 ms
Increase:	0.23	0.58 * 0.40
Interpolated value:	0.35	0.12 + 0.23

Possible drawback of proposed approach 1 could be too much overlap between two independent measurements. When a user leaves a vehicle, the vehicle itself is in a standstill, and if user stops moving the mismatch counter will reset. After vehicle departure, a passenger and vehicle continue their respected movements independently from one another. Mismatch counter will then reset after every random vector intensity match. Although, passenger and vehicle vector intensities will eventually and inevitably mismatch, it is not clear when mismatch threshold will be reached. This uncertainty may lead to a situation where a passenger may be flagged as "in vehicle" which may then ripple further to a ticket charge evaluation problems.

B. *Approach 2*

Potential improvement over the previous approach is to compare acceleration gradient that is difference between two acceleration vector intensities. Compared to the initial algorithm, this modification relies entirely on the difference in intensity, without taking into account the previous parameters and possible extreme situations, such as dropping of mobile device or excessive user movement in a vehicle.

Tests have proved that the only condition for successful detection of passenger leaving a vehicle is that vehicle has small acceleration gradient (e.g. 0.007), as it is the situation in which the vehicle is stationary, while at the same time, device has acceleration gradient greater than 90% of the offset.

To make the comparison valid, similar to approach 1, interpolation has been used. Interpolation of vehicle vector intensities is identical to Table I. After the interpolation is done, acceleration gradient could be calculated for time interval, for both, a vehicle and a device. Comparing the acceleration gradient of a device and a vehicle, for the same time interval, provides the clear sign if the device is in the vehicle or not. Figure 3. shows the situation where the device is outside of the vehicle as it leaves the station and thus has 4.8 times lower acceleration gradient compared to the vehicle.

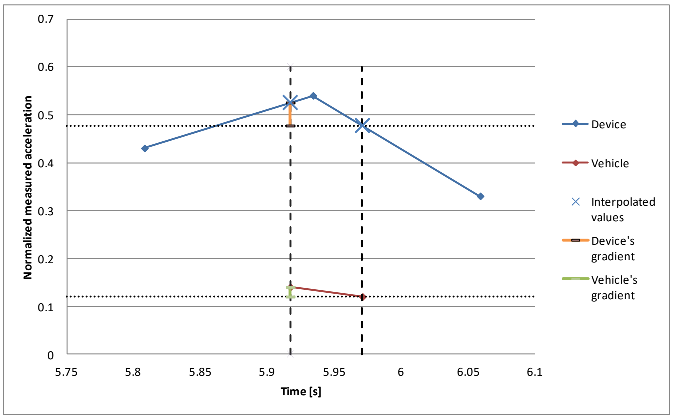

Fig. 3. Vehicle and device normalized measured acceleration vector gradients used for approach 2

Possible drawback of the approach 2 is evident in moments of a vehicle standstill at traffic lights or in traffic jams, when vehicle has small acceleration gradient, while device has intensive movement that leads the algorithm to the conclusion that the device is outside the vehicle. Moreover, in the event that the vehicle is sampled faster than the device, some significant changes in acceleration could be missed possibly resulting in comparison errors.

IV. Solution Evaluation

Data for evaluation purposes is collected through an android application and transferred to MySQL database. Behavior of vehicle and passenger is emulated with two mobile devices, ZTE Roamer and Samsung S3. Normal passenger behavior was assumed during test rides.

The procedure for recording test rides is executed as follows. The first phone, representing vehicle, was placed on a seat inside a vehicle upon entering, after which the recording process was started. The second phone, representing passenger's device, also began recording after the ride starts. It was assumed that a passenger keeps a phone in a pocket or on a belt with occasional shifts and changes in position. On a randomly selected station, the passenger holding the second phone gets out of the vehicle. Thereafter, optionally, the passenger remains standing in place or continues movement on foot. The first phone after few stations stops recording.

