Appendix 1
Pielikums 1

National Research Programme

„Cyber-physical systems, ontologies and biophotonics for safe&smart city and society”

(SOPHIS)

Project No.1

Development of technologies for cyber physical systems with applications in medicine and smart transport”

(KiFiS)

Scientific report

Final report

2017

Contents

Glossary and abbreviations

ADAS - Advanced Driver Assistance Systems;

CPS - Cyber-physical systems;

ITS - Intelligent transport systems;

ECG - Electrocardiogram;

EDI - Institute of Electronics and Computer Science, Riga, Latvia;

EMG - Electromyogram;

KiFiS - Cyber-physical system technology development and their applications in medicine and intelligent transport systems (Project No. 1);

SoC - System on Chip;

SOPHIS - Cyber-physical systems, ontologies, and bio-photonics for safe&smart city and society;

VPP - State Research Programme;

Chapter 1

Introduction

State research program "Cyber-physical systems, ontologies, and bio-photonics for safe&smart city and society" (VPP SOPHIS) and the included project No. 1 "Cyber-physical system technology development and their applications in medicine and intelligent transport systems" (KiFiS) include tasks for the development of new generation of embedded systems – cyber-physical systems (CPS).

Cyber-physical systems include communication, data processing, and control elements, as well as interfaces to the physical world. These systems monitor the processes in real world, process the data, decides on the actions of controlling and improving the situation and enacts these decisions in the physical environment. Such cycles happen endlessly, and both on low level (such as a single room) and high level (such as a smart city). CPS provide a way for solving the economic problems, by providing us with "smarter", more intelligent, more energy efficient, more comfortable vehicles and transport systems, medical services, places of employment, communication systems, houses, cities and personal devices.

To make this vision a reality, there is a range of serious scientific and technological problems, that still need to be solved, connected to data gathering, electrical and optical signal processing, monitoring and control functions, while at the same time providing high enough level of security, stability and privacy. In addition, the system must be low energy, small, mobile and adaptable to new circumstances, as well as oriented to development of user friendly software and its usability. Scientific problems are connected to defining of new paradigms, concepts, platforms (hardware and software) and tool sets for the future development of CPS.

Because of limited resources available in this research project a subset of three specific CPS-related research areas were selected, matching the overall goals of the state research programme, and assigned to three groups of researchers:

- Group *TestBed*: To facilitate the production, programming and usage of CPS and by doing so, also to facilitate development of economically competitive innovative CPS based products while also facilitating their everyday use and reducing the digital divide;
- Group *MedWear*: To improve the quality and convenience of medical

services, while facilitating more efficient prophylaxis, more timely diagnostics and more successful treatment and rehabilitation based on innovative solutions both face to face or remotely in telemedicine;

- Group *SmartCar*: To improve the road safety and convenience of using road vehicles, by the use of intelligent transport system technologies.

In each of these three groups new concepts and platforms are developed based on results of previous state research projects, and improving on existing state of the art. These concepts and platforms are evaluated by comprehensive modeling and simulation research, thus selecting the perspective solutions, which are researched empirically, by creating experimental mock-ups, conceptual demonstrators, software libraries. The technologies which are economically competitive, are be approbated in real or close to real conditions, in cooperation with partners from the industry.

The following document contains detailed description of these research activities in each of the three groups -

- *TestBed* in section 2 describes a testing/prototyping environment and other improvements for wireless sensor system development and testing;
- *MedWear* in section 3 describes smart wearable sensor network infrastructure and wearable systems for energy efficient data gathering for measuring human bio-mechanics, and other health parameters (such as ECG), with applications in medicine, tele-medicine and rehabilitation;
- *SmartCar* in section 4 describes development of Advanced Driver Assistance Systems based on smart image and sensor signal processing, and communication with other vehicles as well as development of an autonomous car based test platform for these systems and related algorithms.

A technological forecast for the long term future of development of cyber-physical systems can be found found appended to this document [Result B.3.1].

The main numerical results of the project can bee seen in Section 5.

Chapter 2

TestBed - Smart sensor and their network innovative hardware and software platform

2.1 Introduction

To ease the production, programming and usage of CPS, thus promoting competitive production of innovative CPS based products in economy, as well as facilitating their everyday usage and bridging the digital divide a set of research was done in the field of sensors, sensor networks and their hardware and software platforms.

Designing Wireless Sensor Networks (WSN) is time consuming process that involves many subsequent steps:

1. definition of WSN use case,
2. design and debugging of hardware,
3. development and debugging of software,
4. evaluation of designed WSN performance,
5. adoption of WSN for real-world operation.

Design of WSN begins with definition of use case – number of sensor nodes, operating environment and desired up-time. There are two possibilities for hardware design (step 2): first – to use commercially available sensor nodes TelosB[1], MicaZ[2] EPIC Mote[3], XM1000[4], second – to build hardware from ground up. The first option requires only adaptation of existing hardware to the desired operation and therefore requires less effort compared to the second option. However, by using the second option it is possible to design hardware that is optimized for specific task and has no redundant components. Sometimes software development (step 3) may reveal that some changes to the hardware or even whole architecture of developed node are necessary or beneficial (to increase performance or reduce software complexity). Therefore, steps 2 and 3 must be iteratively repeated. In step 4 designed WSN is tested in controlled environment to evaluate power consumption, radio communication performance, and other parameters. In step 5 designed WSN is scaled (for operation using 25+ nodes) and/or adapted to real-world operation. Failure to accomplish step 5 may require repetition of previous steps and redesign of WSN.

Without specialized tools efficient execution of mentioned steps can be very challenging. For instance, there are a lot of routine manipulations that slow down the design process, like mounting, reprogramming of sensor nodes and connection of measurement equipment. To decrease development time of WSN, mentioned steps must be simplified.

This project works on solving these problems from two directions - (1) providing tools and know-how for faster and more efficient development of WSN hardware and software, (2) reducing the time and effort required for testing and validating each of the mentioned steps. The first direction is concerned with both low level tools and technologies such as Operating System for WSN (MansOS)[5], efficient communication solutions, precise power measurement etc. and high level programming tools (Seal/Blockly)[6], while the second direction is concerned with the development and testing environment itself, including mobile testing nodes.

In this research direction several new hardware and software solutions were developed, and used in development of a large WSN TestBed where users can perform different tests at different levels of abstraction - from low to high. Our TestBed have 90 nodes located inside and 10 nodes located outside, totaling a 100 node TestBed.

The WSN TestBed design challenges can be divided into three main sub-categories - architectural, hardware and software:

1. Architectural problems - Scaling, upgrading, and adding a new custom hardware;

2. Hardware problems - Selected hardware define overall WSN TestBed performance;

3. Software problems - The most efficient way to use available hardware resources for desired functionality. User-friendly front-end implementation for intuitive TestBed usage, without compromising data acquisition, processing, structuring from TestBed user point of view

Because of the limited resources of the project, the scope of the research has been narrowed to work on specific unsolved parts of these research problems, while reusing the existing state-of-the-art knowledge and results from previous projects for other parts of the testing environment surrounding them.

In this section our specific approach to solving these problems is described, as well as the vision for the system as a whole, defining the direction of the future research in the project.

2.2 Background & related work

Wireless Sensor Networks (WSN) are broadly used in different types of applications, from agriculture to medicine and on body sensor networks. Essence of WSN is to observe the surrounding environment parameters at macroscopic level. For example WSN can be used to monitor temperature distribution in building or vibration levels at the bridge. The quality of designed WSN is defined by individual autonomous devices, called sensor nodes or simply motes, performance, WSN covered area and count of placed nodes.

Typically WSN consists of sensor nodes, that communicates between each other using radio link. Each node has specific sensor set that is necessary to measure desired environmental parameters. Acquired data are gathered from sensor nodes to super node or sink. Typically super node is connected to the local or global network and also is used as bridge to provide easy data access for end-users.

There are many designed TestBeds for WSN. We will review most popular WSN TestBeds.

2.2.1 The TKN Wireless Indoor Sensor network TestBed (TWIST)

This TestBed is developed by the Telecommunication Networks Group (TKN) at the Technische Universität Berlin. It is one of the first largest academic WSN TestBed[7] for indoor deployment scenarios, deployed in 2005 year. It is located across 3 floors, resulting in more than 1500 m2 of instrumented office space. Currently they are using two types of sensor nodes - 102 Tmote Sky[8], 102 eyesIFX[9].

TWIST TestBed architecture is hierarchical in nature, consisting of three different levels of deployment: sensor nodes, micro-servers, central server. A high level view of this architecture can be seen in Fig. 2.1 below.

2.2.2 MoteLab

MoteLab[10] has been deployed on a network of 30 Ethernet-connected MicaZ [2] sensor nodes distributed over three floors of Maxwell Dworkin, the Electrical Engineering and Computer Science building at Harvard University. Also this WSN TestBed is freely available as open source, and several universities and research labs have chosen to use it for their projects.

MoteLab was the first designed WSN TestBed with reduced usage complexity. This was achieved due to the fact that there was implemented a rich-set of features: user-friendly web interface, remote access, automatic data logging for offline data processing, job scheduling, quota system for fairly TestBed usage.

MoteLab consists of several different software components. The main pieces are:

- **MySQL Database Backend** : Stores data collected during experiments, information used to generate web content, and state driven TestBed operation description,

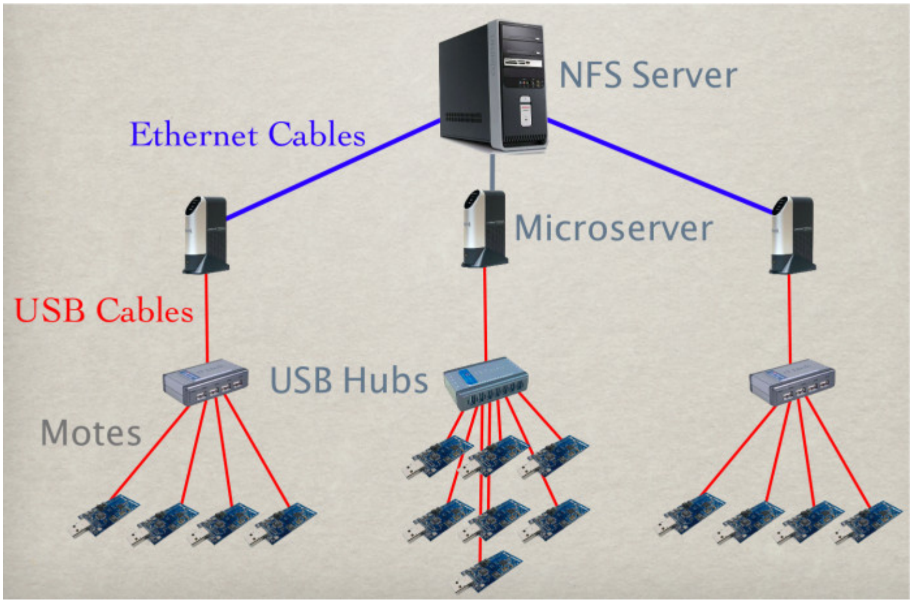


Figure 2.1: TWIST TestBed architecture

- **Web Interface** : PHP-generated pages present a user interface for job creation, scheduling, and data collection, as well as an administrative interface to certain TestBed control functionality,
- **DBLogger** : Java data logger to collect and parse data generated by jobs running on the lab,
- **Job Daemon** : Perl script run as a cron job to setup and tear down jobs.

2.2.3 Indriya: A Low-Cost, 3D Wireless Sensor Network TestBed

INDRIYA is a three-dimensional wireless sensor network deployed across three floors of the School of Computing, at the National University of Singapore[11]. 100 TelosB[1] nodes and 25 Arduino[12] devices are used in INDRIYA TestBed. The INDRIYA WSN TestBed is build on TWIST architecture[7] with modifications regarding cost reduction. To reduce system cost INDRIYA uses MAC Mini devices that is capable of controlling 127 USB like sensor nodes. In this way micro-server count is reduced, thus cost are reduced.

2.3 Our approach

After analyzing the state-of-the-art WSN TestBeds it was decided that there are still many unsolved problems in this field and to properly develop and test potential solutions to these problems it was decided to develop a TestBed of our own, capable of implementing our research results. TWIST[7] was chosen as the ground truth architecture for the TestBed, but two major modifications were implemented:

1. Ethernet switches were replaced with PoE switches. PoE switch supports data transfers and power delivery. There are two PoE IEEE standards: 802.3af, max power rating is 15.4W, second - 802.3at, max power rating 25.5W. This modification allows us to decrease set-up costs and place micro-servers more freely in desired places, but we can't exceed power limitations, thus power efficient micro servers must be used.

2. Additional module, EDI TestBed adapter (described in subsection 2.3.5), is introduced. It is placed between micro-server and sensor node. Our developed module allows users to accurately evaluate designed WSN performance. It provides additional information like: power consumption measurement, battery discharging emulation, real-world sensor data emulation, analog/digital signal debugging.

In the following sections a more detailed view of the developed TestBed is provided, including description of architecture and solutions to specific researched problems, including work on the main challenges:

1. Distribution of the computational resources: The challenge is to split computational power to use full hardware potential, thus reducing computational load from main server;

2. Control all of the TestBed devices: The challenge is to reprogram all sensor nodes (DUT) as well as TestBed adapters remotely and at the same time. This also includes network health monitoring;

3. Efficient data acquisition and structuring: The challenge is to effectively acquire data and structure it in user-friendly manner.

2.3.1 TestBed architecture

The architecture of the TestBed [Result A.4.2.1] (Figure 2.2) consists of the server (section 2.3.3), routers (section 2.3.4), TestBed adapters (section 2.3.5) and devices under test (DUT) (section 2.3.2) and all-together they form a TestBed prototype [Result A.4.3.4].

Routers are connected to the server via Ethernet with PoE. To each of the routers a TestBed adapter is connected via USB connection and to finally the DUT is connected to the adapter either via USB connection (if it supports it) or some other configuration specific wiring.

