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Faculty of Computing

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Object monitoring using low power consumption embedded devices and heterogeneous wireless sensor networks

Summary of Doctoral Thesis

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This thesis contains the introduction, 5 chapters, conclusion, reference list, 4 appendices.

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This thesis is accepted for the commencement of the degree of Doctor of Computer Science on August 31st, 2015 by the Doctoral Committee of Computer Science, University of Latvia.

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Abstract

Wireless sensor networks have become an integral part of the ubiquitous computing and the Internet of Things. During research has been developed and described general method for creating embedded sensor equipment. By applying it one can create tools for object monitoring and data collection using low-power embedded sensor equipment and heterogeneous wireless sensor networks. In the course of work the method was applied to create the tool package suitable for monitoring and determination of activities of wild animals, i.e., Eurasian lynxes (*Lynx lynx*) or Eurasian grey wolves (*Canis lupus lupus*). Some of work's hypotheses are evaluated and results are categorized by applying them to track participants of car orienteering events. As well some assumptions of research are evaluated based on data collection and exchange in monitoring of sites of future renewable energy plants. The results achieved by creating various usage embedded sensor devices shows that general method described in thesis is applicable.

Keywords

Wireless Sensor Networks, Object Monitoring, Wild Animals, Network Communication, Delay and Disruption Tolerant Networking.

Contents

General Description of the Thesis

The Doctoral Thesis sets the hypothesis that it is possible to describe a method of creating embedded sensor device based on externally provided preconditions and restrictions and with energy consumption, information processing and availability optimised for the particular purpose, where optimization is heuristic multicriteria based and optimum criteria value is based on expert's opinion. This means the development of energy efficient wireless sensor device that receives, collects and sends data by using heterogeneous wireless sensor networks with a delay and/or disruption tolerant networking.

The Thesis also defines the sub-hypothesis that the described method can be applied for the general monitoring model divided in four implementation complexity levels. The implementation complexity levels were developed on the basis of monitoring subjects which monitor and the objects being monitored and were grouped starting from most complicated to simplest. The most complicated stage refers to a monitoring subject in motion and an object being monitored in motion and the simplest stage refers to a static monitoring subject and a static object being monitored.

The author has described the created methods and tools for the monitoring of objects and data collection by using low energy consumption embedded equipment and heterogeneous wireless sensor networks.

The research provides the summary of existing solutions of wireless sensors as smart objects that can be located anywhere and with the help of which it is possible to collect information about the situation around and to deliver it to the end user. Within the summarised results the most successful results were achieved in the cases when created systems were simple from the point of view of both the use and the creation. The author in his Thesis also focuses on the creation of convenient and user-friendly solutions.

The topicality and novelty of the selected topic

Small-scale embedded sensor devices and wireless sensor networks are being increasingly used now. This is related to the fact that they can be comparatively easy and fast adjusted for various purposes. Researchers and business representatives use them for monitoring various environment aspects. Wireless sensor networks have become an indispensable part of the Ubiquitous Computing and the Internet of Things.

However, there are several challenges in the research and the development of wireless sensor networks - hardware design, radio communications quality, communications protocols, security, availability, operational stability, operational environment, development of applications, information processing, energy saving and provision, as well as others. Those challenges delay more comprehensive use of WSN on daily basis. Two major directions of research are the increase of the lifetime of sensor networks and the development of intellectual data collection systems.

The challenges above need to be taken into account when developing a new wireless sensor system suitable for monitoring. In the course of the research three most often encountered and most important challenges were identified, in particular - energy saving, information processing and availability. The combination of all the three challenges was also selected as the basis of the research of the Thesis for developing a method by which one can objectively assess which challenges are most important for the particular solution.

In order to test the practical application of the method, several approbation examples were implemented.

There is a topical trend to monitor wild animals within their natural habitat [1]. In cooperation with the researchers from LSFRI "Silava" a monitoring solution for wild Eurasian lynxes was developed. It was capable of autonomous operation for at least one year by collecting a broad set of data that can be timely delivered to researchers.

Gamification elements are involved in education and entertainment events worldwide increasingly often [2]. In cooperation with the organiser of various sports, education and entertainment events in Latvia, the Autoliste Society a concept solution was developed for the management of events by using software and embedded devices.

In order to carry out data exchange in sensor networks, usually various MAC protocols adapted for particular circumstances and application specific data exchange protocols above them are used. This creates issue for the connection of various networks because of non-uniform communication. Therefore IPv6 transport protocol with 6LoWPAN extension is proposed as suitable for applications and this would ensure that the sensor networks and their nodes are the ultimate Internet border. This would solve the mutual communication channels issue, however, the problem of which format should be used for presenting data would remain unsolved.

The idea of the semantic web and the presentation of data in a semantic way that would ensure more simple communication between various systems and equipment has been under development since the beginning of the 21st century. This created a challenge to develop a service-oriented architecture for wireless sensor networks that would combine 6LoWPAN and JSON in such a way that it is possible to have a direct access to sensor nodes without using special gateways while still maintaining low energy consumption.

The goal and tasks of the Thesis

The goal of the Doctoral Thesis is the development of a method applicable to creation of embedded sensor devices with energy consumption, information processing and availability optimised for the particular purpose.

The following tasks were defined for reaching the goal of the Thesis:

- To summarise the theoretical knowledge regarding existing technologies;
- To classify the degrees of complexity of the implementation of the general monitoring model;
- For each degree of complexity:
    - To design a wireless sensor system;
    - To create embedded sensor device;
    - To develop the system software;
    - To perform practical experiments for testing the operation of the system.

Scientific Methods used in the Thesis

During the development of the Thesis following methods were used: interviews with stakeholders were held and references were studied; hypothesis were tested by using broadly applicable computer hardware, ready made electronic components and embedded devices; special application embedded devices were developed; practical experiments with selected technological hardware and software were carried out; the results of the experiments were summarised and statistical analysis were performed.

Major results of the Thesis

The author in his Thesis has described methods and tools created for the monitoring of objects and data collection that uses low energy consumption embedded devices and heterogeneous wireless sensor networks. The methods and tools described were approbated in practice:

- The LynxNet system was created for wild animal monitoring [3];
- The system and tools were developed for the management of dynamic events with gamification elements [4];
- An experimental solution of road surface quality monitoring was created [5];
- An experimental solution for autonomous driving of a car within a cooperative driving scenario was developed [6];
- An environment conditions monitoring system for a fruit garden was developed [7];
- The service-oriented architecture WSN-SOA suitable for wireless sensor networks was created.

Scientific and Practical Significance of the Thesis

The research activities described in Chapters 3-5 were partially performed within the framework of "R&D Center for Smart Sensors and Networked Embedded Systems (VieSenTIS)" project supported by European Social Fund grant No. 2009/0219/1DP/1.1.1.2.0/09/APIA/VIAA/020, managed by *Dr.sc.comp.* Leo Selavo and fulfilled in Institute of Electronics and Computer Science, Riga, Latvia.

The research activities described in Chapter 4 were performed in cooperation with Autoliste Society located Riga, Latvia and managed by Mara Niedra.