Random sample of test rides with exit detection latencies of both approaches are presented in Table II. False exit detection, that happened while device is still in a vehicle, is marked red (early). Undetected exit, meaning that exit is not detected until the end of sampled data, is marked yellow. Latencies of successfully detected exits are presented in cells marked green, given in seconds. Obtained results show that approach 2 has lower latencies in comparison to approach 1. Moreover, approach 2 has higher success rate and lower undetected exit rate, as shown in Figure 4.

TABLE II
EXIT DETECTION LATENCIES OF BOTH APPROACHES.

#	Drive start	Drive end	Ref. exit	App.1	App.2	Vehicle
1	17:50:21	17:53:20	17:52:13	+20 s	+1 s	bus
2	18:04:42	18:06:05	18:05:20	+34 s	+4 s	bus
3	18:14:42	18:17:27	18:15:28	+20 s	+6 s	bus
4	18:35:14	18:41:39	18:39:00	-	+23 s	tram
5	18:49:59	18:53:19	18:51:50	early	+1 s	tram
6	11:38:29	12:01:46	11:57:28	early	0 s	bus
7	11:38:56	12:01:54	11:57:28	early	+1 s	bus

Considering that the tests did not cover extreme situations while vehicle was moving, and that the passenger moved normally after leaving the vehicle, approach 2 successfully detected exit in the first 10 seconds. The assumption is that the passenger, during that time, generates enough acceleration vector values for the algorithm to detect a difference.

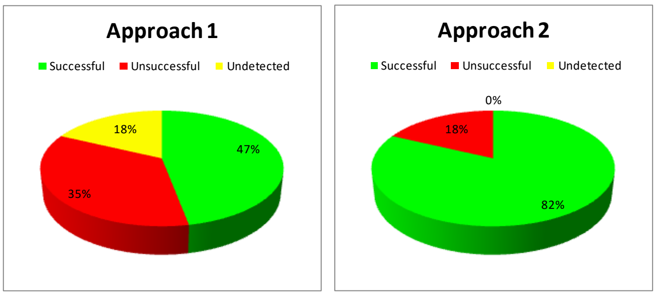

Fig. 4. Success rate of device exit detection

Conducted evaluation shows that false exits (unsuccessful and undetected exits) are more present in tram traffic than on buses. Current algorithm does not include identification of a type of vehicle in which a passenger is located. For example, due to drastically quieter ride and less vibrations in case of trams, parameters used in approaches (e.g. initial offset value, mismatch count threshold, number of samples) must be adapted for a type of vehicle.

V. CONCLUSION

There are numerous public transportation billing systems relaying on different technologies ranging from mechanical systems, through magnetic cards to contact and contactless smart cards. All systems could be classified based on interaction with a passenger as one of the following: person to person, person to machine, or machine to machine. Intention of this paper was to present a solution that could be utilized as a part of machine to machine billing system particularly dedicated to detection of a moment when a passenger leaves a vehicle. The solution relays on data gathered from accelerometer on vehicle and from passenger's mobile device. Particularly, two approaches for comparison of gathered accelerometer data are considered. The first approach compares series of accelerometer vector intensities at corresponding moments. The second approach compares acceleration gradient for corresponding time intervals.

The presented approaches were evaluated by using a newly developed system consisting of client side Android applications and server side application based on PHP/MySQL. The evaluation consisted of series of test rides designed to simulate normal passenger behavior in public transportation. The test rides encompass different types of vehicle, busses and trams. The results show that second approach gives up to 20 times lower latency and up to 75% higher success rate in passenger exit detection. Moreover, the results also show dependency between obtained success rate and type of vehicle.

Very important future improvement, besides detecting passenger exits, is the detection of passenger's entry without any interactions between the passenger and the system. Existence of a large number of factors that have to be considered for correct detection of passenger activities, such as oscillations of the vehicles, calibration of the devices, delays in communication with the server, motion and movement of passengers while driving indicates that a problem might be solved through the fusion of multiple sensors that would make it more precise and robust. Also, some attention should be given to synchronization of devices, the impact on battery life, as well as to the non-technical issues such as user privacy or potential abuses.

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