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Implementation of Participatory Sensing Approach in Mobile Vehicle Based Sensor Networks

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Abstract. In this paper author describes his research with the goal to develop and experimentally verify specific data recording and processing methodologies based on participatory sensing approach implementation in mobile vehicle based sensor networks. To reach this goal, author performed study of literature, testing of hypothesis using general purpose computer devices, adaptation of smartphones for participatory sensing, development of special purpose embedded devices, practical experiments with selected technical equipment and software as well as gathering of experimental results and following statistical analysis. The result of this research are several data acquisition and processing methodologies based on participatory sensing approach and mobile vehicle based sensor networks as well as evaluation of these methodologies.

Keywords: participatory sensing, mobile sensor networks, methodologies, microphones, accelerometers

1 Introduction

The modern world is characterized by the need to take more and more decisions. The decision would be more objective if it would be done based on appropriate amount of information. Further, the information can be obtained by collecting, combining and interpreting certain amount of data.

Decision-making can be based both on directly acquired operational data that describes current situation and indirectly acquired historical data that describes similar situations in the past. The usage of historical data in current decision-making process theoretically increases the possibility of more objective assessment of the situation and helps to take appropriate decision.

Humans' ability to process data and to make decisions without usage of additional technical solutions, unfortunately, has some limits determined by both the physiological characteristics and the amount of available data. Consequently, there is the possibility for the following improvements:

1. Collection and initial processing of operational data – in this case data volume for humans' interpretation is reduced;
2. Collection and storage of historical data – in this case the database for later analysis of the situation is created.

One of the possible solutions for these improvements is the usage of mobile sensor networks. To facilitate development of such networks, often already existing mobile objects, for example, vehicles travelling regular (De Zoysa et al., 2007) or irregular (Eriksson et al., 2008) routes are used for sensor deployment. At the time when research activities described in this paper were started, such networks were characterized by such aspects as specific hardware platforms, necessity for additional external sensors as well as transmission of collected data without initial processing. Therefore mentioned approach was potentially suitable for science oriented data recording and processing experiments.

Another solution for these improvements is the usage of participatory sensing approach characterized by interactive sensor networks formed by everyday mobile equipment and allowing collection, processing and sharing of environmental data (Burke et al., 2006). Significant aspects of such approach are general purpose hardware platforms, usage of available internal sensors, initial processing of collected data with the aim to reduce volume of transmitted data and therefore minimize expenses for maintaining of each separate data source as well as potential application for automatic execution of practically oriented tasks.

At the time when research activities described in this paper were started, such participatory sensing solutions were just emerging and their application was related to other domains but not mobile vehicle based sensor networks. Therefore it was decided to verify the possibility of combination of both mentioned approaches into one new approach.

The remainder of the paper is organized as follows. Section 2 discusses monitoring of road surface using mobile sensor networks with microphones. Section 3 introduces the application of smartphones with Android OS as alternative solution for the same task. Section 4 is dedicated to special purpose embedded device that implements both previous described methodologies. Section 5 reviews the main results of the research. In Section 6 the conclusion about possibilitty of mobile vehicle based sensor networks built as implementation of participatory sensing approach is given.

2 Monitoring of road surface using mobile sensor networks with microphones

The analysis of the road surface including damages of the road surface is important for road maintainers as well as for drivers. One of the options to collect such information is mobile vehicle based sensor networks.

The goal of this particular sub research was verifying of the possibility to collect the information about road surface and its damages using vehicles equipped with microphones for data collection, *Global Navigation Satellite System* (GNSS) devices for metadata collection, and general purpose mobile computer devices for data processing and storage. In the case of an affirmative result this approach could be extended using other sensors for detection of other events. During this sub research sound data recording and processing was performed using general purpose hardware and software as well as influence of particular data processing parameters on results of detection of road surface damages analyzed.