Physically the TestBed is installed in EDI building, across five floors - first, second, third, fourth, seventh. About 20 TestBed workstations will be placed in each floor. The placement grid was defined as irregular. Such sensor node placement assures different environment for testing radio communications and a more realistic close-to-real-world testing environment with different types of rooms, people density and obstacles. 100 TestBed workstations are installed, 90 of them across five floors, 10 outside of The EDI building utilizing also the nearby

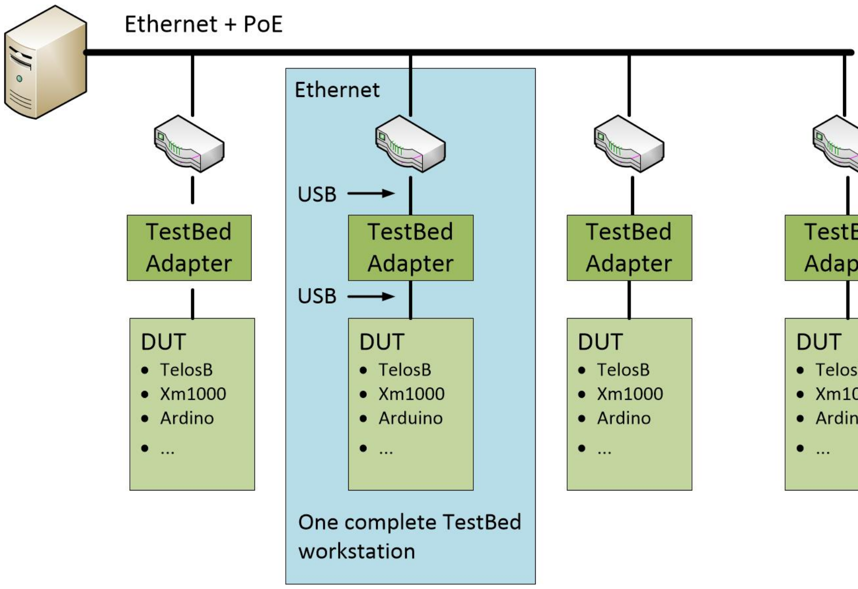


Figure 2.2: EDI TestBed Architecture

forest and exterior structures for even more varied test environment. In figure below you can see TestBed workstation placement in the third floor, Fig. 2.3.

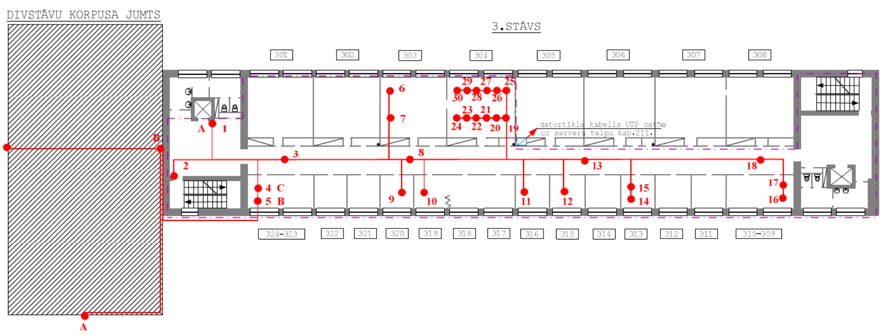


Figure 2.3: Sensor node placement in the 3rd floor

At the end of the second period of the project most of the TestBed workstations are already complete and are in the process of being deployed to their planned locations.

2.3.2 TestBed Devices Under Test (DUT)

We have designed our WSN TestBed in a way that it puts as few restrictions as possible on devices which can be tested. Devices Under Test can be operated under any WSN operating system that the device is capable of running. As for the device itself, we have 100 XM1000[4] sensor nodes which we will use as default sensor nodes, but theoretically any device can be used as long as it can operate from USB power source and use Serial communication through USB, the only restriction being that device must be compatible with reprogramming scripts used in routers, but this can be quite flexible since routers are running Linux operating system and we can add new reprogramming scripts quite easy.

2.3.3 TestBed server

The physical parameters of the server are:

- Manufacturer: ATEA
- Model: sVectron TS26
- CPU: Intel(R) Xeon(R) CPU E3-1220 V2
- RAM: DDR3-1333 4Gb,
- HDD: 1TB, 7200RPM , 64MB cache, SATA3,
- Case: Rackmount type (height 1U).

The server acts as a link between the TestBed and its users as well as a centralized data storage and configuration platform. It provides several critical services, such as:

- Centralized configuration services;
- Web interface for the TestBed;
- Centralized reprogramming control for the connected DUT;
- Online code editor for DUT;
- Data gathering, visualization and analysis utilities.

2.3.4 TestBed routers

Currently the routers used in the TestBed setup are Alix 2d2. The main parameters of these routers are:

- CPU: AMD Geode LX800, 500 MHz;
- DRAM: 256 MB DDR DRAM;
- Expansion: 2 miniPCI slots, LPC bus;
- Storage: CompactFlash socket, 44 pin IDE header;
- Operating system: Linux.

The routers are set up with 'Ubuntu 12.04 LTS' Linux operating system with custom modifications in kernel. Not all of the Linux kernel modules are needed in the current system and by customizing the kernel, we can achieve better performance and get support for additional hardware. Specifically FTDI drivers were added to the kernel, and redundant modules removed.

The routers provide the base functionality of data transport within the TestBed.

2.3.5 TestBed adapter

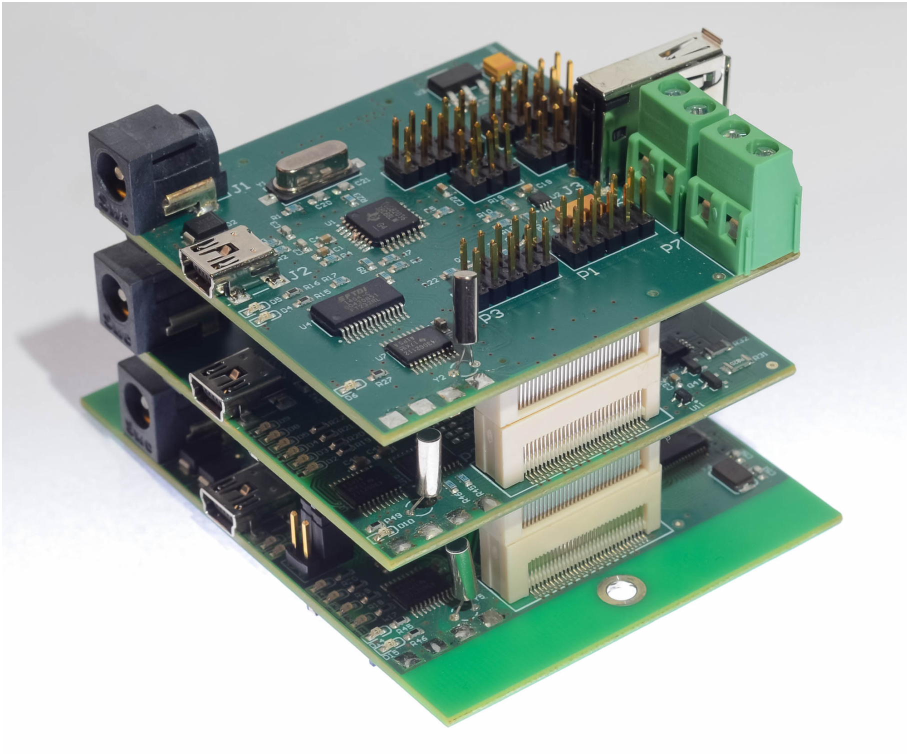


Figure 2.4: EDI TestBed adapter

EDI TestBed adapter (Figure 2.4) [Result A.4.3.1] is a result of previous research work in the institute, related to prototyping and profiling low power embedded systems, such as EDIMote[13]. It is intended to test and debug low speed embedded devices, especially wireless sensor nodes.

EDI TestBed adapter has many features to extend testability for embedded devices:

- Emulate battery discharging,
- Measure consumed current of sensor node,
- Generate - digital and analog signals,
- Measure - digital and analog signals,
- Store measured data on local SD cards.

The adapter is designed with modularity in mind, so that new functionality may be added later as required. Three specially synchronized modules are processing and debugging data. Modules are – communication, power meter and signal conversion. Each module has it own task respectively.

- Communication module: Controls data flow between router and sensor node and other adapter modules. With additional software, stored on router, it is possible to access every stacked module, through communication module. Only one connection at the time, between router and modules can be established;
- Power metering module: This module evaluates connected sensor node power consumption and supply voltage stability;
- Signal conversion module stores and processes data to avoid data loss or modifies the current data as needed.

We also developed our custom adapter to use together with TestBed adapter in case it is needed to measure the power consumption of a node who is connected via USB, this adapter connects USB data lines to the USB hub inside a TestBed adapter and USB power lines to power measuring circuit thus allowing for a simultaneous power measurements and USB communication.

2.3.6 Implementation

We have divided the data management task into five logical steps which directly correspond to our TestBed data flow architecture, more explanations available in publication [Result A.1.2.9][14]:

1. TestBed backend software [Result A.4.1.3]
   (a) TestBed adapter and device under test data generation
   (b) Data gathering on router
   (c) Data processing on router
   (d) Data insertion in database
2. TestBed frontend software [Result A.4.1.5]
   (a) Data representation on web interface

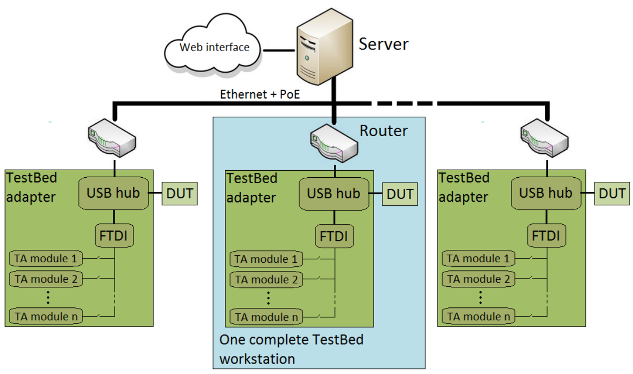


Figure 2.5: TestBed data flow

2.3.6.1 TestBed adapter and device under test data generation

All of the interesting data is generated or acquired at device under test(DUT) or TestBed adapter, both of them are connected to router via USB cable. As you can see in figure 2.5, technically DUT is connected to TestBed adapter, but since TestBed adapter includes a USB hub, we can access DUT as a different USB port from router, so we can gather data from DUT and TestBed adapter simultaneously.

To access TestBed adapter modules we need to switch between them, since we have only one USB connection to TestBed adapter itself, but multiple TestBed adapter modules we need to communicate to. To solve this we have software controllable switches on UART lines after FTDI chip, so we can enable or disable communication to each TestBed adapter module. At the moment we have 3 TestBed adapter modules:

- Main control module
- Power module
- ADC & DAC module

Data transfer To make this communication protocol robust and scalable we decided to use High-Level Data Link Control(ISO 13239) style packets, the packet format for both directions is shown in Figure 2.6.

1 byte	1 byte	1 byte	n bytes	2 bytes	1 byte
Start flag	Length	Command	Payload	CRC	End flag

Figure 2.6: TestBed data packet

Total length of packet minus flags is length + 4 bytes. 16 bit Cyclic Redundancy Check(**CRC**) is used to ensure that received data is valid. Field **command** defines what kind of command/data is transmitted and field **payload** contains data transmitted or command parameters depending on command.

Data flow path Not all modules have the same requirements regarding data flow, understanding where the most of our data comes from helps us to understand how to build an optimal TestBed adapter data management lifecycle.

Main control module contains only few switches controllable by software for DUT control and serves as controller for UART line switching e.g. enabling or disabling communication for other TestBed adapter modules and thus it needs negligible bandwidth.

Power module contains ADC for DUT power consumption estimation and digital potentiometer for battery discharge simulation. Battery discharge simulation is controlled by simply setting discharge rate throughout the experiment or providing a constant battery voltage at certain experiment points, it requires negligible bandwidth to operate. The ADC on power module has 1 channel with 16 bit resolution and it can operate with frequencies up to 500 kHz, which means that the maximum bandwidth it can produce is about 1 MB/s.

ADC & DAC module responds for external signal generation and capturing regarding DUT operation. ADC installed on this module have 8 channels and each channel has 12 bit resolution and it can operate with frequencies up to 1 MHz, which means that the maximum bandwidth each channel can produce is 1.5 MB/s, leading to total maximum bandwidth of 12 MB/s. DAC installed on this module have 8 channels and each channel has 12 bit resolution, it can be controlled by simply setting output value pattern for each channel or controlling each channel at the course of experiment, either way the bandwidth necessary is negligible. ADC & DAC module differs from other modules since it has two FTDI chips, so it basically consists of two logical modules on a single physical module.

Device under test We have also developed communication library for MansOS [5] operating system which uses the same principles as communication with TestBed adapter, so users could easily implement the same communication standard for DUT to router communication with ease.

2.3.6.2 Data gathering on router

Since we have separate USB connections to TestBed adapter and DUT we can read data from both of them simultaneously. This leaves us with only one problem - handling data acquiring from TestBed adapter modules, since we have only one USB connection, but 4 logical modules we need to communicate to. This can be achieved by using the UART line switch and communicating with each TestBed adapter module in turns. This means, that we can't allow TestBed adapter modules to send data whenever they have anything to send, because we can't assure that the UART lines are connected, so we have to develop a communication protocol where router asks for data to TestBed adapter modules and TestBed adapter modules respond only when asked.

To ensure that no data is lost we implemented the communication protocol in such a way that after the request for data has been sent to TestBed adapter, we wait for response, and if we get no response in some defined time, we retry the request up to 3 times. If there is no response after 3 retries we have to assume that the current TestBed adapter module has failed, there are two possible scenarios after such event. If experiment supervisor has allowed to restart failed TestBed adapter modules, we restart the failed module and continue the experiment as planned. But sometimes there might be some very important data saved on TestBed adapter and maybe it is continuing to work and only the communication part has failed, so experiment supervisor has forbidden to restart TestBed adapter modules and after the end of experiment TestBed adapter SD card can be manually examined to understand what exactly caused the fail and check for any usable data the failed module may have saved.

2.3.6.3 Data processing on router

Every message received from DUT and TestBed devices must be parsed in order to structure and save necessary data. Parsing is not very heavy work but it can be problem if carried out in great scale, especially if parsable data is made up from relatively big argument list, for example large vector or matrix. To tackle this problem and introduce more scalability to this TestBed solution a decision was made to do all necessary data parsing on router.

In addition to this basic functionality new firmware version also introduces possibility to do effective data preprocessing on router, distributing computational load and reducing data flow in the network. It is useful in situations when relatively large data sets are being collected, but useful information are obtained only by running algorithm with collected data sets(histogram for example). Custom preprocessing algorithms can be developed and carried out on routers by extending according Python classes. For trivial preprocessing algorithm implementation all that must be done is defining input data length - data that must be collected before running algorithm, output data length - data size that will be passed to database after algorithm execution and algorithm function itself. This way only meaningful data is sent to database and computing is done as close as possible to leafs of the network, increasing network scalability.