The research activities described in Chapter 5 were partially performed within the framework of the research project of the University of Latvia No. 2010/ZP-204 "Cyber-physical infrastructure and modern computer technologies for study buildings" managed by *Dr.sc.comp.* Leo Selavo.

Publications of the Research Results

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14. ICDIPC 2012: The 2nd International Conference on Digital Information Processing and Communications (Klaipeda, Lithuania, 10.-12.07.2012). Artis Mednis, Reinholds Zviedris. RFID Communication: How Well Protected Against Reverse Engineering?

The volume and structure of the Thesis

The Thesis consists of 197 pages; there are also 70 figures, 13 tables and 4 annexes.

Chapter 1 describes a general model of object monitoring by explaining what wireless sensors and their networks are, what their possible applications, challenges and requirements are. The chapter describes the method that can be applied for developing embedded sensor devices suitable for particular monitoring purposes.

Chapter 2 provides a review on the materials and the methods used for research activities during the development of the Thesis. First, the applied computer hardware and software is described, further an insight of the applied ready-made and special embedded devices is provided. The chapter is concluded by the description of the methods used for testing the hypothesis.

Chapter 3 describes methods and tools for wild animals monitoring and identification of their activity by using embedded devices, wireless sensor networks and delay tolerant networking. A broad review of existing solutions is provided. The description of the created system follows containing the information regarding the system architecture, hardware and software developed. As various practical experiments were performed, these are also described. There are conclusions at the end of the chapter.

Chapter 4 describes heterogeneous tool kit for real-time edutainment. Autoliste Society that was interested in improving their organised events proposed the research. It was intended to improve technological aids of the events and provide the real-time reflection of the events to participants. Chapter reviews similar systems and tools. Chapter contains descriptions of system architecture, event management system and dynamic checkpoint embedded device. Next follows presentation of experiments performed and their results. The chapter ends with conclusions and plans for future.

Chapter 5 reviews developed web services architecture for low energy consumption wireless sensor networks. The topic of the research is justified by the necessity to have convenient access to the data collected by sensor nodes without using a special gateway from the Internet to the wireless sensor network. The existing solutions of web services and communication protocols have been studied that is followed by discussion on eventual solution. Finally, a set of embedded devices is developed by means of which the developed data exchange solution was tested in practice.

Summary of the Thesis

1. General model of object monitoring

1.1. What are wireless sensors and their networks?

The technological development of devices and wireless networking has created low cost, low energy consumption, miniature, multifunctional computerised embedded devices that serve as sensor nodes. Using them it is possible to cover a certain geographic region for performing the environment or object monitoring. They can communicate among themselves by using wireless communications and form wireless sensor networks (WSN) in this way. WSN provide access to information gathered virtually at any time and place by collecting, processing, analysing and disseminating data. Thus, WSN actually participates in the creation of smart environment. And according to the researchers [8] they have radically transformed the data collection in numerous fields.

The architecture of a sensor node is relatively simple – in a general it consists of five basic components: a microcontroller, sensors or actuators, external memory, a transceiver and a power source. Devices that have been prepared accordingly can be installed without additional external assistance and in most cases they do not require a specific infrastructure. They can sense, compute and respond accordingly to the physical environment around them and they can also organise themselves and adapt accordingly to support several applications.

1.2. WSN applications, challenges and requirements

WSN may consist of sensors of various types suitable for identifying seismic, magnetic, thermal, visual, infrared, acoustic or other activities and allowing monitoring a wide range of environment conditions.

The scope of application of WSN is very broad and various. Therefore researchers continue adapting sensor network technologies for the issues that are difficult to solve by traditional wireless networking methods.

Still there are quite a few challenges in the WSN research concerning the design of devices, radio communications quality, communication protocols, security, availability, operational stability, operational environment, development of applications, information processing, energy saving and provision. This hinders their more comprehensive use. Two major directions of research are the increase of the lifetime of sensor networks and the development of intellectual data collection systems.

Based on applications and challenges, the general WSN requirements were identified as follows: a high number of sensor nodes, low energy consumption, efficient use of small volume memory, data aggregation, the network self-organisation, common signal processing, requests of data sets.

1.3. Monitoring model

The research of the Thesis is based on the general model of monitoring (see Table 1.1.) divided in four levels of implementation complexity.

Implementation complexity level	**Subject of monitoring (Who?)**	**Object of monitoring (What?)**
1st	Mobile	Mobile
2nd	Mobile	Static
3rd	Static	Mobile
4th	Static	Static

Table 1.1.: General model of monitoring grouped by levels of implementation complexity.

The levels are established based on summarised general WSN challenges (see Table 1.2.). Based on the study of the research's related work, the author has assigned the weight of implementation complexity to each of the selected ten challenges. A coefficient is assigned to each model based on the importance of the particular challenge in its implementation. The multiplication of the weight and the coefficient produces the evaluation of the particular challenge for the particular model. The sum of the evaluation also determines the level of complexity.

For the most complicated implementation level a model where a mobile subject performs the monitoring of a mobile object is selected. This level has the highest evaluation of complexity because most challenges prevail there; i.e. quality of radio communications, implemented communications protocols, operational stability, information processing and energy saving. The monitoring of wild animals described in the Thesis applies to this implementation level.

The next model by complexity is where a mobile subject performs the monitoring of a static object. This level combines the following challenges:

Challenge	Weight	Models								Total
		M-M		M-S		S-M		S-S		
		C	V	C	V	C	V	C	V	
Hardware	1	0,5	0,5	0,5	0,5	0,75	0,75	0,75	0,75	2,5
Quality of radio communications	2	1	2	0,75	1,5	0,75	1,5	0,5	1	6
Communication protocols	2	1	2	0,75	1,5	0,75	1,5	0,25	0,5	5,5
Security	3	0,25	0,75	0,25	0,75	1	3	1	3	7,5
Availability	4	1	4	1	4	0,25	1	0,25	1	**10**
Operational stability	3	1	3	1	3	0,5	1,5	0,5	1,5	9
Operational environment	2	0,75	1,5	0,5	1	0,25	0,5	0	0	3
Application development	1	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,5	1,5
Information processing	4	1	4	0,75	3	0,5	2	0,5	2	**11**
Energy provisioning or harvesting	3	0,75	2,25	0,75	2,25	0,5	1,5	0,5	1,5	7,5
Energy saving	5	1	5	1	5	0,75	3,75	0,75	3,75	**17,5**
Total	**30**		**25,25**		**22,75**		**17,5**		**15,5**	

Table 1.2.: Assessment of WSN challenge complexity against realization of models where subject-object pairs means ”M” – ”Mobile” and ”S” – ”Static”, while ”C” means assigned coefficient and ”V” – it’s value.

availability, operational stability and energy saving. There are several more challenges with a high, but not prevailing coefficient.

The third model where a static subject monitors a mobile object follows. Only one challenge dominates on this level – security. However, several other challenges are close to maximum, i.e. hardware, quality of radio communications, communication protocols and energy saving.

The studies of heterogeneous toolkit for real-time edutainment described in the Thesis correspond to the second and third implementation levels. Also the monitoring of wild animals partially corresponds to third implementation level – base stations as static subject monitor wild animals as mobile objects.

