Embedded Solution for Road Condition Monitoring Using Vehicular Sensor Networks

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***Abstract*—The advantages of vehicular sensor networks over common wireless sensor networks include the possibility to cover wide measurement area using relatively small number of sensor nodes as well as not so strong limitations according device dimensions, weight and power consumption. These attractive features are reason for expansion of vehicular sensor networks for various environmental monitoring tasks - from defects of road surface to air quality in urban areas.**

The contribution of this paper is a customized embedded device dedicated for monitoring of road surface using microphone and accelerometer sensors as well as collection of meteorogical data for creation of detailed road meteorology maps. Selected hardware and software aspects are discussed and the implementation of previously developed method for road surface monitoring using accelerometer data is presented.

***Index Terms*—road surface analysis, potholes, embedded device, vehicular sensor network**

I. Introduction

A sensor is a device used for the measurement of some physical quantity or physical state. Common result of this measurement is an analog signal that is converted to a digital signal using ADC and subsequently processed using some computing device. Typically there is a need to make measurements in several locations and therefore a number of sensors should be configured, deployed and serviced if necessary. This approach - usage of many static deployed sensors - has its drawbacks as sooner or later scalability and maintenance issues will arise. To overcome this problem a large number of static deployed sensors could be substituted by few mobile sensors. One type of objects that could be used as mobile sensor carriers are vehicles. Among the possibility to cover wide measurement area there are other advantages including energy utilization from sensor carrier as well as not so strong limitations according device dimensions, weight and power consumption.

There are several categories of data that could be acquired using vehicles as sensor carriers. First of them is data about vehicle itself, for example, driving speed and actual location. Next data source is vehicle driver characterized by its pulse and time of the reaction. Environment measurements could be collected, for example, data about acoustic noise and air pollution. Last but not least - vehicles are driving using specially deployed infrastructure including road surface, and regular monitoring of this infrastructure could help to optimize necessary maintenance works.

The main purpose of the CarMote embedded device described in this paper is monitoring of road surface using microphone and accelerometer sensors as well as collection of meteorogical data for creation of detailed road meteorology maps. This research was inspired by successful verification of previously developed methods for road surface monitoring using general purpose computing devices and Android smartphones as well as by challenging task - implementation of these methods using customized embedded device.

Related work is discussed in Section II. Requirements and assumptions are listed in Section III. Proposed customized embedded device hardware and software is described and analyzed in Section IV. The evaluation of the developed embedded device including successful test in acquiring of road surface data from accelerometer sensor is described in Section V. The final section presents the conclusion that the proposed customized embedded device allows the implementation of previously developed method for road surface monitoring using accelerometer data and therefore demonstrates the suitability of the device in the context of vehicular sensor networks.

II. Related Work

By our knowledge the term ”vehicular sensor networks” is introduced in 2006 when researchers from University of California and University of Bologna declared a new network paradigm - the use of vehicles as sensors [1]. This paradigm was characterized by high computation power and high storage space therefore potential costs for network deployment and maintenance could be relative high. As primary application of vehicular sensor network was declared urban monitoring, for example, imaging of streets, recognizing of license plates and diffusing of relevant notifications to drivers or police agents [2]. Other applications developed by other researchers include monitoring of infrastructure items as road surface [3], collection of real time vehicular parking information [4], measuring air quality in city areas [5] and mobile surveillance [6].

Among communication between vehicles (V2V or vehicle-to-vehicle) vehicular sensor networks could include communication between vehicles and Road Side Units (V2I or vehicle-to-infrastructure) [7] [8]. In this case, as the number of network nodes could be very large, an effective identity verification should be ensured [9]. In the contrast of traditional wireless sensor networks where network nodes are placed in static locations vehicular sensor networks are characterized by dynamic changes in network topology. Therefore best possible connectivity could be achieved using appropriate combinations of transmission time and transmission range [10]. Nevertheless data gathering using these dynamic networks and data muling and multi-hop forwarding strategies is supposed to have specific delays [11].

Our proposed CarMote embedded device assumes usage of relatively low computation power and low storage space that is characteristic for common wireless sensor network nodes. Combination of these aspects with vehicles as sensor carriers allows performing tasks where a large number of low cost deployed and maintained network nodes have advantages over a small number of high cost deployed and maintained network nodes.