2.3.6.4 Data insertion in database

In previous solution query for writing new data in database was called from main server, but for more scalable system design a slightly different approach was chosen. Instead of sending data to daemon running on server for later saving, router itself connects to database and calls save query on parsed data every time new data is available. This way not only some load is taken off from main server, but independent connectivity provides easier network expanding and better device health monitoring, because router automatically adds itself to database as connected and state of device can be monitored.

2.3.6.5 Data representation on web interface

Every data set saved in database can be visualized in web interface. When call for data visualization is made, query is called to database and received data drawn in necessary format. Data is also refreshed dynamically. Gathered data is streamed to user(web interface session) near real-time. It is done by asking server(sending AJAX request) for changes in data set every 300 ms, this sort of solution does generate overhead which can be avoided by using web socket technology, but it would put more computational pressure on server and heavily increase system complexity.

2.3.7 Evaluation

In this section we describe our effort at understanding the limitations, capabilities and bottlenecks of EDI WSN TestBed.

2.3.7.1 TestBed adapter hardware estimation

To improve the accuracy and quality of the measured data and find the relevant values, it is essential to apply post-processing techniques. When a large collection of numbers is assembled, usually the actual value is not in the individual numbers, but rather in certain descriptive quantities such as the average or the median. In our case, the actual value is obtained using averaging and the Gaussian distribution functions as explained in more details in the following material and described more deeply in publication [Result A.1.2.13]

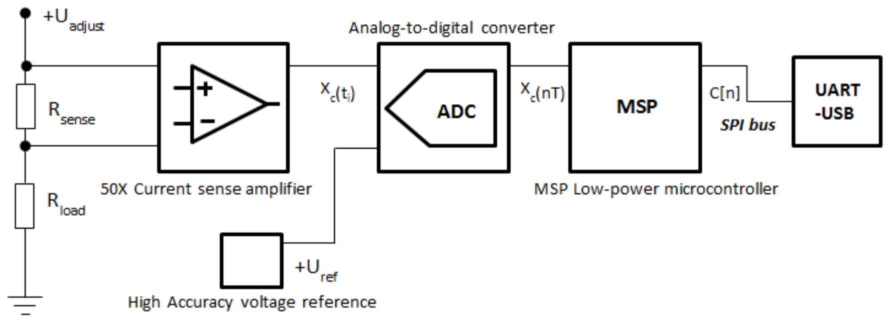


Figure 2.7: Basic block diagram of current measure circuit

Current measurement circuit is shown in Fig.2.7. It consists of three parts: Analog value acquisition circuit, with low-noise-current-sense amplifier, digital pre-processing system and finally, digital value processing and preparation for serial data translation.

All collected data, from the ADC is received in the MSP microcontroller and transferred to the PC, using UART-USB data bus. This information contains true value and noise. Necessary evaluation must be done by using computer software or different high quality system to preserve the original quality of the data.

Calculation steps, of actual value of measured data is shown in equation 2.1, where Q is the number of quantization bits, $C[n]$ that came from some continuous-time signal $X_c(t_i)$ (Fig.2.7), is a binary formed data, but during measuring process this value has been changed, $X_c(nT) = X_c[n]$ as data samples with a specific frequency. $X_c(t)$ is an analog value of the line received by the ADC.

$$I_{sense} = (X_c[n] \cdot Q) \cdot \frac{1}{50} \cdot \frac{1}{R_{sense}} \tag{2.1}$$

$$Q = \frac{U_{ref}}{2^{bit}} \tag{2.2}$$

Quantization bit value can be estimated by equation 2.2. U_{ref} is reference voltage provided to ADC and powered by the value of ADC bit resolution number

This value after formula 2.2 consists of several components noise and true value, but this data is scattered. To get measured value of data stream, we must understand the quality of signal and noise. Because, sometimes there are lot of distractor components which affect each other. E.g. digital clock signal is generating high frequency noise, but this noise can be found using Fourier transformation. At first, it is necessary to analyze data. To make sure, the mean value conforms to the measured, calculations are made in equation 2.3.

$$X_c(t_i) = mean(X_i) = \frac{1}{N}\sum_{i=1}^{n} X_i \tag{2.3}$$

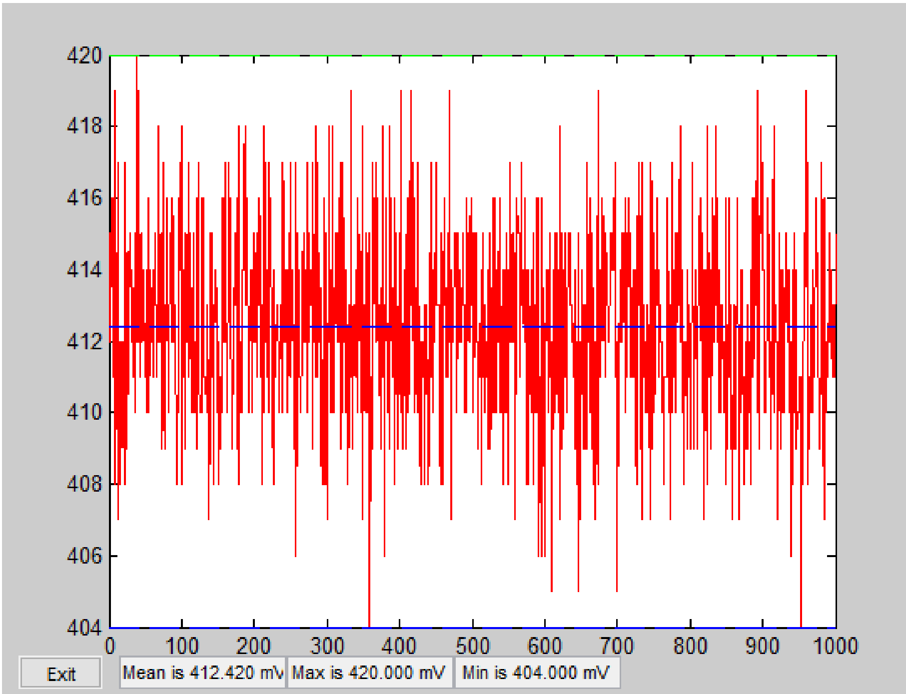


Figure 2.8: Data stream, measuring passive load in current sense circuit

In figure 2.8 a data stream stream is shown, measuring passive load (resistor) using 4.096 reference voltage and 3.00 supply voltage in current sense circuit U_adj.

$$X_i = mean(X_i) - X_{dir} \tag{2.4}$$

Equation 2.4 returns mean value of data streaming and this value conforms to real, expected unit by comparing with value from another measuring device. Calculating the systematic error of measured signal, attention must be paid to direct component. In this circuit there is direct component caused by current sense circuit in analog part of circuit. To get this value measurements with open circuit in current-sense part must be made (without any load), after calculating, must subtract this direct component from $mean(X_i)$ value.

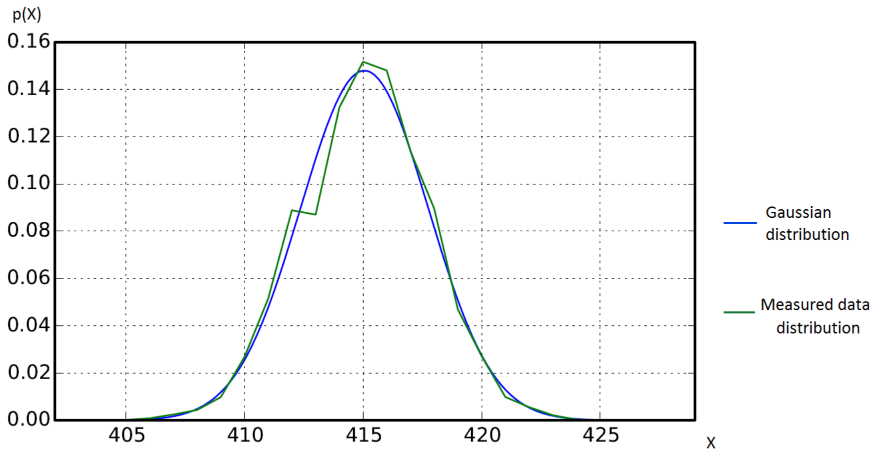


Figure 2.9: Measured probability density function - green line. Gaussian distribution calculated for measured dispersion σ and mean value $\bar{X}$ - blue line

Even after this calculation eliminates the systematic error, this value still contains noise and electrical disturbance. It is easy to calculate and compare the data after using formula 2.3, but to determine the nature of the error, most common solution is processing data with a Gaussian distribution and standard deviation functions. In Figure 2.9 two lines are shown, blue line is calculated using Gaussian distribution function, but green line presents a measured data probability density function.

The results of processed data are as shown in equation 2.5 below. For this the Gaussian distribution was calculated by equation 2.6, Sigma was calculated by equation 2.7 and ΔX was calculated by equation 2.8 meaning standard deviation.

$$\begin{aligned} X \pm \Delta X &= 415.056 \pm 0.054 (For 10000 samples) \\ X \pm \Delta X &= 415.87 \pm 0.17 (For 1000 samples) \end{aligned} \quad (2.5)$$

$$f(x) = \frac{1}{\sqrt{2 \cdot \pi} \cdot \sigma} \cdot e^{-\frac{(X - X_{mean})^2}{2 \cdot \sigma^2}} \quad (2.6)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (X - X_{mean})^2}{n - 1}} \quad (2.7)$$

$$\Delta X = 2.0 \cdot \frac{\sigma}{\sqrt{n}} \quad (2.8)$$

In these equations, the number X is combination of ADC value and error. Error depends on the number of samples; in the case of 10000 samples error is rather small. From the graph it can be seen, that the error has the nature of a Gaussian distribution. It means the error is random caused by some physical parameter like heat, low level electron flow etc.

2.3.7.2 Power module current measuring and error

Evaluate each TB-adapter, must be calibrated accordingly, to acquire real (expected) value coincides with measured values. Before this process, has to evaluate error and noise distraction.

Measured data from ADC consist of real value and error, in this case must do the calculation to get real value out of the data value stream, as mentioned before in the material.

Analyzing Testbed-adapter power measurement module functioning and try to find the cause of data scattering, lot of experiments was made. To find their exact cause of the data scattering, in this measuring system, the easiest way is to use a low noise power source, what is a noise-free element, several tests was done using this method. The obtained results are showed in 2.10) and it present, that measurement results contain variance, it means that the noise is created inside the measuring system.

Measured ADC values	Voltage	Noise in ADC	Noise in Volts
25537	1,5961	3,2	0,000200
25536	1,5960	2,2	0,000138
25535	1,5959	1,2	0,000075
25533,8	1,5959	0	0,000000
25533	1,5958	-0,8	-0,000050
25532	1,5958	-1,8	-0,000112
25531	1,5957	-2,8	-0,000175
25530	1,5956	-3,8	-0,000237

Figure 2.10: EDI TestBed adapter, power module measured data table,with constant power source measurement

Dispersion of the measured data are in microvolts. Comparing by constant flow current, the noise level is obtained low, but a significant problem is DUT - (device under test) and it low-state power consumption as ”Sleep mode” or ”Idle mode”.

Working around this problem, several methods were used to avoid data scattering. Main part takes the reference voltage source and test results sowed, that small data dispersion is created in this section, for about 200-300 micro volts. This noise is determined with reference measuring method. This is one of the most important points, because reference voltage source determines the fair value of accuracy and, if the source is noisy, then all the results will be inaccurate. Simply to solve the dispersion by adding a filter after reference power source is the easier solution, otherwise, all system have to be modify or even rebuild, and it would exceed unambiguous high costs. Results after small modification in the measuring system is shown below in 2.11).

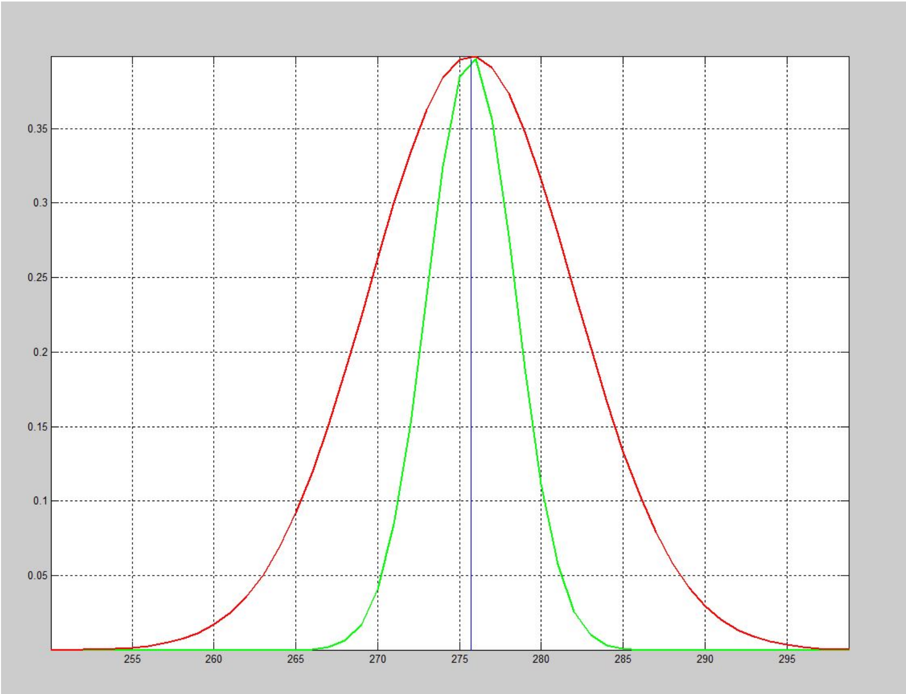


Figure 2.11: EDI TestBed adapter, current measurement data calculation of Gaussian function and compare with improved results

In 2.11) red line presents data dispersion using original (unmodified) measuring system with ADC value

$$X \pm \Delta X = 275.7 \pm 0.394$$

. Green line presents the same current ADC value, but with system Modification, with ADC value

$$X \pm \Delta X = 275.7 \pm 0.016$$

After the system modification, improvement is about 55% of data dispersion. This is a huge progress, but the downside of this improvement is a systematic error enlarging. In ADC values it is about, 62.6 units in this particular case.