Finally, the simplest implementation model is where a static subject monitors a static object. Just one challenge – security – dominates on this level similar to one level above. However, two more challenges are close to maximum, i.e. hardware and energy saving.

Embedded devices described in the Chapter 5 of the Thesis correspond to the third and forth implementation complexity levels.

1.4. General method of WSN device development

In order to develop the general method for the development of embedded sensor devices, the author used the summed overall model evaluations in the last column of the Table 1.2. as the basis. Thus, the list of WSN challenges arranged in the order of essential impact in various general monitoring models was obtained.

Based on the obtained results, three major challenges were selected. All of them have to be taken into account in the developed of new embedded sensor devices – energy saving, information processing and availability.

The energy saving of devices was selected with valid justification because mobile sensor devices have higher energy consumption needs and existing energy harvesting methods cannot provide enough long-term operation. This is proven by the analytical calculations of energy consumption of the solution adapted for monitoring of wild animals. Therefore devices need to be designed and applications for them need to be developed for ensuring maximum utilisation of the available energy.

Also information processing is among major challenges in the development of new embedded sensor devices. In case of monitoring, information collection, storage and transfer are an important part of research. Because in the result of monitoring a lot of minor information units from available sensors are collected and, prior to forwarding them, it is necessary to summarise and pre-process them, thus contributing to energy saving, i.e. by not operating the radio transmission without a reason.

Finally, the third major challenge that needs to be taken into account in the development of new embedded sensor devices is availability. Due to that this Thesis focus on the monitoring of wild animals, the availability is also understood as the end of mission and device retrieval protocol.

2. Materials and methods used

2.1. Hardware and software

All the tasks of research and software development activities of the Thesis were performed on an *Apple* computer with *MacOS X* operating system. For the certain tasks virtualisation solutions to run Ubuntu Linux and Microsoft Windows operating systems were used.

The embedded devices firmware was mainly developed by using *Arduino IDE*, *IAR Embedded Workbench for TI MSP430* and *Energia* tools.

2.2. Embedded devices

Most of embedded sensor devices implemented during research were created using ready-made development kits or sensor modules offered by electronics manufacturers. Some devices used were special embedded devices.

From ready-made kits mainly *Texas Instruments MSP430* microcontroller based and *Atmel megaAVR* microcontroller based *Arduino* development boards were used. *MSP430* is a series of mixed signals microcontrollers that are based on 16-bit central processor and suitable for embedded devices requiring low costs and low energy consumption. *Arduino* is a tool developed for the electronic hobbyists interested in easy prototyping of embedded devices. This is an open source platform consisting of simple *Atmel megaAVR* 8-bit microcontroller based boards and software development environment.

Tmote Sky and *Tmote Mini* sensor nodes and also *Telonics* VHF receiver should be mentioned among special embedded devices.

3. Wild animal monitoring using WSN

3.1. Introduction and motivation

Wild animals, in particular endangered species in a particular region or the ones requiring in-depth research, present an essential object of research for biologists.

The idea of the development of an embedded device suitable for the monitoring of wild animals was born thanks to the clearly defined requirement of biology researchers to study Eurasian lynx (*Lynx lynx*) as well as other wild animals in future, i.e. Eurasian grey wolf (*Canis lupus lupus*) or brown bear (*Ursus arctos*). The region of Latvia where the created embedded monitoring system will be used is Kemeri National Park.

The monitoring of wild animals includes the collection of information on the animal's behaviour in its natural habitat [1]. This information can be used both for scientific purposes and also for the maintenance of the species.

Primarily, the information regarding the location of an animal at particular points at particular time is collected. The next level is the information about physiological parameters being collected, i.e. heartbeat, body temperature, activity like hunting or sleeping.

At present there are numerous animal monitoring and tracking systems that use a GPS receiver and/or radio communications for transferring information. However often their functionality is restricted. This assured that a system capable of long-term operation and offering a broad range of possibilities should be developed. It also included the possibilities which are not available with the current tracking system of the particular type of animals or which are implemented on a low level, i.e. the identification of the animal's activity type (including the identification of individual movements).

In compliance with the recommendations by biologists, the minimum requirements of an embedded device were defined as follows:

- Animal tracing with accuracy $\leq$ 100m;
- Data collection for analysis with relatively low latency (weeks instead of years);
- Identification of the animal's activity type (hunting, sleeping, moving, etc.);
- Adaptation of the system duty cycle and accuracy depending on pre-defined or automatically set parameters.

During the study an embedded device and methods suitable for the monitoring of wild lynxes were developed.

3.2. Related work

During the research the existing solutions were reviewed in order to gain an overview of the methods that are globally used for animal tracking.

The most popular and most often used solutions were reviewed and analysed – *VHF* tracking, *ARGOS* satellite tracking, *GPS* tracking, as well as other solutions based on wireless sensor networking. Pros and cons of each solution were identified.

VHF and *ARGOS* tracking as well as tracking solutions of older implementations of *GPS* are not suitable for usage nowadays without serious modification. Newer *GPS* devices as well as sensor embedded devices provide more opportunities. However non-compliances with the set requirements were also found in them.

There were identified research and solutions of embedded devices and software which have provided essential contribution in animal monitoring or which use any of the author's selected components in applications similar to ones discussed in the Thesis.

3.3. Approach

3.3.1. System architecture

The proposed system architecture (see Figure 3.1.) is based on wireless sensor networking and its nodes characterised by mobile data collection and rare access to the network. The architecture offers an animal oriented paradigm where data collection takes place at the edge of Internet.

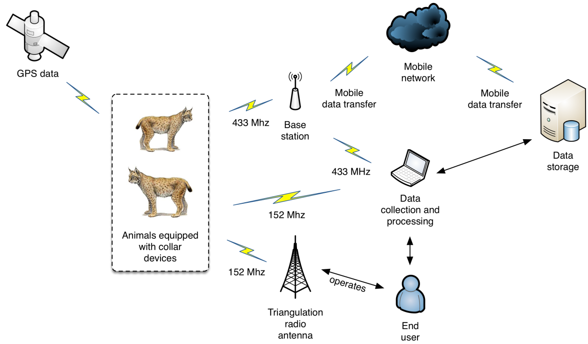

Figure 3.1.: System architecture of *LynxNet*

3.3.1.1. Principle of operation

The basic principle of operation of the system is the collection of data about an animal's habits in its natural habitat by using the sensors built-in the animal's collar.

The following basic data collection settings are defined - data from GPS, ambient temperature and relative humidity and ambient light sensors are collected once per hour, data with 20 Hz frequency from a 3D accelerometer, 3D gyroscope and 3D magnetometer are collected for 5 seconds every 5 minutes.

In cases when a device collects data over a longer time period, in addition to basic settings, a microcontroller listens to the interrupt created by the accelerometer, after which data with 20 Hz frequency from a 3D gyroscope and 3D accelerometer are collected for 30 seconds followed by a pause of 30 seconds.