III. Requirements

The following requirements were chosen as a basis for the development of the first prototype of the CarMote embedded device:

1) The hardware of the first prototype should be based on MCU that is inexpensive and relatively widespread used including applications in the domain of wireless sensor networks. Selection of an advanced MCU best suited for each possible application scenario is left for future work.
2) The sensing part of the first prototype should include microphone that allows implementation of the RoadMic approach [12], accelerometer that allows implementation of the Potroid approach [13] and a set of meteorogical sensors that allows making of experiments in creation of detailed road meteorology maps. There should be a possibility to add position metadata using GPS and a possibility to extend sensing part with other sensors in the future.
3) The power supply part of the first prototype should ensure the possibility to use electrical system of the vehicle as main power source and internal battery pack as alternatively power source with automatic switching between them. Implementation of internal battery charging as well as energy harvesting is left for future work.
4) The storage part of the first prototype should ensure the possibility to store acquired sensor data and corresponding position metadata on media that has a relatively widespread use and could be removed from the embedded device for data reading. Implementation of several supported media types as well as management of several media devices is left for future work.
5) The communication part of the first prototype should ensure the possibility to transmit acquired sensor data and corresponding position metadata using relatively widespread used communication standards. Usage of the communication part for other scenarios as investigation of the communication infrastructure is left for future work.
6) The software part of the first prototype should be based on operating system intended for usage in wireless sensor networks. The possibility to program several application scenarios without deep programming experience should be classified as advantage.

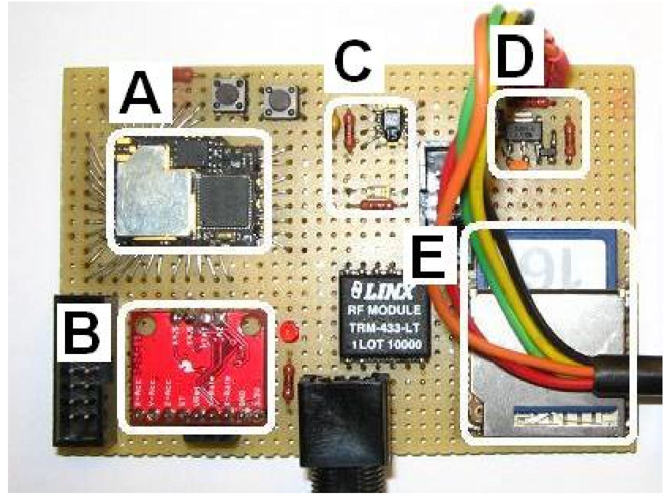

Fig. 1. The main board of the CarMote embedded device: A - TMote Mini wireless sensor network module, B - IMU Analog Combo Board, C - sensors SHT15 and TEMT6000, D - voltage regulators, E - SD flash memory card.

IV. Approach

The development of the first prototype of the CarMote embedded device was performed using as the basis the first version of LynxNet collar device developed during our past research activities related to wild animal monitoring using sensor networks [14]. This approach already fulfilled a part of previous set requirements. In addition, common hardware basis for both device types facilitates reusability of the software.

A. CarMote hardware design

The heart of the first prototype of the CarMote embedded device is TMote Mini wireless sensor network module (Fig. 1 - A). This module contains TI MCU MSP430F1611, TI/Chipcon transceiver CC2420 and ST EEPROM M25P80. The same MCU is used in other wireless sensor network modules, for example, EPIC [15], 3MATE! [16] and others. Selection of this popular MCU device allows to use the experience from previous developments as well as compatibility with available open source software.