2.3.7.3 TestBed adapter and device under test data generation

We have made an estimation of data flows inside TestBed to better understand where are the choke points, we briefly explain the results in following material and more detailed analysis is available in publication [Result A.1.2.10][15].

We measured how much data can we read on TestBed adapter ADC & DAC module from ADC. Test was performed reading all 8 channels sequentially, this way we can read data from ADC at about 187.8 KB/s, which is a lot less than theoretical 12 MB/s, this is due to MCU not being able to read ADC fast enough.

We measured how much data can we read on TestBed adapter Power module from ADC. Test was performed reading 16 bit value repeatedly, this way we can read data from ADC at about 600.2 KB/s, which is less than theoretical 1 MB/s, this is due to MCU not being able to read ADC fast enough.

2.3.7.4 Data gathering on router

We performed multiple bandwidth tests using different payload sizes, from 5 to 255 bytes with step of 5 bytes, and different test scenarios, to evaluate the bandwidth we can achieve with current hardware and software, the results are shown in figure 2.12. Testing was done using constant data stored in TestBed adapter module MCU memory, before every message sent by router it switched to target TestBed adapter module to ensure that the correct module is selected, this is also applied to tests where only one TestBed adapter module was used. Each test with different payload size was continued until at least 10 KB of data was transferred. We performed such test for each TestBed adapter module except main module, because main module does not have an MCU with full UART connection capabilities. We also performed a mixed test, where random TestBed adapter module was chosen for each message, for example, when using payload size 100 bytes, we need to send 100 messages to send total of 10 KB of data, so for each of those 100 messages a random target TestBed adapter module was used.

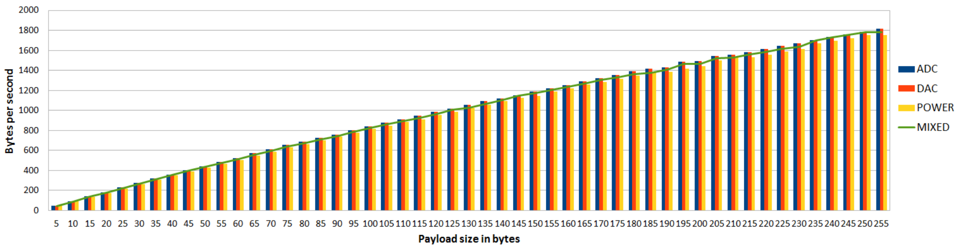


Figure 2.12: TestBed module data bandwidth

The results show that there is no noticeable bandwidth difference between TestBed adapter modules. Also it is clear that when using mixed data sending, it does not affect bandwidth, so we don't need to worry about very careful scheduling of module switching. At larger payload sizes the bandwidth increases because the ratio between payload and overhead increases. When using payload of 255 bytes, we can achieve the bandwidth of approximately 1.8 KB/s, which is way less then the bandwidth theoretically produced by ADC on TestBed adapter modules, which means that we will have to lose or pre-process the data before sending, for example we could send some average values over time or send only the relative differences when they occur.

2.3.7.5 Data processing on router

As mentioned before, in current software version, all data received from adapter and DUT is parsed by router. Data parsing speed on router is so effective that it is hard to generate data sets that would create noticeable lag. Roughly one millisecond for 1000 elements with 3 arguments each. In real life scenario DUT can't generate data sets of that size in such a short time. The only time when parsable data can grow larger than 1000 elements is when adapter returns gathered data from long period of time - energy consumption etc. But because it happens over large time span it is not even close enough for system slowdown and thus growth of parsable queue is not likely to happen. Pre-processing functionality performance is hard to measure, because it depends on algorithm implementation, but it is faster than processing data on main server or client machine for several reasons. There is no need to call database queries for required data because all data that is needed for algorithm is saved in router RAM or disk memory based on required data size when it is received from DUT or adapter. Data is stored until necessary set of data is collected for algorithm to perform and only then result is saved to database. In comparison, if target algorithm would be carried out on main server or client, it would need an extra database query for data. It would put noticeable pressure on database and server if large sets of data are necessary for algorithm and also generate huge amounts of network traffic if carried out on clients machine. For some algorithms it is also possible to generate intermediate results from incomplete data sets making calculations while the data is still being collected. This sort of solution can only be effective if all data is stored in memory. It greatly increases parallelism and network scalability.

2.3.7.6 Data insertion in database

In previous software version, as mentioned before, data was written in database by daemon running on same hardware as database engine. This functionality was moved to the router because tests prove that under pressure(when more than 20 write operations are executed at once) writing speed is almost identical even with data traveling over local network. Write speed on current hardware is about 8ms per data vector which consists of long integer, string with length of 255 symbols, integer and timestamp. Writing to database directly from router was slightly slower(9ms-10ms), as expected, but by structuring data path in this manner router becomes independent from main server. This property can be of great use in the future, for example, if data needs to be streamed to different database servers or connected with other TestBed solutions with different architecture.

2.3.7.7 Data representation on web interface

Data representation can be divided in two time consuming actions. First one is loading and visualizing already existing data from data base and second is refreshing data set while it is being viewed by user. For both actions elapsed time consists of initial AJAX call, reading from database, data parsing and callback. Tests were carried out on local network with initial data set of 1000 elements and 3 new elements added every second. AJAX call and callback tends to run in time frame between 30ms - 50ms, but, of course, it is heavily dependent on network speed and data set size. Database read speed is about one millisecond for 10 elements and is also almost identical in both actions.

Data parsing happens in an instant - one millisecond for 1000 elements. As mentioned before, data is only asked for server once every 300ms which is main slowdown in data refreshing. Web sockets can be used to eliminate this overhead, but, depending on implementation, it would disturb router and its network child nodes "independence" and put more pressure on database, router or client machine.

2.3.8 Mobile TestBed

We created mobile Testbed nodes as described in publication [Result A.1.2.12], because only simulations and emulations are not sufficient for deployment of new embedded devices, since they are too far from ever changing real world conditions. Testbeds allow to increase the prototyping speed by quite a margin, but the still operate in some-what semi real-world conditions due to limited mobility of testbed nodes.

Mobile testbed workstation consists of a wireless router, testbed adapter and DUT. Only hardware addition is battery for mobility and sealed enclosure for adapter itself. Mobile workstation is supplied with a battery with small solar panel for longer battery life during outdoor experiments. To ensure survivability in outdoor experiments IP65 enclosure is used for testbed adapter. To enable wireless communication a wireless router was chosen to replace stationary testbed router.

The prototype for mobile adapter [Result A.4.3.9] is described in a publication [Result A.1.2.12].

2.3.9 Directional wireless transmissions

As a sub-direction of the wireless sensor network TestBed also electronically steerable directional antennae were researched, thus providing future possibilities of more energy efficient and secure communications between wireless sensor network nodes.

Usually for wireless sensor nodes radiation pattern of build-in antenna is fixed. The use of antennas with electronically steerable radiation pattern opens several opportunities:

- using proper regulation of antennas it is possible to reduce power consumption on transmitting of signal;
- for different pairs of nodes it is possible to use the same communication channel simultaneously;
- measurements of RSSI for different antenna regulations give the possibility to estimate the direction of arrival for signal and localize the position of node.

In Figure 2.13 wireless sensor node based on the `Tmote Mini` module equipped with compact size electronically steerable parasitic array radiator antenna is presented. This antenna consist on 3 Yagi–Uda antennas shearing the same

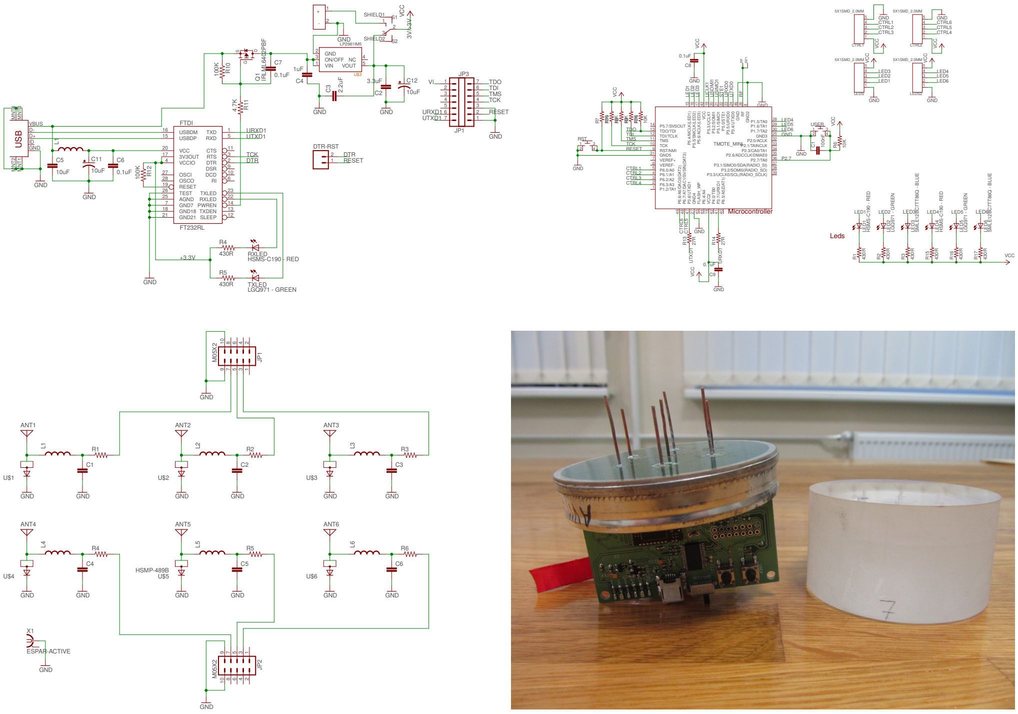


Figure 2.13: Wireless sensor node width electronically steerable antenna: schematics and construction.

driven element on the center. The switched circuit for reflector and director elements includes PIN diode and choke inductance. The size of antenna is reduced by enclosing the elements of antenna into dielectric material. This node is driven by `MansOS` operating system.

This work was published in [Result A.1.2.8][16] and demonstrated in Microsoft Indoor localization Competition [Result B.1.1.5].

2.4 Results

This group during the project has produced 5 scientific publications and 2 patent applications.

Based on this work 2 bachelors thesis have been defended and also 3 doctoral thesis are in process of being developed.

The project has resulted in 2 software prototypes 1 architecture concept and 3 hardware prototypes all of the prototypes have been collectively validated by 3 different companies one of which has also licensed the TestBed technology for use.

Additionally the knowledge base, technologies and skills provided by the project has improved 4 university courses as well as already led to synergy with 2 other projects.

These results in more detail are discussed below.

2.4.1 Involvement in international projects

2.4.1.1 Usage in train integrity monitoring system development

In Bachelor thesis [Result A.2.3.6], method for train integrity monitoring with wireless sensor network (WSN) was presented. The proposed system consists of WSN Nodes (deployed on each wagon), the Coordinator and the Serial Gateway (both deployed on each wagon). Each WSN Node measures accelerometer and GPS data, which are further send to Coordinator, which holds the accelerometer and GPS reference measurements against which the measurement from each node are compared to detect the train integrity. Coordinator is also measuring Received signal strength indicator (RSSI) from all nodes, thereby the decision on whether the train is complete or not is made based on three distinct measurements. If integrity is lost, alert message is sent to higher level applications for further decisions. This thesis was developed under DEWI project.

Basis for wireless sensor technology for train integrity control system was developed under international 7th Framework programme project: DEWI (Dependable Embedded Wireless Infrastructure (Grant Agreement no 621353)) (see http://www.dewiproject.eu/) [Result A.4.4.8][Result C.6.10]. With 40 million budget (EDI part: EUR 132 000.00) and 58 partners from 11 countries, the project was implemented between March 2014 - February 2017 [1]. The original idea ("WSN based on accelerometer, GPS and RSSI measurements for train integrity monitoring") was proposed in autumn of 2015, and further developed locally by EDI.

Tests in EDI TestBed were used mainly for debug purposes - to develop efficient radio communication between devices and inspect basic data gathering routines. Problems with proposed method can occur, so it is necessary to test the hardware and software architecture for successful future WSN deployment on a real train. Furthermore, since it was necessary to perform often software updates on this WSN (couple of times a day), possibility to reprogram the system remotely saved a tons of time.

The tests were mainly done by issuing commands to Serial Gateway, therefore tests of different WSN scenarios were performed – examination of sensors, data transmission tests, analysis of acquired data and WSN parameter observation and configuration.

Great advantage was the ability to place nodes in a hallway where EDI TestBed is deployed, enabling great environment for simulating communications in settings similar to freight train trucks in railway.

2.4.1.2 Involvement in ENACT project

By using the accumulated experience in WSN field a new WSN related H2020 project "ENACT" was proposed and started after the end of Testbed development[Result A.4.4.5][Result C.6.5]. ENACT is international project where EDI is one of the partners, mainly responsible for WSN part.

2.4.2 Usage in Bachelor thesis

As part of TestBed development Bachelor thesis [Result A.2.3.5] ”Wireless sensor network TestBed software” by Arnis Salmins was written, it is mainly a description of his involvement in Testbed development.

2.4.3 Usage in ongoing doctoral thesis development

EDI TestBed has been used for doctoral thesis [Result A.2.1.5] as a platform for directional antenna radiation pattern acquisition. As a result of TestBed development and lessons learned from it [Result A.2.1.6] doctoral thesis idea was formed. During early TestBed development ideas were described in doctoral thesis [Result A.2.1.9].

2.4.4 Improved courses

1. “Introduction to digital design” / “Ievads digitālajā projektēšanā” [Result A.3.1], University of Latvia, R. Ruskuls. Course demonstrates development of digital devices, and uses TestBed adapter as an example for specific lessons.

2. “Concepts of Operating systems” / “Operētājsistēmu koncepcijas” [Result A.3.2], University of Latvia, K. Nesenbergs. Course demonstrates concepts of operating systems, including lessons from development of the operating system for wireless sensor networks (MansOS).

3. “Special course: cyber-physical systems” / “Specseminārs: Kiberfizikālās sistēmas” [Result A.3.3], University of Latvia, L. Selavo. Course demonstrates the workings of different cyber-physical systems including wireless sensor networks, demonstrating examples of systems developed in the project.

4. “Wireless sensor networks” / “Bezvadu sensoru tīkli” [Result A.3.4], University of Latvia, J. Judvaitis. Course teaches development and programming of wireless sensor network nodes and students use the TestBed environment for practical tasks.