The result of this particular sub research is the methodology evaluated using 5 classes of typical road surface irregularities – big potholes, small potholes, pothole clusters, gaps and drain pits (Figure 1). The detection of previously marked road surface damages was performed using thresholding of sound data with different threshold levels from 15% to 90%. The results showed that such approach allows to detect up to 80% of pothole clusters, up to 90% of small potholes and virtually all big potholes.

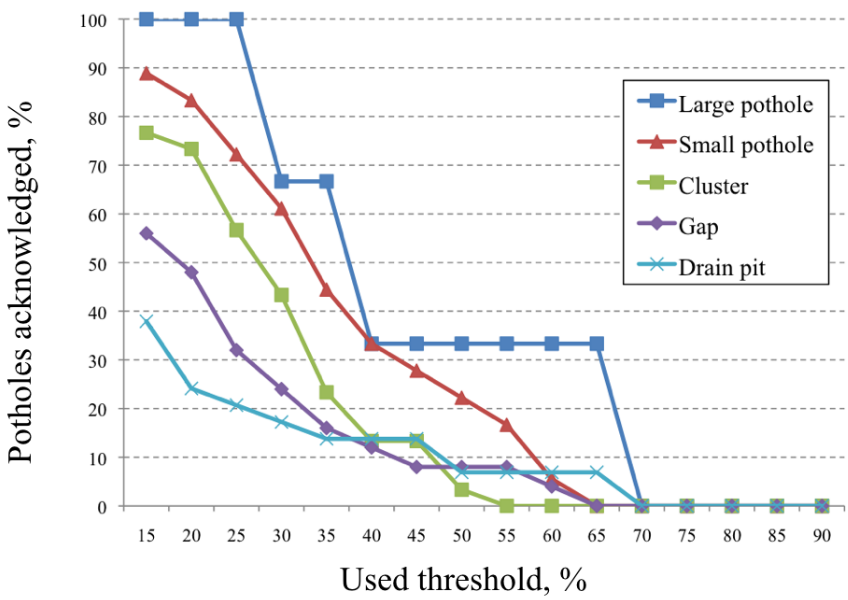

Fig. 1. Statistics of detected road surface damages based on analysis of recorded sound signals using different threshold levels (Mednis et.al., 2010)

Gaps and drain pits were detected less successfully (respectively, up to 60% and up to 40%), but these road surface irregularities only occassionally could be classified as real road surface damages. The acoustic background inside the vehicle has little effect on the application of methodology.

During this particular sub research following conclusion was drawn – the usage of relatively simple sensors and simple data processing methodology allows the collection of data with practical application that corresponds to implementation of particular sensing approach. Additionally this sub research encouraged the development of special purpose embedded device described in Section 4 of the paper. The detailed results of this particular sub research are published in (Mednis et al., 2010).

3 Monitoring of road surface using smartphones with accelerometers

The importance of the road infrastructure for the society could be compared with importance of blood vessels for humans. To ensure road surface quality it should be monitored continuously and repaired as necessary. The optimal distribution of resources for road repairs depends on the availability of comprehensive and objective real time data about the state of the roads. Participatory sensing is a promising approach for such data collection.

The goal of this particular sub research was development of a mobile solution for road surface monitoring based on vehicular sensor networks established through smartphones with internal accelerometers and Android operating system. During this sub research development of the data processing algorithms capable to operate using only resources available in smartphones, optimization of the parameters of algorithms, and evaluation of the algorithms using real world data collected using different smartphones was performed.

The results of this particular sub research are 4 accelerometer data processing algorithms Z-THRESH, Z-DIFF, STDEV(Z) un G-ZERO intended for usage in devices with limited hardware and software resources and capable to detect up to 90% of previously marked road surface damages (Table 1).