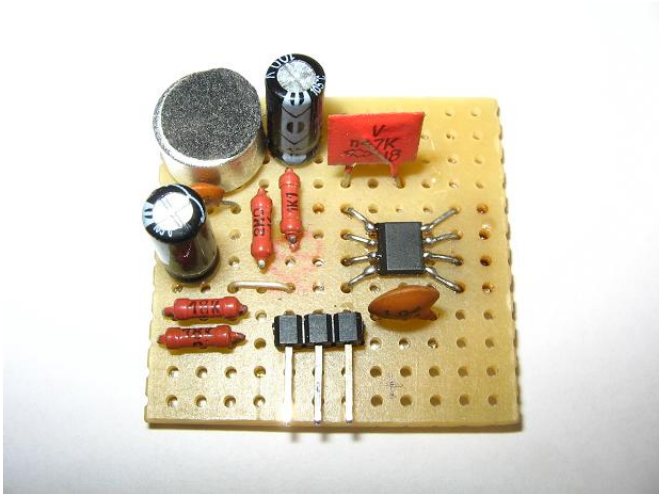

Fig. 2. The microphone board of the CarMote embedded device

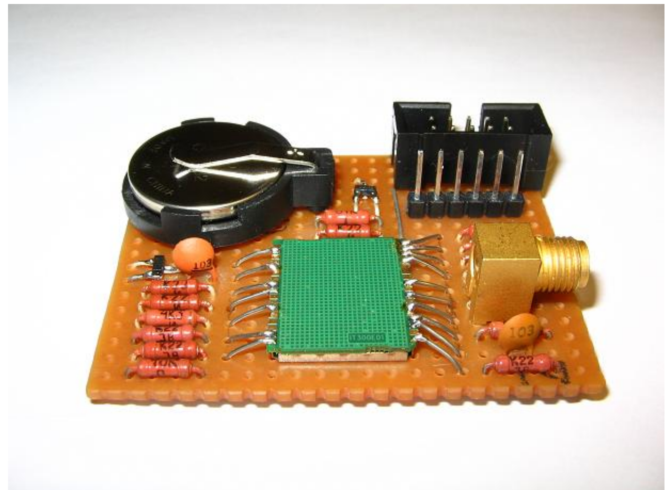

Fig. 3. The GPS board of the CarMote embedded device

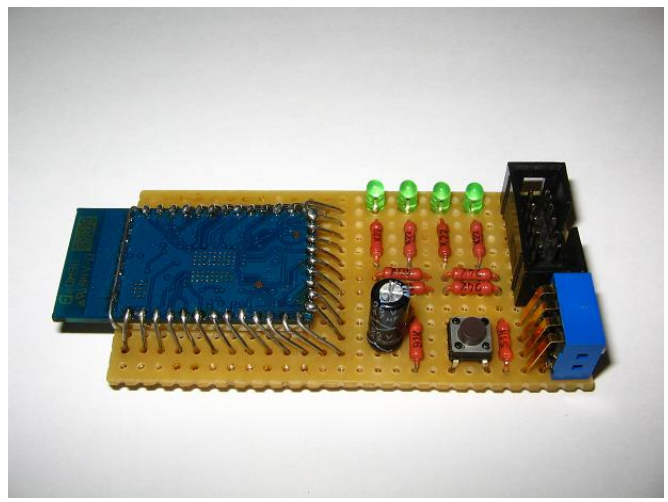

Fig. 4. The Wi-Fi board of the CarMote embedded device

To ensure the possibility of implementation of the RoadMic approach the main board was equipped with attachable board consisting of electret microphone BCM9765P-44 and corresponding amplifier stage built using operational amplifier TS952ID (Fig. 2). The output of the amplifier stage is connected to the ADC input #7 of the MCU.

To ensure the possibility of implementation of the Potroid approach the main board was equipped with IMU Analog Combo Board from SparkFun (Fig. 1 - B). This board contains triple axis accelerometer ADXL335 and dual-axis gyroscope IDG500. Outputs of accelerometer X, Y and Z axis are connected to the ADC inputs #0, #1 and #2, but outputs of gyroscope axis X and Y - to the ADC inputs #3 and #4 of the MCU.

To ensure the possibility of experiments in creation of detailed road meteorology maps the main board was equipped with humidity and temperature sensor SHT15 as well as light sensor TEMT6000 (Fig. 1 - C). First of them was connected to MCU using I2C interface, but second - using ADC input #5. Implementation of barometric pressure sensor SCP1000 is left for future work.