3.3.1.2. Data exchange packages

The microcontroller of the *LynxNet* end device uses obtained data to form data exchange packages and store them in the internal memory. At the first opportunity based on the *LIFO* principle they are sent to the base station, or if several animals equipped with end devices participate in the system, the data are transmitted to the met animal.

The reading of each sensor is of a particular size that generally determines the size of each data package. As the activity data are read into series, their data exchange packages are formed in such a way that the first package would describe the series and each next package could be related with the particular series and would contain the data of a single measurement.

Two types of data exchange packages are distinguished:

- The location and the environmental data package containing the timestamp, the unique identifier of the device, information about the geographic longitude and latitude, GPS communications quality information, ambient temperature, relative humidity and ambient light intensity;
- The activity data packages series consist of two types of packages where the first package contains the timestamp, the unique identifier of the device, the unique identifier of the series and its size. Each measurements package of the series contains the unique identifier of the series, the unique identifier of the device, the unique identifier of the package, data from the 3D accelerometer, 3D gyroscope and 3D magnetometer that can be used for calculating the animal's motion vector.

3.3.2. Hardware

3.3.2.1. **LynxNet** *end devices*

Totally three *LynxNet* end device prototypes were developed and designed during research. Only two of them were implemented in practice.

Initial embedded device (see Figure 3.2.) was created based on the *Tmote Mini* wireless sensor node equipped with a *Texas Instruments MSP430F1611* microcontroller and a built-in *Texas Instruments CC2420* 2.4 GHz transceiver. In addition a *LINX TRM-433-LT* 433 MHz transceiver was added. Device was equipped with antenna that used ring-form directional operation diagram. A slightly modified *Qstarz GPS* device was used as a *GPS* receiver. For the purpose of measuring temperature and relative humidity a *Sensiron SHT15* sensor was used. For measuring the ambient light a *Vishay TEMT6000* light sensor was used. The 3.7 V voltage 1200 mAh capacity lithium ion battery powered the device.

The newest prototype's functional scheme is presented in Figure 3.3. It consists of the main module based on a *Texas Instruments CC430F6137* microcontroller with a built-in 433 MHz transceiver, and the emergency operation module based on a *Texas Instruments MSP430FR5737* microcontroller and a *Analog Devices ADF7012* transmitter for operation at 152 MHz frequency. In the development of the device's main module the focus was on ensuring that it is energy efficient. All its components uses digital interface that both allows simpler data collection and also reduces energy consumption. The following components are used: *u-blox MAX-7W GPS/GNSS* receiver; *Analog Devices ADXL345* 3 axis accelerometer; *InvenSense IMU-3000* 3 axis gyroscope; *Honeywell HMC5883L* 3 axis magnetometer; *Sensirion SHT21* relative humidity and temperature sensor; *Intersil ISL29003* light sensor. For the production device a *XENO XL-205F* D size lithium ion battery with 3.6 V voltage and 19.0 Ah capacity for each of modules are used. To improve battery productivity a *Panasonic EEC-RG0V105H* 1 F 3.6 V supercapacitor is used.

Figure 3.2.: Initial end device

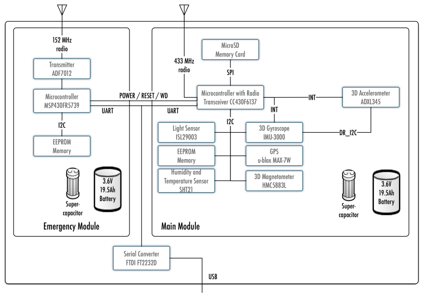

Figure 3.3.: Functional scheme of latest end device

3.3.2.2. **LynxNet *base station***

The base station consists of 4 main parts – a *Raspberry Pi* micro computer, a *Texas Instruments CC430F6137* microcontroller with a built-in 433 MHz transceiver based communication module, a mobile broadband data modem and a *Arduino Pro* based sleep controller.

A lead-acid battery with 12 V voltage and 19 Ah capacity is used as the power source for the base station.

3.3.3. Software

The device software is developed using *MansOS* [9]. The software of *LynxNet* devices introduced the following improvements in the *MansOS*

– access to the flash memory, drivers for relative humidity, temperature and light sensors, *GPS* readings analyser, *DCO* recalibration support, transceiver drivers, broader *MSP430* based microcontroller support, as well as a new *MAC* level communication protocol architecture.

3.4. Evaluation

3.4.1. Experimental setup

Experiments with the initial device were performed in July 2010 and a dog was used instead of a lynx. Comparative tests of a 433 MHz *LINX TRM-433-LT* and 2.4 GHz *Texas Instruments CC2420* transceivers were performed in Riga, Latvia at Rumbula airfield and in Sampeteris forest. In this way their performance were assessed both in a direct sight and in the environment close to the actual, i.e. a mixed deciduous forest.

Experiments with the newest equipment were performed at a laboratory.

3.4.2. Results

3.4.2.1. Tests of 433 MHz and 2.4 GHz transceivers

Both transceiver tests were conducted in similar way – the base station was located at a set place – it was either attached to a car parked in Rumbula airfield or to a tree trunk in Sampeteris forest.

An animal with an end device was moving away from the base station, and the tests of data packages receiving were performed after each 50 metres. The coordinates of the base station and measurement points were recorded by using a handheld *Garmin GPS* device. The results of the data transmission tests of the *TRM-433-LT* transceiver are summarised in Table 3.1.. In an audible form the 433 MHz signal was heard at a distance of up to 550 metres. The data transmission of the 2.4 GHz transceiver was capable of operating at a distance of up to 150 metres in a direct sight conditions and up to only 65 metres in forest conditions.

3.4.2.2. Tests of 433 MHz and 868 MHz transceivers

Tests with the transceiver built in a *TI CC430F6137* microcontroller were performed in laboratory conditions – first, by using the *TI EZ430-Chronos* development tool at 868 MHz frequency and after that – a module designed for a *EdiMote* device which initially operated at a 868 MHz frequency and later was transformed for operation at 433 MHz frequency.

Distance (m)	Received packages		RSSI level	
	Airfield	Forest	Airfield	Forest
50	80-100%	80-100%	2700	2800-3000
100	80%	80-100%	2200	2200-2500
150	80%	70-90%	1900-2000	2300
200	40-80%	10-50%	1600-1800	1600-1800
250	10-80%	20-50%	1600-1800	1600-1800

Table 3.1.: TRM-433-LT transceiver test results, where ”Airfield” – ”Rumbula airfield”, ”Forest” – ”Sampeteris forest” and max level of RSSI could reach 4095.

3.4.2.3. Tests of the 152 MHz VHF transmitter

First, the reverse engineering of an existing *Telonics VHF* device was performed and the accurate frequency of operation was established in laboratory conditions. Then a corresponding emergency module device operating at 152 MHz frequency was built and tests were performed in laboratory conditions.

3.4.2.4. Activity identification and detection tests

Initially the data were collected at a *5-DOF* level – from 2 axis accelerometer and 3 axis gyroscope. The collected data allowed partial identification of the animal's motion vector. As the first prototype had both restricted sensor resolution and restricted processing capacity, the data were processed on a computer.