Table 1. Statistics of detected road surface damages based on analysis of accelerometer data using different algorithms (Mednis et al., 2011)

Road surface damage class	Z-THRESH	Z-DIFF	STDEV(Z)	G-ZERO
Big potholes	3 (100%)	3 (100%)	3 (100%)	3 (100%)
Small potholes	15 (83%)	16 (89%)	16 (89%)	14 (78%)
Pothole clusters	25 (83%)	27 (90%)	27 (90%)	27 (90%)
Gaps	31 (78%)	36 (90%)	30 (75%)	27 (68%)
Drain pits	10 (59%)	17 (100%)	11 (65%)	8 (47%)
Altogether	84 (78%)	99 (92%)	87 (81%)	79 (73%)

During this particular sub research following conclusion was drawn – smartphones as general purpose devices with internal sensors optimally meet requirements for implementation of participatory sensing but performance of developed algorithms is an affirmation for main research goal. The detailed results of this particular sub research are published in (Mednis et al., 2011).

4 Embedded device for road condition monitoring

Embedded device described in (Mednis et al., 2012) was developed with the aim to obtain the tool for road surface monitoring using microphone and accelerometers as well as collection of meteorological data that could be useful for creation of detailed road meteorological information maps. Mobile sensing platform in the form of an embedded device allows execution of larger experiments because it can be operatively deployed on different vehicles and therefore suitable for experiments without direct participation of scientific staff. Significant encouragement for development of this embedded device were previously developed road surface monitoring methodologies using general purpose computer devices and Android smartphones described in the Section 2 and Section 3 of the paper as well as the challenge to implement these methodologies in special purpose embedded device.

Embedded device (Figure 2) consists of the main module (A) – wireless sensor network node *Tmote Mini*, *Inertial Measurement Unit* (IMU) *Analog Combo Board*, sensors *SHT15* and *TEMT6000*, voltage regulators and *SD* memory card, as well as *Wi-Fi* (B), *Bluetooth* (C), microphone (D) un GNSS (E) add-on modules.

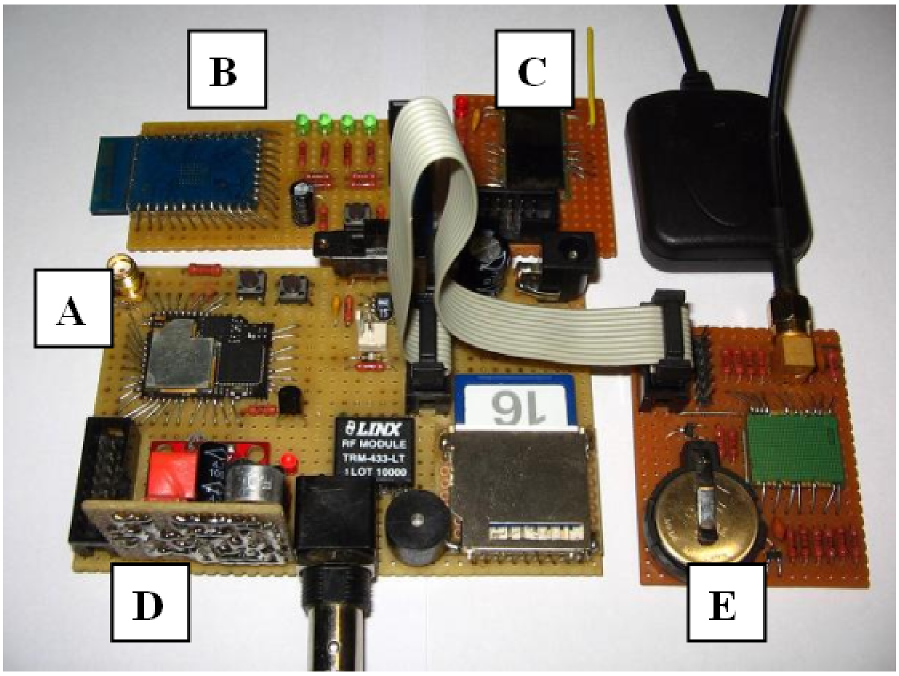

Fig. 2. The main module and add-on modules of developed embedded device

5 Results

Research activities carried out with the aim to verify the possibility of mobile vehicle based sensor networks built as implementation of participatory sensing approach and described in the thesis led to following results:

1. Verified what information about road surface and its damages can be collected using general purpose mobile computer devices and acoustic sensors. As a result, the methodology for road surface monitoring using mobile sensor networks with microphones was developed.
2. Verified what information about road surface and its damages can be collected using general purpose devices with internal sensors. As a result, the methodology for road surface monitoring using smartphones with accelerometers was developed.
3. Using as the basis developed methodologies, implementation of prototypes was performed.
4. Using as the basis developed prototypes, practical experiments in data collection and processing were carried out.
5. Using as the basis statistical analysis of the data collected during practical experiments, evaluation of the developed methodologies was performed.

6 Conclusion

The results of the research activities described in this paper led to the conclusion about possibility of mobile vehicle based sensor networks built as implementation of participatory sensing approach.

The title of this paper consists of two subjects – mobile vehicle based sensor networks as well as participatory sensing approach for data recording, initial processing, collection and storage. At the time of beginning of research activities it was found that there exist individual methodologies with individual attributes, for example, usage of mobile sensors for data collection, that allow to classify these methodologies as adjacent for usage in mobile vehicular sensor networks. At the same time implementation of these methodologies contained individual aspects that significantly limited or even made impossible their application in the context of participatory sensing, for example, specific hardware platforms, usage of external sensors and transmission of all collected data without the initial processing.

RoadMic and Potroid methodologies described in this paper are based on *general purpose hardware platforms* – PC and smartphones with Android OS, therefore the necessity for specific hardware platforms characteristic for BikeNet (Eisenman et al., 2007), BusNet (De Zoysa et al., 2007), Pothole Patrol (Eriksson et al., 2008) methodologies is eliminated. At the same time developed methodologies can be implemented in special purpose sensor node. The usage of simple *internal* sensors – microphone and accelerometer, allows to reduce the number of components necessary for the implementation of the methodology compared to BikeNet, BusNet, Pothole Patrol and Nericell (Mohan et al., 2008) methodologies where external sensors are used. Methodologies are oriented towards execution of a practical task – automatic monitoring of road surface that is out of scope of BikeNet and SoundSense (Lu et al., 2009) methodologies. Further, *locally* performed initial data processing allows reduction of transmitted data amount compared to BikeNet, BusNet and NTU (Tai et al., 2010) methodologies. Therefore RoadMic and Potroid methodologies described in this paper comply with initial statement, given in Section 1, about attributes characteristic for mobile vehicle based sensor networks built as implementation of participatory sensing approach. Detailed comparison of the methodologies by mentioned attributes is given in Table 2.

Table 2. Comparison of existing and developed mobile monitoring methodologies by their adequacy for particular application – road surface monitoring using mobile vehicle based sensor networks

Methodology	Hardware platform	Used sensor	Sensor placement	Data processing location	Application for road surface monitoring
BikeNet	sensor node[a] + smartphone[b]	microphone	external	remote	–
SoundSense	smartphone[c]	microphone	**internal**	**locally**	–
BusNet	sensor node[d]	accelerometer	external	remote	+
Pothole Patrol	embedded computer[e]	accelerometer	external	**locally**	+
Nericell	smartphone[f]	accelerometer	external	**locally**	+
NTU	smartphone[g]	accelerometer	**internal**	loc.+rem.	+
RoadMic	PC/special sensor node	microphone	**internal**	**locally**	+
Potroid	smartphone[h]/sp. sensor node	accelerometer	**internal**	**locally**	+

[a]Tmote Invent [b]Nokia N80 [c]Apple iPhone [d]Crossbow MICAz [e]Soekris 4801 [f]with Windows Mobile OS [g]HTC Diamond [h]with Android OS

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