To ensure the possibility to add position metadata using GPS the main board was equipped with attachable board consisting of GPS module Fastrax IT300 (Fig. 3). This board ir connected to MCU using USART #0 interface and NMEA protocol. Operation of this board using SiRF protocol supported by Fastrax module is left for future work.

To ensure the possibility to use electrical system of the vehicle as main power source two sequential voltage regulators were used (Fig. 1 - D). First of them is dedicated to acquire 5V but second one - 3.3V. Four AA size battery pack is used as internal power source. Automatic switching between external power source and internal power source is ensured using low-loss Schottky diodes.

To ensure the possibility to store acquired sensor data and corresponding position metadata on media SD flash memory card was used (Fig. 1 - E). This removable media is connected to the MCU using SPI mode and respectively configured USART #1 interface.

To ensure the possibility to transmit acquired sensor data and corresponding position metadata two options were selected. First of them is Wi-Fi that could be used for medium range communication and the second one - Bluetooth that could be used for short range communication. Hardware for Wi-Fi communication was implemented as attachable board consisting of Roving Networks module RN-131C (Fig. 4) but hardware for Bluetooth communication - as attachable board consisting of Rayson module BT-220A2 (Fig. 5). Both attachable boards have serial interface for communication with MCU. During device prototyping stage just one module with serial interface (GPS, Wi-Fi, Bluetooth) is connected to MCU interface USART #0 at the time. Software driven multiplexer for commutation of several modules is left for future work.

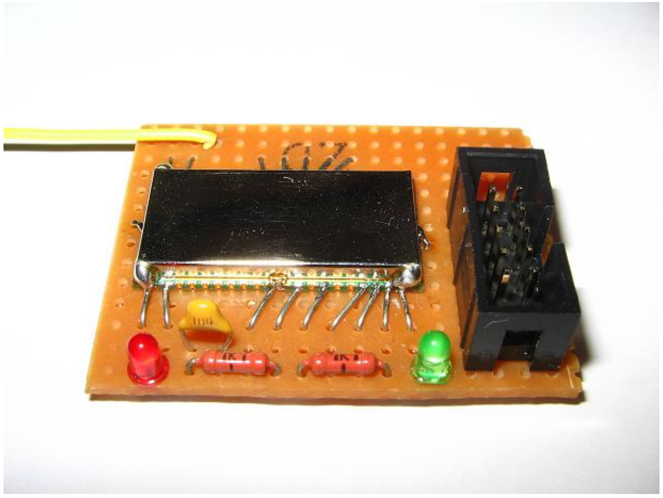

Fig. 5. The Bluetooth board of the CarMote embedded device

B. CarMote software design

In order to program CarMote, we have adapted MansOS operating system [17], a small and energy constrained device OS developed at the University of Latvia and Institute of Electronics and Computer Science (EDI). The OS aims to be user-friendly and easy to learn for individuals with C and UNIX programming experience.

The MCU of CarMote has a built-in 12-bit ADC. We sampled accelerometer's Z channel to evaluate the sampling speed. Sample rate 1820 samples per second (sps) was achieved without logging the data, and 1400 sps when logging the data to SD card. The rates are sufficient for the kind of applications CarMote was designed for, such as pothole detection.

An essential component of a highly mobile device is localization system. MansOS supports data interface with GPS devices, including NMEA[1] protocol parsing and online processing.

Last but not least, SD card support is included. It can be used either in *raw* mode, or by writing data to a filesystem. We have developed a custom filesystem to efficiently use local storage devices; although it is primary targeted for flash chips with no automatic rewrite options, it can be used for SD card as well. The FS provides buffering and automatic error detection features.

MansOS configuration system can enable these components when needed, or disable them to optimize compilation length. In either case, the system automatically detects when a component is not used and optimizes binary code by pruning unused components from the final executable.

A declarative scripting language called SEAL is available on top of MansOS. SEAL is targeted towards domain experts and novice progammers. SEAL features extremely concise syntax for describing common tasks: sensor sampling, data processing, and data communication. A few complete application examples are given in Listing 1 and Listing 2.