Comprehensive *9-DOF* level activity identification and detection tests in the real life were not performed. They were only performed in laboratory conditions and with separate modules while adapting them for operation with *LynxNet* software. On the basis of the collected data, the animal's motion vector was simulated on the computer. The results are better than the ones from *5-DOF* level, however, the data from a *GPS* device are periodically required because otherwise the animal's actual motion vector does not correspond to the simulated one and essential adjustments are needed.

3.4.2.5. Analytical calculations of end device lifespan

All the calculations of the end device energy consumption are based on the data of all the three devices developed and their components obtained from data sheets. The consumed energy of all the components in calculations is based on the maximum value. It can be lower in practice. All the calculations take into account the planned duty cycle of devices and the self-discharge process of the used energy sources.

The results of the analytical calculations regarding the hourly energy consumption, total lifetime and collected information volume are presented in Table 3.2.

	1st prototype	**1.5th prototype**	**2nd prototype**
System's voltage:	3.3 V	3.0 V	3.0 V
Energy source:	1300 mAh @ 3.6 V	6800 mAh @ 3.75 V	19000 mAh @ 3.6 V
Operation	mA	mA	mA
MCU sleeps	0.058	0.116	0.113
MCU works	0.069	0.072	0.145
GPS	1.050	0.485	0.375
Activity sensors	0.026	0.026	0.220
Environment sensors	0.380	0.222	0.375
Radio RX	0.010	0.007	0.007
Radio TX @ 433 MHz	0.497 @ 9.77kbaud	0.188 @ 38.4kbaud	1.873 @ 38.4kbaud
SD card	0.058	0.057	0.067
Total per hour:	**2.175 mA**	**1.183 mA**	**3.201 mA**
Total hours:	**594**	**5443**	**5611**
Information volume:	**605 kB**	**7.9 MB**	**83.7 MB**

Table 3.2.: Analytic calculations of *LynxNet* end device lifespan.

3.4.2.6. Analytic calcultions of base station lifespan

Similarly to the end device the base station energy consumption is calculated analytically on the basis of the information available in technical documentation and the device duty cycle. The total hourly energy consumption of a micro computer, broadband modem and communications modem which all use the same power source amounts to approximately 27.34 mA at 5 V. The hourly energy consumption of a controller that has its own power source amounts to 1 mA at 3.3 V. The operation of more than one year can be ensured for both groups of devices with their designed power sources.

3.5. Conclusions

In total three *LynxNet* end device prototypes were developed. Each next one of them is more energy efficient and with a higher data collection resolution. The newest prototype developed is distinguished by both fast identification of an animal's location and by the fact that it's fully digital device. This has been achieved by using sensors that are equipped with digital interface. That allows placing them on a single bus, thus ensuring lower energy consumption. It should be admitted that due to increased data collection requirements the total energy consumption of the last prototype is higher than that of the preceding ones.

It should be noted that until now the last end device prototype has been distinguished against others by the fact that it supports the collection of activity data on *9-DOF* level, while the other solutions known to the author and used by biologists for the monitoring of wild animals do not provide more than *6-DOF* level.

The animal's end device is also equipped with a *VHF* transmitter that allows it's tracking in a traditional manner, i.e. by performing triangulation. As the *VHF* transmitted is driven by a separate emergency module it is possible to recover the device even if the device's main module is no longer operational.

The *LynxNet* base station module has been developed that ensures the data exchange with the end devices and performs data storage and transfer to biologists who can process it with a much less data latency compared with the other solutions used.

The results of the current experiments prove that the system is viable and can be used for monitoring of wild animals.

4. Heterogeneous Tool Kit for Real-Time Edutainment

4.1. Introduction and motivation

Nowadays digital technology is blending with our lives more and more including education and entertainment. Both fields quite frequently encounter situations when someone needs to control or coordinate tasks in different locations to be performed just in time, sometimes with limited resources in mind. There exist multiple ways with various levels of complexity how such issues can be solved. One of such ways is the application of gaming elements at education and entertainment events [2].

The history of sports, education and entertainment events related to orienteering dates back to the end of the 19th century when orienteering was a part of military training and only later became a type of sport available to general public. Initially only a map and a compass were needed for these activities to be able to orientate within an unknown area. Car orienteering is similar to the classic orienteering and initially originated from a rally where maps were used for finding one's way in an unknown area.

The Autoliste Society is among the pioneers of car orienteering in Latvia as it started organising such events as early as in 2001. As time passed by a necessity to organise technologically more complicated events comprising complicated tasks emerged. This in turn required more resources for their control and fast reflection of the results. Therefore requirements for a robust management and monitoring solution were defined – to develop a web-based application that would perform the user's interface and event management functions and a microcontroller based embedded device as a dynamic checkpoint.

During the research, a set of tools suitable for both education and entertainment has been gradually created and developed. All the developed tools are approbated in actual conditions at car orienteering events of various scope and specifics.

4.2. Related work

In the course of the research and development of a set of tools for edutainment, the related work in the field of both open-air and indoors game-based training was reviewed. Most of the existing studies were based on the principles that partially overlap with the ones described in the Thesis. However they were mostly intended for children's educational experience and not adults.

The common link for both the events organised by Autoliste and the ones referred to in other studies, is that they are based on a story line which links various sub-tasks into one big common task.

4.3. Approach

4.3.1. System architecture

The research performed is based on the system architecture presented in Figure 4.1. where the Event Management System (EMS) has central role.

4.3.1.1. Event Management System

Two goals were defined during development of the EMS – the reduction of the administrative tasks of organisers and the creating of dynamic environ-

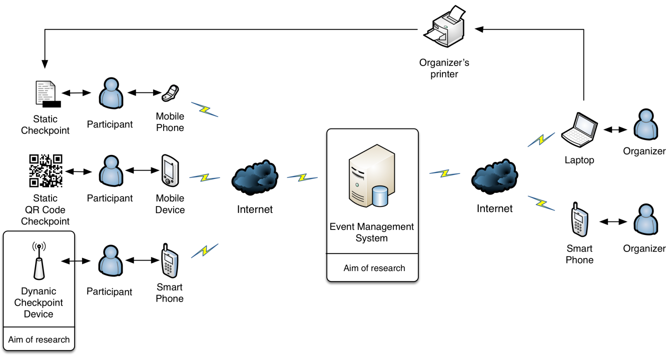

Figure 4.1.: System architecture of event management

ment for the event participants. The following additional non-functional requirements were defined: the system's users will use various mobile devices; it should be available upon request and without use of special equipment.

Following the requirements a web-based EMS was developed. This implementation covered most of the Internet connected mobile devices available for use.

The EMS comprises the following event organisation aspects: registration of participants and their activation for participation in the event; definition of tasks; management of the placement and activation of checkpoints; automatic or manual distribution of tasks to participants; tracking of the completion of tasks; evaluation of the results; *GPS* track analysis, traceable communication between organisers and participants of an event.

The definition of tasks and their evaluation is among the most important organisation aspects. This allows evaluating participants' contribution and calculation of end results. A task can be linked to a particular location and it can also be set available only within a particular time period or periods. At least one question and at least one answer with a defined value in points is linked with a task. Depending on the selected evaluation algorithm this score can be added to a participant's result. In order for a task to be deemed completed at least all its questions labelled as mandatory must be answered. The total score of a task within an event can be balanced by setting its coefficient.