2.4.5 Applied for, registered, and valid patents or plant varieties in the territory of Latvia in the framework of the programme

1. 2017-11-02 Submitted Latvian patent application No. P-17-69. Name of invention “Mobile device for a more efficient development of wireless sensor networks and their nodes in target environment” / “Mobila ierīce bezvadu sensoru tīklu un to mezglu efektīvai izstrādei mērķa vidē”. Inventers: Leo Seļāvo, Krišjānis Nesenbergs, Jānis Judvaitis, Didzis Lapsa, Rihards Balašs, Arnis Salms, Modris Greitāns. [Result C.2.1.1]

2. 2017-12-29 Submitted Latvian patent application No. P-17-97. Name of invention "Metohod of controling of antenna radiation patterns by using transmission lines on printed circuit board" / "Metode antenas virziendarbības nodrošināšanai, izmantojot tikai spiesto plašu celiņus ar pielāgotu garumu". Inventor: Ivars Driķis. [Result C.2.1.2]

2.4.6 Aprobation

TestBed was used by multiple third party users with a goal of understanding the capabilities of a system and its use cases in a real-world scenarios as well as test the system performance and user interface capabilities.

TestBed was used for sensor node and base station development based on Atmel ATmega platform using LoRa radio communications by SIA "19 points" [Result C.3.3].

Mobile testbed nodes were aprobated in Institute of Horticulture where 10 mobile nodes were scattered in a fruit garden to gather the data about microclimate and test the mobile testbed functionality, this test is described in publication [Result C.3.5].

Testbed was used on "Wireless sensor networks" / "Bezvadu sensoru tīkli" course in University of Latvia [Result C.3.6], where students used TestBed in practical lessons and provided early feedback about its capabilities and user experience, to summarize the reviews - the learning curve was a bit too steep and user interface was not easy to use at the time, but functionality-wise TestBed suited all their needs. Based on this a licensing agreement contract No. 1.1.1.-5/23-17, with University of Latvia, about licensing the TestBed system for student use as part of course material [Result C.4.1] was made.

2.5 Discussion and future work

After the end of programme the improvement of testbed system wont stop, authors have gotten experience with testbed systems and with the help of customer feedback will continue the research and development to make EDI TestBed a convenient and powerful tool helping people around the world to develop their wireless sensor networks or test their prototypes faster. This includes:

- Improving our user interface to make it more convenient as well as more functional;
- Improving data visualization by introducing a lot of different ways of graphical data representation to suit every need;
- Adding support for cloud program compiling and online code editor linked together with MansOS and SEAL for faster and easier code development;
- Researching the best possible hardware solutions for testbed adapter and creating a robust and powerful adapter for WSN development;

- Providing monetized public TestBed access to users who wish to use it

Chapter 3

MedWear - Medicine and telemedicine uses of CPS

3.1 Introduction

In this section healthcare applications of cyber-physical systems are researched to reach the goal of improving the quality and convenience of face to face medical services as well as remote telemedicine services, while facilitating more efficient prophylaxis, more timely diagnostics and more successful treatment and rehabilitation based on innovative solutions.

The evidence for beneficial applications of wearable computing can be found in many different fields, such as medicine [17] from early detection [18][19][20][21] to treatment [22][23], care for the elderly [24][25][26] and frail[27], exercise [28][29][30], mental health [31], entertainment [32][33] and potentially many others.

Also it is not hard to imagine, that both patients and doctors could benefit from low-cost unobtrusive smart clothing, which could be used for patient compliance monitoring, long term medical data analysis in patients everyday environment as opposed to special testing facilities, telemedicine, unobtrusive vital sign and traumatic event monitoring etc.

Unfortunately each of these examples of previous work in the field of wearable sensor applications have been working on their own custom wearable sensor platform. Because of this a lot of time and energy goes into reinventing the wearable data gathering infrastructure, which could be better spent in researching beneficial applications to wearable technologies.

A standardized architectural, hardware and software process for development of smart clothing could provide tools for development of customizable wearable sensor and actuator networks with little effort and low budget. In addition such wearable sensor ecosystem could provide similar benefits to the growth of the field of wearables as personal computers did for the field of computing - competing companies could work on specific parts, such as specific sensors and not be concerned about the complexity of developing and marketing a full wearable system.

Because of this our team researched the state-of-the-art in these fields and defined a vision of smart clothing architecture capable of providing these benefits. Because of the limited resources available in this research project, priority directions were selected and specific key parts of this vision were researched (such as key architectural elements or use of specific wearable sensors) thus ensuring, that the overall vision of smart wearable systems is moved forward, and an effective foundation is laid for future applications of this research.

A variety of different illnesses or injuries, for example, cerebral palsy, can often lead to posture and different body part control problems in a number of daily situations. Correct posture, body part alignment, etc. is essential to ensure accurate operation of respiratory system, cardiovascular system and other body functions. In addition, this information can provide context of human activity that allows to better interpret data obtain with other sensors. Currently posture and body alignment monitoring and training in a variety of different rehabilitation programs normally is done in close supervision of medical specialist. This approach limits availability of rehabilitation and maintains high work load of medical staff. In addition, the monitoring duration is limited to special dedicated sessions, making the daily monitoring of patient outside medical facilities practically impossible. To overcome previously stated limitations a variety of aiding technical apparatus are being used, however, the availability of these are limited in terms of functionality and also ease of use. In this project, a particular subtopic is devoted for development of methods that allow monitoring of human posture, different body part alignment and movements in real time with wearable devices.

3.2 Architecture for multi-sensor smart wearable systems

While working on wearable computing and smart clothing and reviewing the state-of-the-art, common use case scenarios have been defined and common requirements have been based on those, providing basis of a universal smart textile as described in the introduction and published in [Result A.1.1.2] [34] and [Result A.1.2.5] [35] and also a journal publication is prepared [Result A.1.2.21]. This work is also being described in the doctoral thesis [Result A.2.1.2].

The defined common use scenario of a smart textile, facilitating rapid, low-cost development and deployment of wearable computing, is as follows (Fig. 3.1):

1. The cloth with wiring integrated within in a universal grid is mass produced resulting in rolls of smart textile, similar to the rolls of ordinary textile;

2. Clothing is tailored from the smart textile in the same way as ordinary clothing;

3. Wiring from different physical parts of the clothing, such as sleeves and torso, is connected together in the same network;

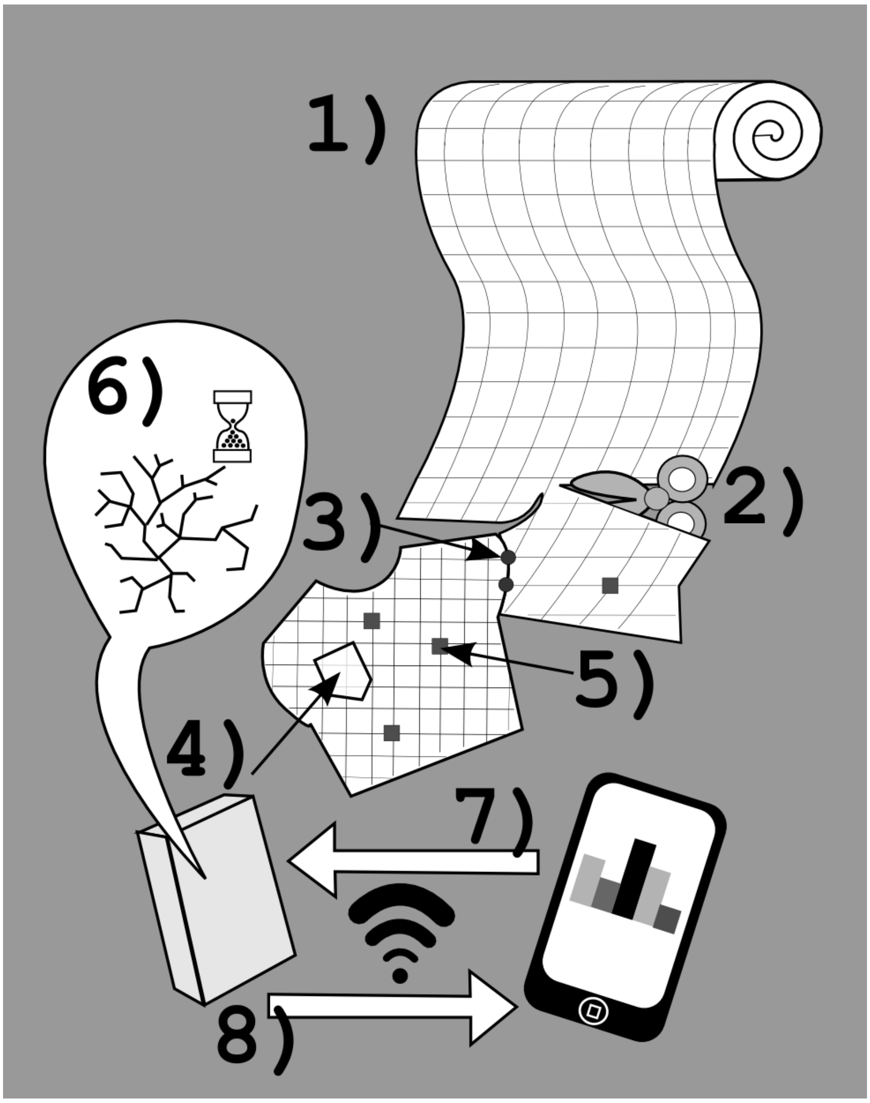


Figure 3.1: Envisioned use scenario of a universal smart textile for medical applications

4. At some point in the clothing a special connector and pocket is added for central data gathering endpoint containing a battery and wireless communication module;

5. Depending on the specific task for which the smart clothing is being created sensors are selected and placed in the relevant spots of the ready clothing turning it into a wearable sensor network;

6. The system is turned on and it runs self-diagnosis mapping the network and routing the power, data and clock lines through existing wire connections for optimal data gathering;

7. If needed, specific sensor or actuator drivers are loaded to the whole sensor

network, and these drivers are seamlessly distributed throughout the piece of smart clothing;

8. The data is gathered by the central data gathering endpoint and transmitted over wireless connection to a computer or a mobile device and there software can be developed for the specific purpose envisioned.

To facilitate this scenario a series of basic requirements must be met, which the authors have defined as follows:

- Wires - Wiring system for sensor node connections providing power and signal lines to each of the sensor nodes must be realized with the minimum number of wires. This is because wires are hard to implement in stretchable textiles and they are the most fragile and expensive part of such a smart textile requiring that their number should be kept to a minimum;

- Physical layout - A regular pattern of densely placed sensor node connection points is preferable allowing more universal solutions instead of sensor positioning for a specific problem. Each square meter of textile should include more than 100 sensor nodes - the more potential connections for sensor nodes, the better the chance that a specific node will be close enough to a specific point on the body required for a specific use case. Also a better resolution can provide a more complete picture of the data;

- Connections - Wiring topology connecting the sensor node connection points should provide redundancy for rerouting in cases when some wires are cut while creating clothing from the smart textile - as custom electronics manufacturing is very expensive, it would be more beneficial to develop a universal smart textile. This means, that while tailoring the smart clothing cuts could be made almost anywhere and this potential damage to the network must be taken into account;

- Electronics - The hardware should be small and unobtrusive enough to integrate in the textile and elastic and robust enough to survive everyday use, moisture and other typical stresses. The technology will not gain mass market appeal if it is not easy to wear and will not be robust enough to pay back for its value. Electronic chips and sensors usually are quite resilient. The most fragile part of such smart clothing is usually the wiring and connectors. It must be applied with specific technology to provide elasticity and at the same time maintain the specific electric properties, such as resistance and at the same time protect the electronics from outside elements, such as moisture (The requirement for constant resistance is one of the reasons common methods of developing elastic conductive threads[36] are not a good solution);

- Data gathering endpoint - At any point at the discretion of the clothing designer there should be a possibility to add an endpoint capable of gathering the data from the smart device, providing power to the wearable sensor network and transmitting the gathered data further for processing and displaying. The battery should be small enough to be unobtrusive and capable enough to power the whole device for a full day of use. This means that the whole system must be built on energy efficient components and principles of energy saving;

- Software - The software accompanying the smart textile should be able to gather the data from all sensor nodes irrespective of the final configuration of the smart clothing and the place where the endpoint is connected. This requires smart mapping of the final garment;
- Updates - Irrespective of the number of sensor nodes and topology of the network it should be easy to reprogram the system with new software or drivers for sensors or actuators without disassembling the network. This means, that sensor nodes should be re-programmable through the network, without direct hardware access to each node. System updates should come from the wireless connection of the endpoint and propagate throughout the network, while it is still powered on;
- Speed - The system should provide data rates of at least several full frames per second for the system to be usable in real time - this includes gathering data of every sensor in the system in each frame and transmitting the gathered data for processing;

In addition - for the system to become widely used and accepted it has to have a potential to be economically viable through mass production, there should be standardized software tools for using the gathered sensor data and the hardware and software standards should be open and accessible for mass acceptance.

This architecture concept has been partially based on the line-topology smart clothing architecture described by the institute in previous state research project. In this project specific parts of this architecture have been developed further, as well as some specific sensors and applications for this architecture have been researched.

As an alternative to this architecture through skin communication has also been researched and the findings prepared as publication [Result A.1.2.20].

Additionally such wearable systems require unobtrusive energy sources - because of that also the possibilities of energy harvesting have been examined closely and described in bachelors thesis [Result A.2.3.7].

3.3 Our approach

Our approach to this problem is to identify specific parts of the overall solution and concentrate project resources on those parts e.g. specific problems in data gathering architecture or specific sensors and their synergy with other sensor types, as well as energy efficiency and data gathering/transfer.

In below sections these specific tasks, on which our team has worked during the project are described in detail, as well as the resulting innovation from this research.

3.3.1 Overview of technologies developed in project

3.3.2 Multi-branch architecture

During State research program "IMIS" project no. 2 „Innovative signal processing technologies for smart and effective electronic system development" a method was developed to form a network with large number of low-power sensors and acquire their data in real time. This method was based on the daisy-chain principle. It provides a number of benefits when sensors can be connected in series.[37] The proposed enhanced daisy-chained SPI network greatly reduces the amount of wires in the system. New sensors can be easily connected at the end of the chain, with little software adjustments. View of this architecture can be seen in Fig. 3.2 below.