[1]www.gpsinformation.org/dale/nmea.htm

Listing 1 SEAL code for accelerometer sampling and measurement storing

```
// define sensors
define AccelX AnalogIn, channel 0;
define AccelY AnalogIn, channel 1;
define AccelZ AnalogIn, channel 2;
// sample the sensors
read AccelX; read AccelY; read AccelZ;
// store sampled data to SD card
output LocalStorage;
```

Listing 2 SEAL code for pothole detection with STDEV algorithm

```
// define sensors
const ACCEL_Z 2;
define AccelZ AnalogIn, channel ACCEL_Z;
define Deviation stdev(take(AccelZ, 10));
// when STDEV value exceeds threshold:
when Deviation > 100:
   // read the detection time
   read Uptime;
   // indicate a pothole presence via beep
   use Beeper, on, duration 200ms, frequency 1000;
end
// log the detection time to SD card
output LocalStorage (Uptime);
```

V. Evaluation

To evaluate the described CarMote embedded device the following set of the activities were performed:

1) test drive with Android smartphone HTC Desire and CarMote embedded device;
2) acquisition of the accelerometer data for pothole detection using Potroid approach;
3) comparative analysis of acquired accelerometer data.

Accelerometer data acquisition was performed 37 times per second using CarMote embedded device (Fig. 6) and 53 times per second using Android smartphone (Fig. 7). Analysis of the acquired data revealed that, taking into account slightly different positioning of both data collection devices, acquired data are practically identical and therefore data from CarMote embedded device are suitable for usage for pothole detection using Potroid approach. Relatively better sensitivity of the CarMote embedded device in the context of accelerometer Z axis value could be considered as advantage because this axis value is the most affected by potholes passed by vehicle.

Serious advantage of CarMote embedded device over Android smartphone equipped according Potroid approach and laptop computer equipped according RoadMic approach is the native possibility to use electrical system of the vehicle as main power source. In this case long term data acquisition and processing sessions are possible almost eliminating the hazard of empty internal power source.

VI. Conclusion and Future Work

This paper describes CarMote embedded device dedicated for monitoring of road surface using microphone and accelerometer sensors as well as collection of meteorological

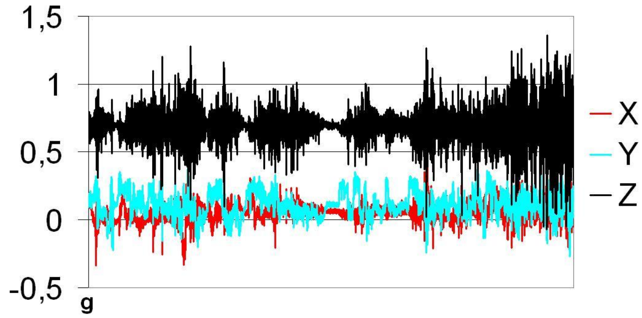

Fig. 6. Accelerometer data acquired using CarMote embedded device (a fragment, sampling rate 37 Hz)

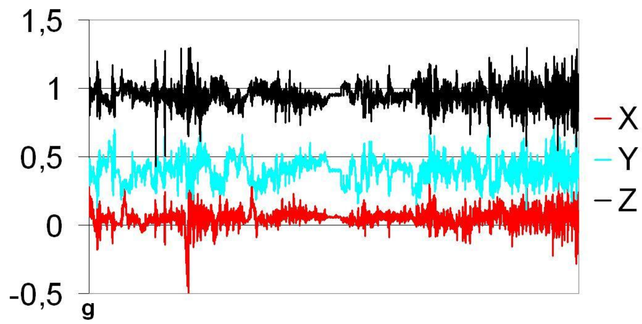

Fig. 7. Accelerometer data acquired using Android smartphone HTC Desire (a fragment, sampling rate 53 Hz)

data for creation of detailed road meteorology maps and its evaluation on a particular task - implementation of previously developed method for road surface monitoring using accelerometer data. The evaluation tests resulted in identical software operation and data acquisition in both hardware platforms - Android smartphone as well as CarMote embedded device. Therefore CarMote embedded device is suited for usage in vehicular sensor networks.

The future work includes development of the software for transmission of acquired sensor data and corresponding position metadata using Wi-Fi and Bluetooth as well as experiments in creation of detailed road meteorology maps.

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