The selected data structure of tasks together with the algorithms for evaluation of the different types of answers is sufficient for being able to define various types of tasks, i.e. the authorisation of an orienteering checkpoint by using the entry of a single code from a code sheet or a timed test – a task with a time restriction and the minimum number of answered questions.

The allocation of tasks to participants by means of a system allows accurate control over which tasks are available to them at what time period. This approach can provide benefits in organising dynamic events, i.e. by making a task available to a participant at a specific moment of time irrespective or his/ her location or by making a task available depending on achieved results or by allocating a task to a participant based on the total progress of the event.

In order to make the entry of data easier from mobile devices the system provides several entry methods – a selection of pre-defined answers, free entry of a text or scanning of a *QR* code.

Tracking the performance of tasks and the evaluation of results within the EMS takes place in real time. Automatic evaluation of results allows use of more complicated algorithms. Both results and participants' answers are immediately available to the event organisers allowing the monitoring of the course of action and by making adjustments when required. Depending on the event rules and the type of tasks these data can also be set available to the participants.

The evaluation of results can also comprise the *GPS* track analysis by uploading the file in *GPX* format to the EMS after finish of the event. The analysis of tracks can be performed taking into account the following aspects – the maximum speed (including the adjustment of eventual errors that can be caused by the equipment problems), the authorisation of checkpoints. The obtained *GPS* track data can be used for creation a visual presentation of the event.

Communication in EMS is implemented using traceable messages that can be sent individually or to a group.

Taking into account the developing trends of mobile devices and applications a new architecture of the EMS has been engineered where the main focus is shifted on mobile application as the system interface. The EMS per se provides the mutual data exchange between all the stakeholders and retains the feature for organisers to manage an event, ensure the registration of participants and other organisational tasks via it.

Based new design the applications suitable for *Apple iOS* and *Google Android* platforms will be developed. Smart phone applications will ensure the following functions - geolocation, the authorisation and management of checkpoints, augmented reality function and the exchange of messages.

4.3.1.2. Hardware

It was defined as a goal to design and develop device that would be with a simple end-user interface, non-expensive to create and to operate, as well with low energy consumption. Also technical requirements were defined – device should use Short Range Device (SRD) radio transmitter; it should operate on the basis of a pre-programmed list; it must have separate memory for data storage; have ability to operate in an autonomous mode without the replacement of batteries for minimum 350 hours.

The prototype of the dynamic checkpoint device (see Figure 4.2.) is based on a *Atmel ATmega328P* microcontroller with an external 8 MHz crystal oscillator. For upload of software and configuration the device communicates with a computer using serial port.

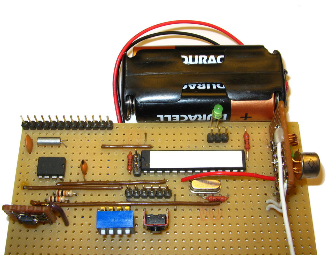

Figure 4.2.: Dynamic checkpoint device

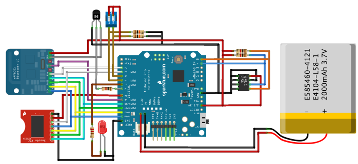

Figure 4.3.: Functional scheme of *Bluetooth 4.0* equipped device

For the user interface of the initial device an FM SRD radio transmitter was selected. Such design choice was made because corresponding receiver devices are widely available. Morse code was selected as the most appropriate data transmission type for this user interface.

To operate in compliance with pre-programmed list of actions embedded device uses built-in Real Time Clock (RTC) chip *NXP PCF8593P*. In order to have sufficient storage memory for storing content to be transmitted device is equipped with a *EEPROM* memory chip *Atmel AT24C64C*. The size of the *EEPROM* memory used in the particular prototype is 64 kilobytes. It allows storing of up to 2048 4 to 8 digits long checkpoint codes. Codes can be changed from 1 to 30 times per hour ensuring 68 up to 2048 hours of continuous operation upon the condition that the device is equipped with a sufficient capacity power source.

The energy consumption of dynamic checkpoint device is determined by the consumption of individual components and their duty cycles. Energy measurements are summarised and presented in Table 4.1. The analysis of this data revealed that by transmitting a 4 digits long code and sleeping for 8 seconds between two consecutive transmissions, the dynamic checkpoint device by using 2 AA type *Alkaline* batteries with the standard capacity of 2000 mAh can operate in an autonomous mode for up to 536 hours. In case of 8 digits long code transmission it can operate for up to 460 hours.

Mode	**Consumption, mW**
Device sleeps	0.89
Configuration mode (FM transmit off)	11.23
Device active (FM transmit on)	15.12

Table 4.1.: Energy consumption of dynamic checkpoint device in various modes

Latest version of the dynamic checkpoint device (see Figure 4.3.) is developed using ready-made modules. The *Arduino Pro* device is used as the main module. For communication with *Bluetooth 4.0* devices a *Bluefruit LE* module is used. In order to control time, the *DeadOn RTC* module is used. This RTC module was selected because it is more accurate than the one used before due to that it has a temperature compensated crystal oscillator and an backup 3 V battery for information retaining. For storing additional data and the configuration, similarly to the initial device, a *EEPROM* memory chip is used.

The software of the embedded device is developed in such a way that to operate it only a computer with a USB connection and serial terminal emulation program is required. All the configuration commands and their parameters are in numerical form and they all have a uniform format (4.1.) where A identifies a command, B – the first parameter of a command, C – the non-mandatory second parameter of a command, $*$ – the argument separator, and $\#$ – the end of a command.

$$A \, * \, B \, [\, * \, C \,] \, \# \qquad (4.1.)$$

The length of a command and parameters is only limited by the size of serial buffer of the *ATmega328P* microcontroller that is 128 bytes long. In case of most commands after processing of a command the embedded device returns message starting with the number of the command sent and followed by `OK` or `NOK` (*Not OK*), which are mutually separated by $*$ and line is terminated by `#`. The configuration mode may also be used for reading the parameter values stored in memory registers that ar located in the microcontroller's internal 1-kilobyte *EEPROM* memory. The reading of data takes place by using the same command format (4.1.).

4.4. Experiments and their results

The EMS has been tested in several events organised by the Autoliste Society, the association "CDT" and the "4x4 klubs" Society since May 2008.

The prototype of the dynamic checkpoint device was approbated in the event organised by the Autoliste Society in September 2011. 20 teams performed the tests with 2 to 6 participants per team.

Until June 2014 the set of heterogeneous tool kit for education and entertainment in real time was tested in action at 23 various events where 5 to 30 teams with 2 to 8 participants per team participated and they have included the following variations:

- One event with the dynamic checkpoint device and static checkpoints;
- Three events where only *QR* codes as checkpoints were used;
- Five events where participants' *GPS* tracks were evaluated;
- Two events where participants had to find and "catch" the organisers' car within the event region by following their online transmitted *GPS* coordinates. After "catching" of organisers participant received a task based on which one or several static checkpoints had to be found and the finding and "catching" of organisers had to be repeated again;
- Twelve events with only static checkpoints and other tasks, i.e. a timed test or a task controlled and evaluated by judges.