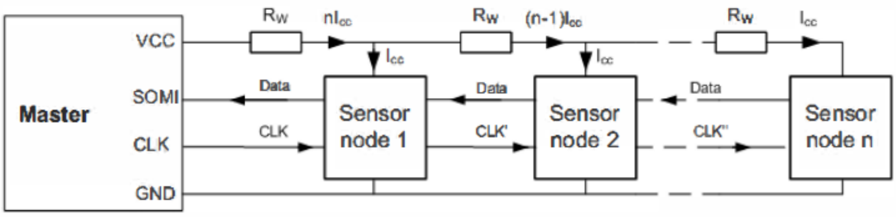


Figure 3.2: Enhanced daisy-chained SPI [37]

Several potential improvements to this architecture were considered in this project to limit its drawbacks and improve its properties when gathering data from sensors on the whole human body not just specific parts. One of such improvements was the multiple branch network architecture. Main goal for using this architecture is to increase the rate at which whole system measurements are received as well as to simplify access to remote parts of human body (e.g. feet, palms). This architecture also has to provide the option to connect non-homogeneous sensors and sample them at different frequencies. This architecture consists of one master controller with multiple branches of series connected smart sensors.

Structure of proposed multiple branch architecture can be seen in Fig. 3.3 below. For this application, previously described enhanced daisy-chain connection is used for every branch.

A master controller module is responsible for gathering the data from the network and forwarding it for processing via Bluetooth or Bluetooth LE (low energy) connection. It provides clock signals and control for the whole network. A simplified flowchart of master controller module program is displayed in Fig.3.4.

The resulting architecture has been published in [Result A.1.2.7][38] and has provided basis for later synergy with European ERA-NET project CONVERGENCE [Result A.4.4.4][Result C.6.4] and project HIPPAC [Result A.4.4.2][Result C.6.2].

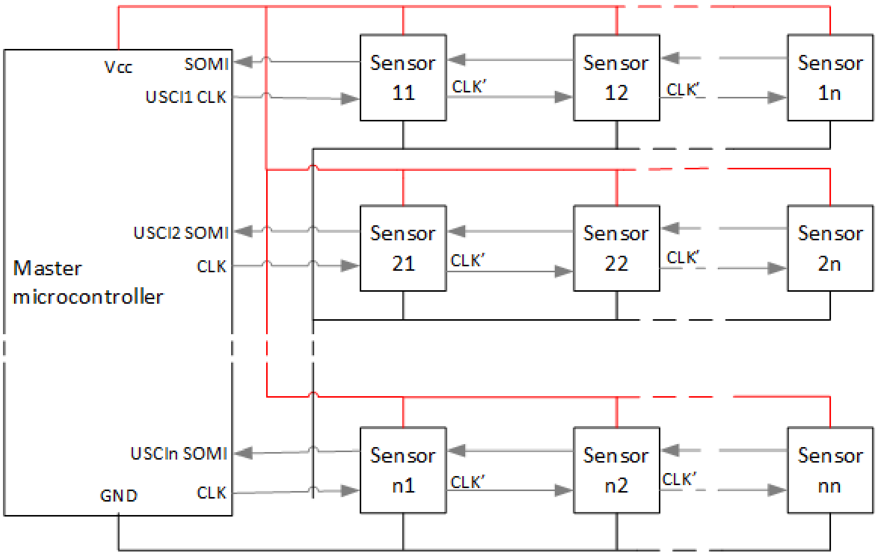


Figure 3.3: Multiple branch BSN SPI structure

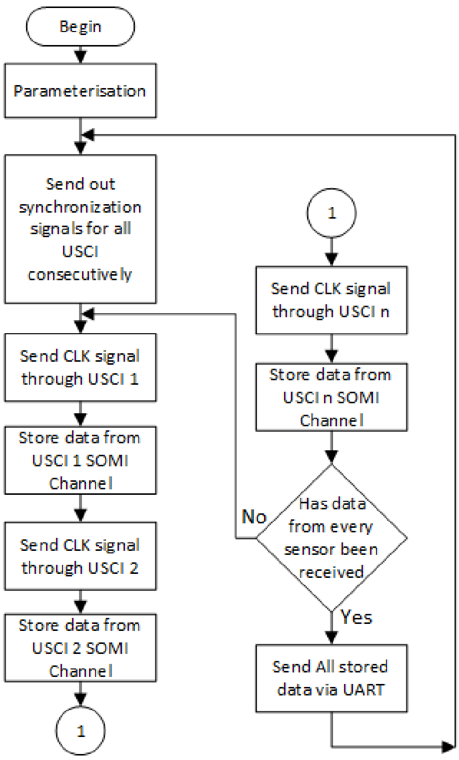


Figure 3.4: Master controller code flowchart

3.3.3 Gathering wearable sensor data on a remote server

In various projects we propose systems, that are using mobile platforms in order to visualize, analyze and store data. Mobile platform was chosen taking its availability, ease of use and high computing power into account. Collected data on the smartphone can be stored in cloud infrastructure in order to provide data accessibility and security for both patient and health specialist. By using cloud services it is possible to provide communication in the scope of application between two parties: patient, doing rehabilitation and sharing his statistics with rehabilitation specialist, who can manage prescriptions and view data from patient.

3.3.4 Sensors for biomechanic

In this project methods for real time monitoring of human posture, movements and body part alignment using wearable sensors were developed. In project period a number of new aproaches and methods for wearable sensor node signal processing were studied and implemented. Particular focus was aimed towards inertial and magnetic sensor measurement fusion to obtain more accurate sensor orientation leading to better measurements of human body biomechanics.

Acceleration and magnetic sensor network for shape sensing During State research program "IMIS" project no. 2 „Innovative signal processing technologies for smart and effective electronic system development" , an acceleration sensor network [39] was developed that allows to monitor shape of the fabric and can be used in smart wearable garments for posture monitoring [40].

A significant drawback arise from the fact that accelerometers alone can only measure direction of single reference vector, providing incomplete sensor orientation estimate. In order to obtain full 3D surface model another reference direction have to be measured such as Earth magnetic field.

Together acceleration (in static conditions - dynamic acceleration $<< g$) and magnetic sensors provide two vector observations, which is enough for full orientation determination, therefore, to obtain orientation data some deterministic algorithm such as TRIAD [41] can be used. Triad is one of the fastest, singularity free and computationally simple algorithms for orientation calculation from vector observations. This results in acquiring sensor orientation relative to Earth reference frame.

This allows the reconstruction of the shape of the fabric by approximating it to many rigid segments for which the orientation is known, as seen in the surface model in Fig. 3.5 and resulting in a 3D point cloud defining the shape of the body similar as in a 3D scanner.

Proof-of-concept prototype was designed to demonstrate feasibility of our system and validate performance. An architecture described in [37] was used to test surface with 63 sensor nodes. Data processing was implemented on PC in Matlab environment and as Java application. In addition, Android application

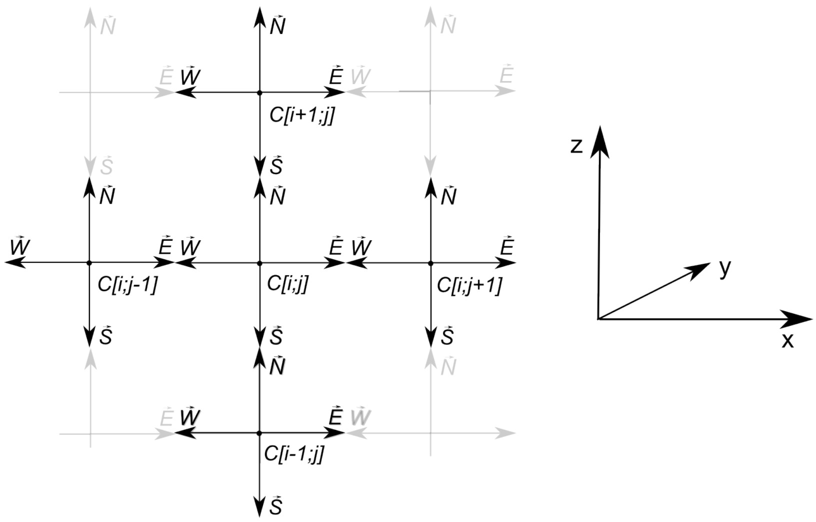


Figure 3.5: Surface segment structure. Each segment consists of center C and four direction vectors $\vec{N}$, $\vec{E}$, $\vec{S}$ and $\vec{W}$.

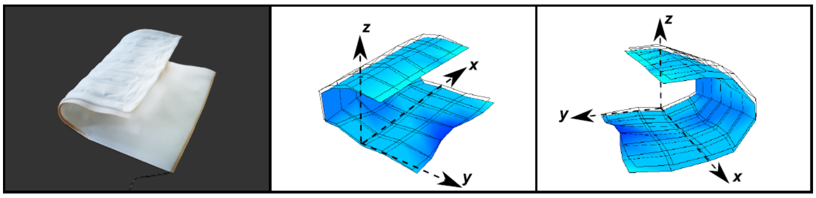


Figure 3.6: Sensor sheet and reconstructed shape rendered in Android application with 10 Hz frame rate.

was developed demonstrating ability to implement real-time system on portable devices with limited processing power (Fig. 3.6).

More detailed information about tests with experimental setup as well as computer simulations and evaluation can be found in [Result A.1.1.1] [42] and [Result A.1.2.3][43].

The work on this solution has been described and defended in a doctoral thesis [Result A.2.1.1] and has provided synergy to project [Result C.6.8].

Additionally the 3D model using custom information segmentation algorithms was also implemented and aprobated on a volumetric 3D display developed by EuroLCDs LTD [Result C.3.1], which later lead to future contract research [Result C.1.3].

Inertial/magnetic sensor module for motion tracking Fast dynamic accelerations as well as electromagnetic noise introduce high frequency noise in the reference vector measurements that are used for orientation estimates. This is a particular problem when fast human movements have to be measured which requires bio-mechanics model estimation in dynamic conditions. To eliminate this problem acceleration and magnetic sensor data are often fused with gyroscopes. For this reason an additional sub-task is dedicated for design of

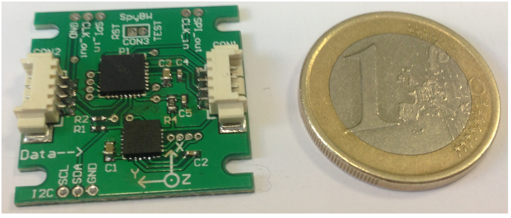


Figure 3.7: Prototype of wearable sensor node with accelerometer, magnetometer, gyroscope sensor module.

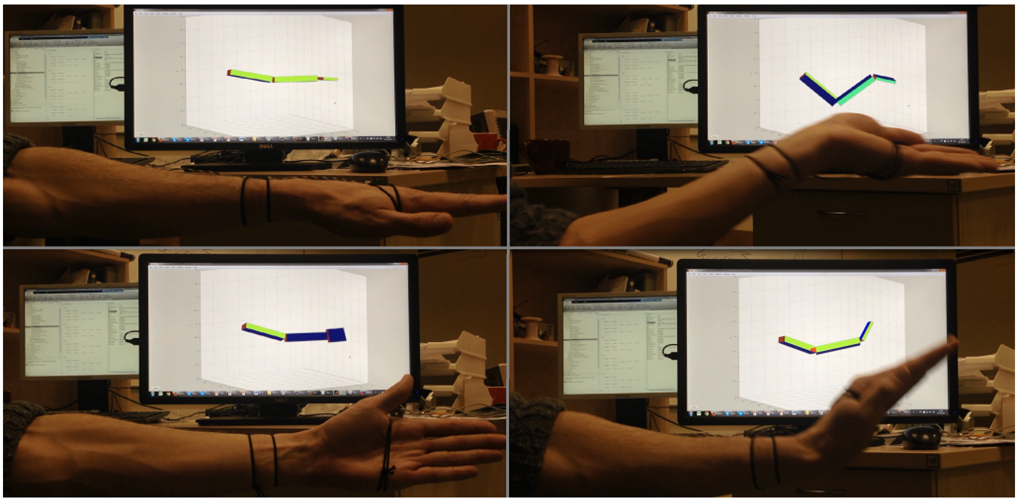


Figure 3.8: Human hand movement bio-mechanics reconstruction from wearable sensor node data.

small/low-cost/low-power sensor node that can accurately estimate orientations in human bio-mechanics model during dynamic movements.

Several methods for acceleration, magnetic and gyroscope sensor fusion have been explored and a prototype was built using complementary filters [44] originally designed for applications in Micro Areal Vehicles. This algorithm was adapted for application in wearable sensors for human bio-mechanics measurement. A specific sensor node was designed consisting of 9-axis sensor (accelerometer/magnetometer/gyroscope) and microcontroller (Fig. 3.7, that can be connected to our previously used sensor architecture [37].

In Fig. 3.8 a demonstration of an early human hand bio-mechanics monitoring prototype can be seen.

A master thesis was dedicated to the research of multi branch network application for human biomechanic monitoring using inertial/magnetic sensors [Result A.2.2.2]. During the research complete human body bio-mechanic model using 12 inertial/magnetic sensors was developed and compared to Microsoft Kinect produced human skeleton model.

A major drawback for low-cost MEMS inertial and magnetic sensor application for orientation estimation arise from imperfect sensor parameters such as scale errors, bias errors and axis cross sensitivity and misalignment. Work

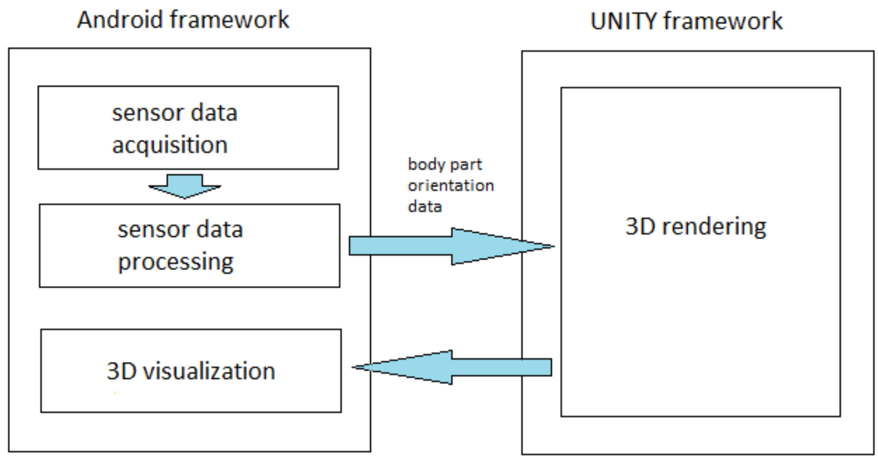


Figure 3.9: Motion tracking visualization software diagram on Android using Unity

has been done to develop automatic calibration without external equipment, that would allow on-the-fly calibration during the use of the device. This approach can provide essential contribution to inertial/magnetic sensor systems applications in general by removing the necessity of cumbersome calibration routines, that are usually required before each use of the system.