4.5. Conclusions

During the research experience was obtained in developing and testing a web-based application as well as the dynamic checkpoint embedded device with a RTC for accurate operation, extended memory for storing the information to be transmitted and the FM SRD transmitter for information transmission.

The main conclusion gained in the course of the development of the set of these tools is the correctly taken decision to focus on mobile solutions in the very beginning of the development. The current trends of devices becoming smaller and more powerful and the increase of their use just prove the correctness of this decision.

5. Web services in low power consumption WSNs

5.1. Introduction and motivation

Wireless sensor networks consist from some to up to several hundreds or thousands of sensor nodes that can be placed without a certain system and perform the physical or environmental monitoring. The data collected by them are usually transmitted to a central point that performs their collection, storage and/or further transfer. The data transmission is the one that usually causes the biggest issues – both from the point of view of energy consumption and the data exchange between two unlinked sensor networks. The last aspect is related to the fact that until now there is no uniform *de facto* standard for data exchange on wireless sensor networks [10].

Often communication within WSN is organised in the form of multi-hop transmission. In this way remote network nodes send data to the nodes located closer to the base station until it is reached. This approach is not efficient in cases when sensor nodes are not densely located. Due to the increased distance between nodes more energy is consumed for data transmission. Still, also within a very dense sensor network the nodes that are located closer to the base station will be forced to consume more energy just for relaying data from remote nodes, thus consuming their energy reserve faster.

As an alternative to the direct communication, there is an approach based on mobile sensor network nodes or ”data mules”. This approach ensures efficient data collection and transmission. A data mule is moving along a field of sensors by collecting data from met sensor nodes at the moment when the communication distance is optimal. Later all the collected data are transferred to the base station.

This caused the author’s interest to investigate this problem in depth and to find a possibility to decentralise communications within a sensor network. This can be done by adapting the service-oriented architecture to sensor networks and applying web technologies such as web services.

The author set the following requirements for web services in low power consumption wireless sensor networks:

- They have to use *6LoWPAN* [11] [12] and delay and/or disruption tolerant communication;
- Data exchange shall be based on the *RESTful* architecture;
- It shall have a session based ”store-and-forward” type user protocol;
- Data transfer shall be done by grouping the content in packages;
- It shall be possible to prioritise data packages.

5.2. Related work

The idea of a service-oriented architecture is not novel and it has been successfully used in the traditional computer science for several years. However, until now is has not been comprehensively implemented in the Internet of Things (IoT) environment.

In wireless sensor networks data exchange cannot be visualized without various MAC, transport and above them application specific data exchange protocols adapted for particular conditions. This is a major restriction for the connection of various networks because the communication is not uniform.

The chapter reviews existing solutions that are related to MAC and transport protocols, web services and delay and disruption tolerant networking used in wireless sensor networks.

5.3. Approach

The developed approach is based on web services that are a part of the service-oriented architecture. Approach is the *RESTful* architecture over the *HTTP* protocol and delay and/or disruption tolerant networking (DTN), which has been briefly defined by the author as *WSN-SOA*.

The author expects that on level of the embedded operating system operate an *WSN-SOA* module. Module actually is a miniature *HTTP* server that receives *REST* requests and sends information in response to them. The *6LoWPAN* is used as a transport protocol. Use of it determines that the sensor device is on the edge of the Internet. Taking into account the *6LoWPAN* specification there has to be a router in the wireless sensor network that would ensure the connection with the standard *IPv6* or *IPv4* networks and would perform the retransmission of data packages from and to the WSN. It should be noted that the *HTTP* application protocol, at least inside the sensor network, operates on the basis of the *UDP* and not the *TCP* transport protocol.

As the data exchange format within *WSN-SOA* the *JSON* is used. It's an open standard format that uses a text readable by people to transmit data objects consisting of attribute-value pairs.

5.4. Evaluation

5.4.1. System architecture

By choosing suitable architecture (see Figure 5.1.) for evaluating the advantages of *WSN-SOA* the author decided to stay with the one that can be found comparatively often in WSN and consists of two main elements - sensor nodes combined in a wireless sensor network and the edge router or the base station.

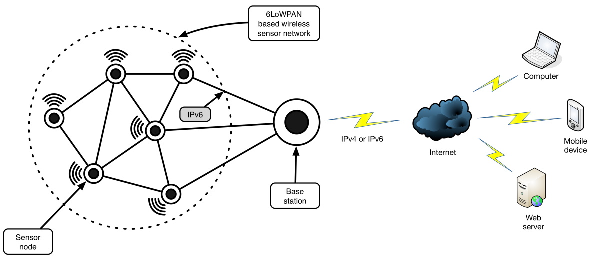

Figure 5.1.: *WSN-SOA* system architecture used in evaluation

Within the sensor network, the *IPv6* with *6LoWPAN* support is used as the transport protocol. The base station that communicates with the outside world using broadband Internet connection coordinates all the communications and data exchange.

5.4.2. Hardware

5.4.2.1. Sensor node

The sensor node (see Figure 5.2.) is intended for the monitoring of meteorological conditions by collecting data of the wind direction and strength, the solar energy amount and precipitation, relative humidity and temperature.

The device is based on a *Texas Instruments MSP430FR5379* microcontroller. In addition the following is used: *NXP PCF8593P* RTC microchip to synchronize data transmission; *24LC256 EEPROM* memory to store the configuration and data; *Amber Wireless AMB8420* 868 MHz transceiver for communications with the base station.

In order to collect data, external sensor modules are connected to the device - wind direction and strength sensors, precipitation sensor, relative humidity and temperature sensor.

The device gets energy from an autonomous power source (see Figure 5.3.).

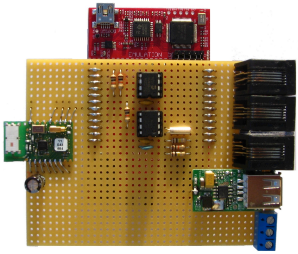

Figure 5.2.: Sensor node

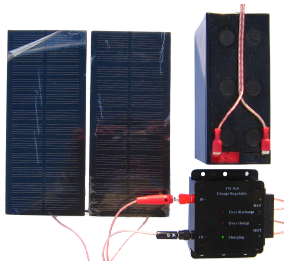

Figure 5.3.: Sensor node power block

5.4.2.2. Base station

The base station (see Figures 5.4. and 5.5.) is based on the *Raspberry Pi* micro computer that ensures both vast possibilities for data collection, storage and processing, and is small by size and sufficiently energy saving. When the Internet connection is added to the base station it becomes a comprehensive edge router.

In order to improve energy saving the *Arduino Pro* device in combination with the *NXP PCF8593P* RTC microchip is additionally used. It controls energy consumption and at the moments when the base station does not need to be operated switches it off by means of a relay built in the scheme. The *Arduino Pro* device operates on its own independent power source. The base station is operated from a 12 V sealed lead-acid battery.

For the communication with the sensor network, the base station uses a *Amber Wireless AMB8420* 868 MHz transceiver.