This research has synergy with CONVERGENCE project [Result A.4.4.4][Result C.6.4] in which the gathered date is used for activity classification.

Motion tracking visualization on Android with Unity game engine For motion tracking system to be usable for physiotherapists or trainers the software for visualization was developed. Initially motion tracking data acquisition, processing and visualization was implemented in MATLAB as it allows rapid development and testing of algorithms. Physiotherapy specialists and trainers are usually not familiar with MATLAB computation environment, and also MATLAB framework is commercial software and in order for them to use software developed for this framework, they would need to purchase MATLAB license which is costly. To avoid that the software for motion tracking sensor data acquisition, processing and visualization was developed on Android OS. To run this software only device with Android OS is required, which allow system to be easily deployed for specialists that could be interested in motion tracking system.

Sensor data acquisition through Bluetooth and some parts of sensor data processing algorithms where already implemented using Android framework in Java previously for different applications which used sensor network architecture. To reuse existing code, architecture shown in Fig. 3.9 was implemented. It can be

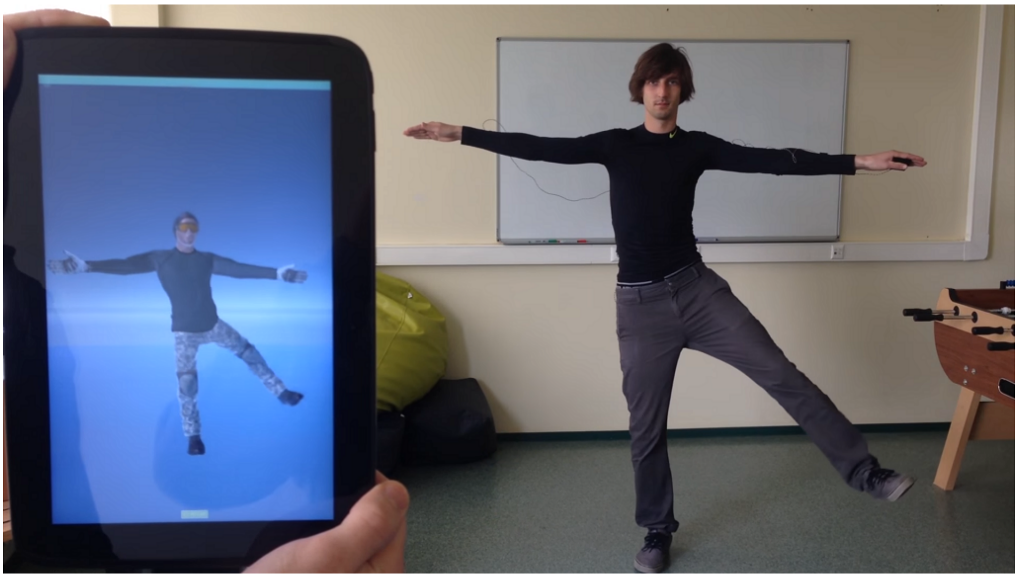


Figure 3.10: Motion tracking Android application

seen that Android framework is used for sensor data acquisition and processing, then the computed body segment orientations are transferred to UNITY engine, where 3D scene is rendered, and transferred back to android application, where scene is displayed on screen. The android application is illustrated in Fig3.10

The resulting know-how has resulted in a spin-off company [Result C.5.1].

3.3.5 Mobile device for ECG monitoring

3.3.5.1 Abstract

Judging from Disease prevention and control center data the main cause of death in Latvia still is the heart and vascular diseases. The most important heart and vascular disease test is Electrocardiogram (ECG). There are three different ways to do this test – stationary, load, and long term. The most common is stationary, which is also the most accurate, but the length of the test is less than a minute. Load test is for patients who complain about problems when doing some physical activities. Long term test is for patients who need to monitor heart for longer periods, for example 24 hours. Using Holter system for these long tests is uncomfortable for patient because it is necessary to deliver this system back to doctor for analysis. As a part of our MedWear sub-project we are developing a sensor for patients heart monitoring with potential to integrate it in the overall smart clothing architecture and gain the added benefits of activity monitoring together with ECG monitoring. We are making an embedded system that is easy to use for the patients, doctors and supervising staff. The collected data is sent to the database over the air using the advantages of wireless sensor networks. Doctor can monitor patient's health from distance and decide what to do before the system is even returned. Human movement and environmental factors are interfering with data that is why there is a need for data analysis to filter noise

and get more believable results. Using other MedWear sensors we can monitor patients movements and predict noise that needs filtering.

3.3.5.2 Introduction

Electrocardiogram (ECG) is the most important test that is used for patients with potential heart diseases. Wilhelm Einthoven was the first who invented this system in 1903, later in 1924 he got the Nobel Prize in medicine for his invention.

The same method is still used nowadays. Different electrical signals from heartbeats are monitored using electrodes that are connected to patients flesh. ECG test provides important information about inner workings of the heart and helps diagnose serious heart rhythm disturbances. To use this test firstly patient has to have some complaints about dizziness, blackouts, palpitations etc. ECG is important for patients of all ages, because it provides important information about patient's health.

Most common is the stationary test that is concluded in doctor's cabinet and is no more than a minute long. That means that there is a small chance that in this moment doctor can see the real problem with a patient's heart for example arrhythmia, if it appears only once in a week. To get more accurate readings doctor sends patient to get Holter monitoring system which monitors patient's heart for at least 24 hours. This system lets patient go on with his everyday life while it collects the data. In addition patient has to fill a diary about his feelings, like dizziness, coming blackout, or even an argument with a neighbor. Using this system patient has some discomfort, because, patient can't get wet not to break the system. But the biggest discomfort of all is that patient has to deliver the system to doctor on his own, so that the data can be read and analyzed.

Previously we reviewed various producers of ECG and holter devices and concluded that all producers of ECG and holters at the same time are the direct sellers of their own production first and only then their production has been delivered by other dealers.

Our group made our first prototype Mobile ECG monitoring device [Result A.4.3.6] based on CC3200 ARM Cortex M4 Micro controller, with embedded WiFi chip, for data streaming via network channels. At the heart of our device data acquisition is ADS1292R analog to digital converter, that is build for the specific purpose of gathering various heart signals, and amplifying them with programmable gain starting from 1 going up to 12.

As the first prototype board was finished it was subjected to various tests starting from basic Ground and Power supply inputs, ADC's internal square wave tests and heart rate signal simulator circuit inputs. The tests and the results are explained below.

3.3.5.3 First prototype mechanical debugging

As the first prototype was completed we encountered couple of problems associated with its hardware design:

- **Flash memory chip not working** Used to store program code. Solution was to tie the HOLD pin to power supply line;

- **SPI signals not reliable.** Used in communication with CC3200 and ADS1292R. Solution was to add couple of pull-up resistors to each of SPI data pins and pull-down resistor to clock pin;

3.3.5.4 First prototype tests

For the first test, all input channels were down, ADS1292R generated test signal by it self and sent it over SPI. As was expected, the CC3200 could gather data from ADS1292R over SPI and send them to the PC. At this moment we was not able to monitor the form of the signal. Using processing language and Processing IDE was written UART plotter which could draw the receiving data and save then in .txt file.

Next task was, to apply some output signal to the ADS1292R inputs and draw corresponding graph on the PC. Sending to the ADS1292R square wave with 1kHZ frequency and 2.5V amplitude, we were able to observe the save square wave on the UART plotter on the PC.

But, according to that the heart generates about 5mV, which is several orders of magnitude lower than the previous test signal amplitude, next test signal have to have amplitude about 5mV. The minimal amplitude of frequency generator, which is at our disposal, is 50mV. The parameters of the following test signal are 1kHZ frequency and 50mV amplitude. The waveform of the plotted signal reminds nothing but noise, as shown on the figure 1.3.12.

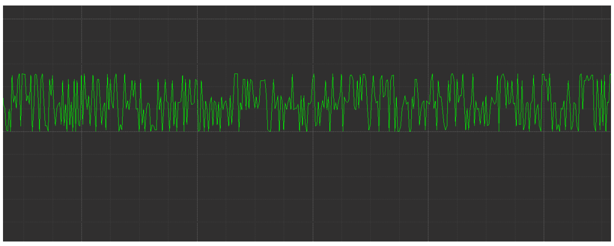


Figure 3.11: 1kHZ, 50mV signal after digitization

Unfortunately, the noise level of the surrounding space is commensurable with the heart generated signal. The solution was to reconfigure ADS1292R, put higher gain on the first channel, enable reference buffer and change data rate to 125SPS. After reconfiguration, we were able to observe the signal without noise.

For the following tests were used the ECG Simulator which could generate sine wave with 10/60/100HZ frequency, square signal with 0.125hz and 2 hz, 2hz saw tooth signal, and hear beat signal with 30/60/120/240 heart beats per second with 2mV amplitude.

As shown on the figure 1.3.13, the green graph represents the signal from first channel and the yellow one from the second. The same tests were made for the following signals: square signal 2HZ, 2mV; saw tooth 2HZ, 2mV; heart signal with 30/60/120/240 bpm. If the output square signal was more or less commensurable with the input, the saw tooth brought more dissonant results.

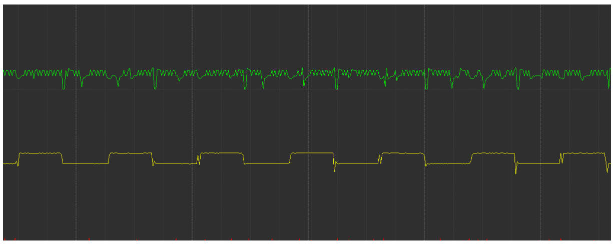


Figure 3.12: 1kHZ, 50mV square signal after digitization, ADS is reconfigured. Green - CH1. Yellow - CH2

As shown on the figure 1.3.14, the yellow signal is clear, but the form of the signal doesn't reminds the saw tooth. However, it looks like the signal is separated in three pars, that could be because of the overflow.

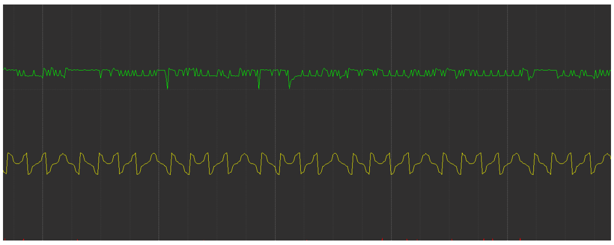


Figure 3.13: 2HZ, 2mV saw tooth signal after digitization, Green - CH1. Yellow - CH2

The same problem with overflow, we could see on the following figure 1.3.15, where is displayed the digitized heart beat signal at 60bpm.

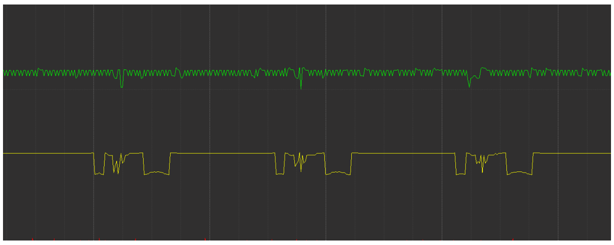


Figure 3.14: 60bpm heart beat signal after digitization, Green - CH1. Yellow - CH2

Besides problems related with the digitization, data storage problems have been found. The CC3200 cant store this amount of data that we gonna receive from the ADS1292r, so that means that we have to use external storage. All SDcards, which could be used as the external storage are using SPI interface to write and read data. But, CC3200 have only one SPI communication interface, and it is used by the ADS1292r already. There are two solutions - the first one is to share SPI interface between SDcard and ADS1292, but that means that we could not be able to read data from ADS and write them to SDcard as the same time, as well as we could not be able to send data over WiFi to the database and read data from the ADS. The second solution is to change CC3200 to another microprocessor with same parameters and 2SPI interfaces.

1. I prototype debugging

   Continuing the tests of the first prototype several bugs and significant mistakes were observed, which were totally spoiling the idle operating process of system.

   - Existing filter wrong design

     At the First, as was mentioned before, the acquired signals were nosy, according to the design of system, signals not supposed to be such irreconcilable and kind of "overflows" were observed in digitalized signal, but at all, schematic revision showed that input analog filters were configured to sustain respiration monitoring for one of existing channels. Due to this design, the specific configuration for ADC is necessary. First input circuit configuration is shown on Figure3.15.

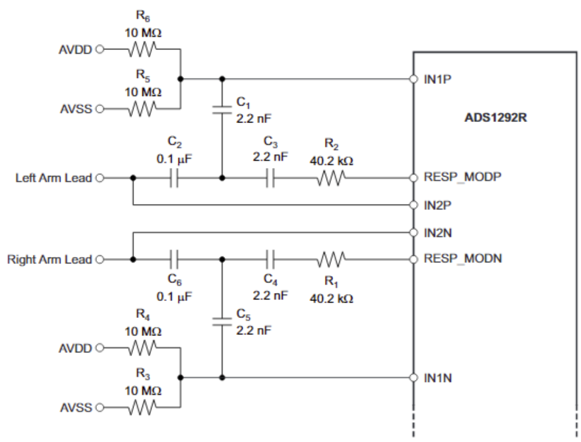


Figure 3.15: Input circuit configuration

   - adding SD card Slot it was already claimed that it is necessary to add an external storage to the system due to small capacitance of inner storage, about 250K. After designing the SD card schematic and PCB design, testing PCB circuit was made to be sure, that all components are working correctly. On the Figures 3.20 and 3.21 we could see the schematic and prototype PCB, respectively. On Figure 3.20 we could notice that to the SD card slot power line is driving by NPN transistor. Such thing was made to ensure power management. According to SD Card's data-sheet, the power consumption of SD Card is about 30 mA, for such energy Dependant device there are very significant power consumption. The energy efficient SD Card controlling algorithm is based on the fact that writing speed is much more higher than data acquisition rate. The top speed for SD Cards in SPI mode could be around 1MB/s, and data acquisition rate is about 500SPS, so that mean that only 14% of all working time the SD Card will receive data, all other time it is doing nothing. According to this information, wold be logically to turn of the SD card between writing phases.