5.4.3. Software

Using the *Energia* development tool the initial version of the software intended for the sensor node was built. This allowed understanding the

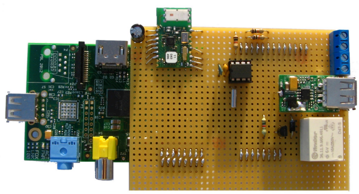

Figure 5.4.: Top side of base station

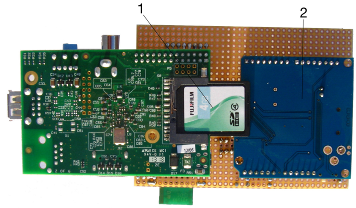

Figure 5.5.: Bottom side of base station

code volume for creating something similar, but more efficient with the help of MansOS [9].

The base station uses Linux distribution*Raspbian* as the operating system. The sensor network control software is written in *Python* and performs communication with sensor nodes via the connected transceiver, as well as collects information, forwards it to outside by using the Internet connection.

Taking into account that the *Raspberry Pi* cannot be easily put to sleep and later awaken, *Arduino Pro* is used as energy consumption controller managed by the software developed in the *Arduino IDE* environment.

5.4.4. Challenges

The extraction of data from sensor nodes is not always an easy task. They can be located at places that are not easily accessible. Therefore it creates several unique challenges. Also in case of *WSN-SOA* they have been encountered and this has allowed gaining a better understanding of eventual solutions summarised below:

- The miniaturisation of devices is essential because many systems are placed at restricted locations and they should not be disturbing;
- Energy management is essential for a long-term operation;
- The stability of radio communications cannot be successfully evaluated for humid locations with strong wind, which has a considerable impact upon the dissemination of radio waves;
- In order for a network to be more easily scalable, it is recommendable to use multiple base stations;
- For the systems located in isolated locates and where regular visits are not possible, remote access is essential;

- If it is planned to place sensor networks by teams who buy them as ready-made solutions, they have to become more easily installable, maintainable and understandable;
- The compatibility between ready-made modules, for example, GPS or weather stations, is very low and a separate code development is needed for each integrated module in practice;
- Security issues are important on all sensor network levels starting from the physical level up to the data protection against interfering.

5.5. Conclusions

Wireless sensor networks intended for the environment or object monitoring still present an exciting technical challenge.

The development of sustainable sensor devices for the natural environment is a difficult task. Communication technologies, energy management, placement, weather adjustments, stability, and remote diagnostics – all the above listed challenges are interesting from the point of view of research.

The developed approach is non-trivial based on the fact that for the purpose of achieving the desired result, the author has taken into account the limited resources of embedded sensor devices and the fact that until now nobody has developed and service-oriented architecture suitable for wireless sensor networks that would use the *UDP* protocol based *HTTP* server supporting *REST* requests and returning data in *JSON* format.

The main conclusion drawn from the research is that the combination of WSNs and their nodes with the semantic web is an essential link in the chain allowing to obtain globally accessible, usable information from non-processed data.

6. Conclusion

In the research the author has defined a thesis that it is possible to develop the general method for the development of embedded sensor devices. Based on the general monitoring model and 10 most essential challenges of WSNs it was developed. While developed method is valid, however, it is not possible to create it fully unique where the result would be definitely obtained by defining all the requirements.

During research four sub-models or implementation complexity levels that can be used in developing wireless sensor systems have been created. They have various subjects which monitor and objects being monitored pairs – ”mobile-mobile”, ”mobile-static”, ”static-mobile” and ”static-static”.

In case of a new application, first its compliance with the 10 most essential challenges of wireless sensor networks should be defined. Then it should be compared to the existing implementation complexity levels of the general monitoring model. Thus, it would be possible to evaluate the compliance of the application with any of them and to carry out adaptation if it is possible. In cases when complexity levels differ considerably, a new sub-model needs to be developed by adding it to the general monitoring model.

Both simplest implementation levels assert the defined thesis that based on one model it is possible to develop several mutually similar wireless sensor systems, i.e. the renewable energy resources monitoring system described in the Thesis and the fruit garden environment conditions monitoring system [7]. The base station for the wild animals monitoring and the dynamic checkpoint device for edutainment events both comply with the above statement and can be attributed to 3rd implementation complexity level.

The 2nd implementation complexity level also confirms the defined thesis. The example of the approbation of heterogeneous toolkit for real-time edutainment studies with the participants of car orienteering events who perform the monitoring of checkpoints by using smart phones proves it. Same applies to developed experimental solution for the registration of holes and other defects on the road [5] [13] [14].

The most complicated implementation level of the general monitoring model also confirms the defined thesis because the end device suitable for the monitoring of wild animals described in the Thesis and the developed experimental solution for the autonomous driving of a car in a cooperative driving scenario [6] complies to it.

Working on the development of embedded devices the author concludes that prior to the development of a sensor system careful planning needs to be done in order to understand in which monitoring model it will be included. This can be achieved by identifying as many as possible requirements and comparing them with technological possibilities and identified WSN challenges.

During the research the author has arrived at the conclusion that it is not important what particular data a sensor device collects. However, it is important how easy it is to achieve that the device works and collects data at all. Also the device interaction with a user is an essential fact – it has to be user friendly in order to be able to obtain collected data and to use them for processing and analysis in a non-complicated way.

Also the work at the development of software for embedded devices yielded conclusions – not always the tools intended for engineers can be used in daily situations or for fast prototyping, i.e. *Code Composer Studio* development environment. Instead of that, quite often and faster the author assured the correctness of set assumptions by using the open source projects, i.e. *Arduino IDE* or *Energia*.

There are still technological obstacles for developing sustainable embedded devices that would possess broad functionality and a power source of sufficient capacity and be small by size. However, thanks to the work by the engineers of *Texas Instruments* and other producers of microcontrollers, a new horizon has opened for the development of small scale and simple embedded systems powered by the energy obtained from the environment.

The newest end device suitable for the monitoring of wild animals supports the collection of activity data on *9-DOF* level, while the other solutions known to the author and used by biologists do not provide more than *6-DOF* level. The device is distinguished by both fast identification of the animal's location and by the fact that it's a fully digital device. Therefore lower energy consumption can be achieved.

Working at the set of heterogeneous toolkit for real-time education and entertainment, the author concludes that the decision to focus on mobile solutions adopted at the very beginning of the development has been correct. The current trends of devices becoming smaller and more powerful and the increase of their use just prove the correctness of this decision.

The web service-oriented solution described in the Thesis is non-trivial due to the fact that it combines limited resources of embedded sensor devices and the service-oriented architecture solution suitable for wireless sensor networks where a *UDP* protocol based *HTTP* server is used which supports *REST* requests and returns data in the *JSON* format.

The general method for the development of embedded sensor devices described in the Thesis will not only be useful for the author working on the development of new sensor systems, but the author assumes that the obtained results will also be useful for other WSN researchers who work in the development of applicable WSN.

The author concludes that the research performed and the results of activities are sufficient for stating that the aim regarding a general method for the development of embedded sensor devices has been achieved.

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