- Testing circuirty

  After removing the respiration circuit from the design and direct signal attachment to ADC inputs, the problems with ”noisiness” and ”overflows” were solved. On Figures 3.16 and 3.17 we could observe the digitized ECG signal with 60 and 120 beats per minute, respectively. After such tests, and conformation that system is working correctly, the next step is to capture ECG from human body.

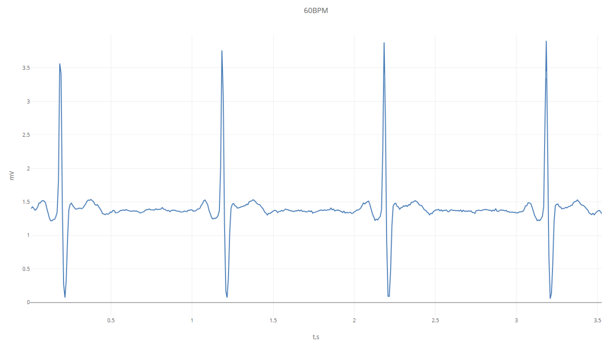


Figure 3.16: 60 BPM

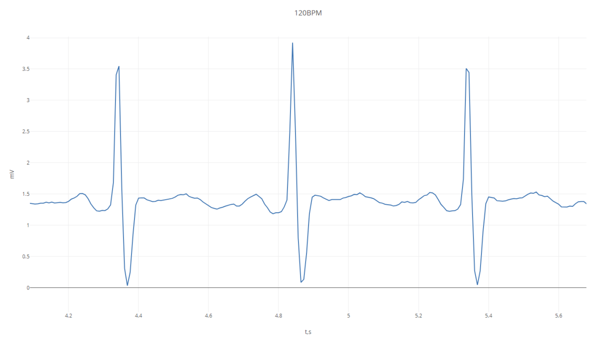


Figure 3.17: 120 BPM

- Designing EMI and anti-static filter Despite the fact that it is possible to connect ECG leads from human body directly to the ADC input, the fact that simple static shock could totally burn the whole system, means that we must deal with this problem. The solution, and also improvement of existing system, is the implementation of anti-static protection with EMI filter - Figure 3.19 represents the design of analog input protection circuit. And, also, prototype PCB on Figure 3.22.

2. I prototype testing

    - Capturing ECG wave from human body The final step of prototype life-cycle is to capture the ECG signal from human, save it on SD Card and download the data to PC. One the Figure 3.18 is shown, the stored on SD Card, digitized ECG signal from human

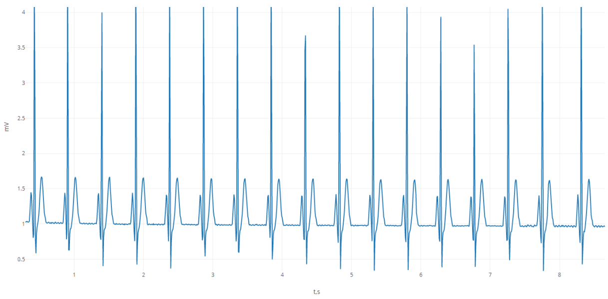


Figure 3.18: ECG

3. II prototype designing

    After successful tests of I prototype the next step is to develop a full 12 lead ECG system [Result A.4.3.11], keeping in mind all previous lessons. To increase the number of leads the ADS1292 was replaced with similar ADS1298 which contains the 8 differential analog channels. The SD Card slot and driving transistor were included to design, as well as EMI filters with anti-static protection. In addition, to increase the stability of the system and noise resistance the power supply of analog and digital parts of schematic was separated. The new design is shown on the Figure 3.23.

4. II prototype debugging The next prototype had much fewer problems but there were still a few that were eliminated fairly quickly. These include that the MOSI and MISO pins were swapped, and the enable pin of ADS1298 was floating in the air.

5. II prototype testing Assuming that the circuit design is fine, and nothing will interrupt the idle operation mode, we are moving to the test part. The first test was unsuccessful, as we can see on Figure 3.24, the resolution of captured 10Hz sinusoidal wave is very low. Seems to be, that the configuration of channels works not as we wanted, and the input gain level is about 1.

3.3.5.5 ECG analaysis embedded algorithm

To provide real time feedback from the device itself in an energy efficient manner, an algorithm for detecting the key points in the ECG signal was implemented.

To find QRS complex (Figure 3.25), P and T waves at first ECG data must be filtered to get smoother data and lose data noise. When data is smoothed, it

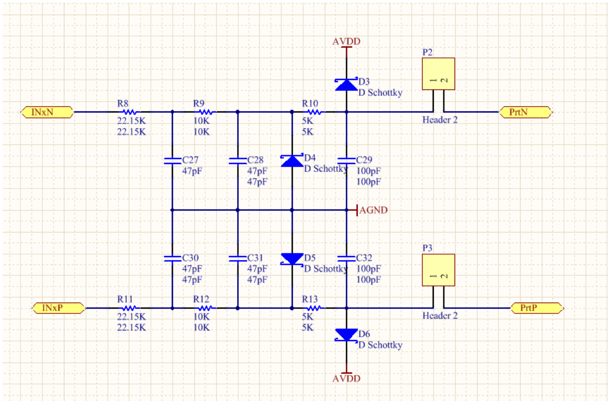


Figure 3.19: Analog Input Protection and EMI filter

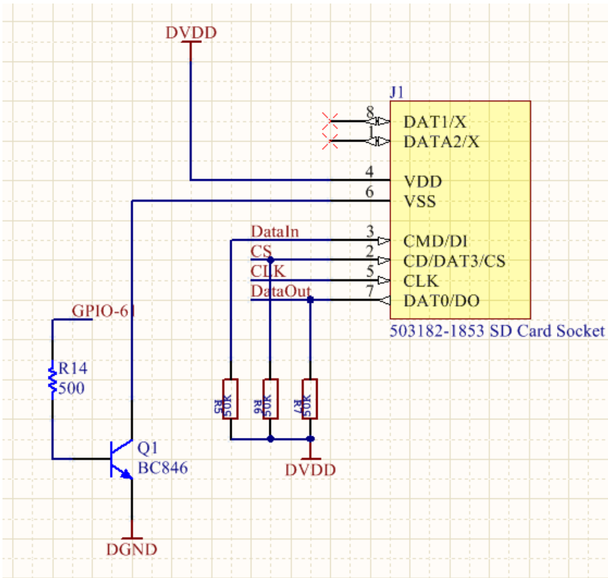


Figure 3.20: SD Card Slot Schematic

must be differentiated and afterward all data processing must be done with this differentiated data. To find R peak the PK_n position must be found. PK_n is the first peak in processed data which is above H_n value ($H_n = 0.7 * H_n + 0.3 * (0.7 * PK)$). Initial H_n value is is 70% of maximum value of the processed data in the first 2 s. When PK position is found, nearest peaks before (PK_b) and after (PK_a) PK must be found. If the absolute value of the PK_b is greater than PK_a , then R peak is at the zero-crossing point between PK_b and PK_n , otherwise it is at the zero- crossing point between PK_n and PK_a . Q peak is zero-crossing point preceding R peak, but S peak is zero-crossing point following R peak. To find the beginning of QRS complex Q_i point must be detected which is peak preceding Q point. The beginning of QRS complex is nearest point preceding Q_i point which is less than 50% of Q_i absolute value. To find T wave a window in which it will be searched must be defined. If the average R to R value is more

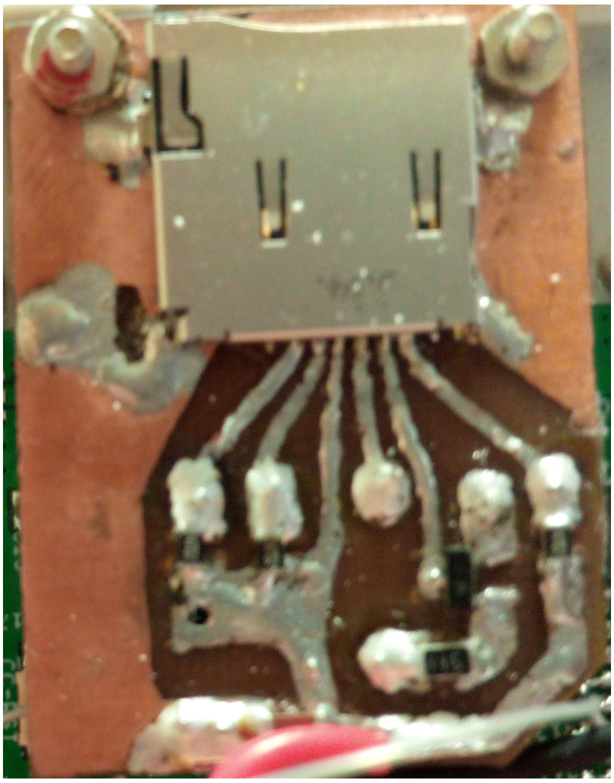


Figure 3.21: SD Card prototype PCB

that 700 ms, then beginning of window (bwind) is 150 ms after R peak, but the end of window (ewind) is 500 ms after R peak. If the average R to R value is less than 700 ms, then bwind is 100 ms after R peak, but ewind is 70% of average R to R value. In this window minimum and maximum must be found. If min position is before max position a minimum (mina) between the max position and ewind must be found. T_i point must be determined, it can be min, max or mina position (depending on T wave morphology). The first value which is less than 50% of T_i absolute value, is T ending point, but the peak of T wave is the first zero-crossing point backward from T_i position. P wave is searched in a window which is between point which starts 225 ms before R peak and end 155 ms later. If the minimum and maximum values in this window is 2% of QRS complex maximum slope then zero-crossing point between min and max position is P wave's peak, otherwise there is no P wave.

Algorithm diagram is shown in figure 3.26.

3.3.6 Electromyography in wearable network system

Electromyography (EMG) is technique for evaluating and recording the electrical activity of muscles. It is often used in clinical diagnostics and research of human movements. Moreover EMG signals in combination with other sensors can be used as control signals for prosthetic devices and human-computer interface.

In this project EMG is one of the sensor types researched to complement our

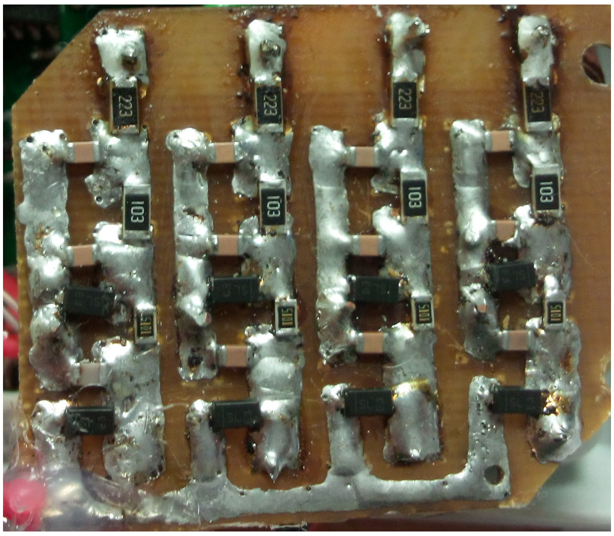


Figure 3.22: Analog Input protection and EMI filter prototype PCB

MedWear system with additional measurements which may be combined with other sensor data.

A basic EMG recording device consists of biopotential amplifier and at least 3 electrodes - two for biopotential sensing and one as signal reference. A commonly used EMG amplifier scheme with instrumental amplifier and actively driven ground was adopted and successfully tested with wet Ag/AgCl electrodes. Because of the excellent signal quality and reduced motion artifacts Ag/AgCl electrodes are common choice in clinical applications. But Ag/AgCl electrode operation requires electrolyte gel or solution applied on layers of the skin, which encumbers system wearability.

Other approach is to use dry-contact electrodes designed to operate without explicit electrolyte. Instead, it is usually supplied by moisture on the skin (i.e.,sweat). Because of increased skin-electrode impedance, these electrodes suffer from considerable induced motion artifacts and stray interference. But nevertheless the universal and simple design makes them attractive for non-clinical applications.

In its simplest form dry-contact electrode consists of conductive layer (i. e. metal disc) in contact with the skin. For more comfort the conductive layer can be made of conductive rubber, foam or fabric. Additionally softer materials better comply to skin reducing contact resistance and improve signal quality.

To improve system wearability EMG sensor prototype using rigid dry-contact electrodes was developed and successfully tested by obtaining EMG signals from eye squeezing muscles during subsequent eye squeezes.

To implement detection of muscle activity three EMG signal processing approaches were tested and compared:

- single-threshold method with raw and filtered amplitude,
- double-threshold method described in [45],

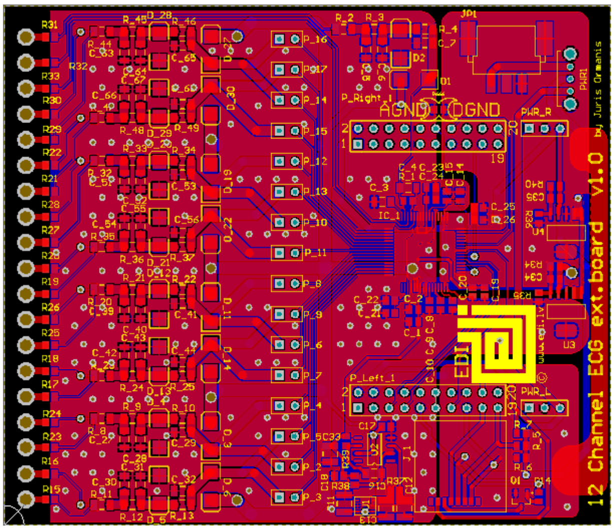


Figure 3.23: 2nd ECG monitor PCB design prototype

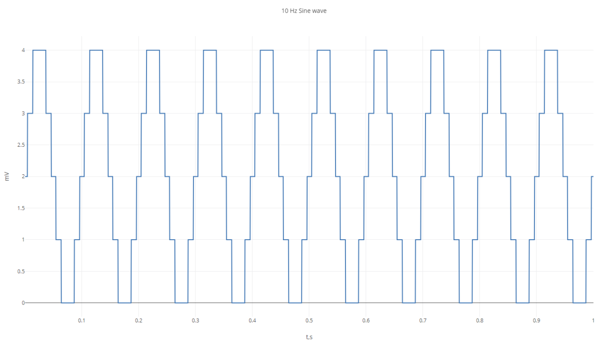


Figure 3.24: 10 Hz sinusoidal wave captured from ECG simulator

- detector matched to MUAP (muscle activation potential) shape described in [46].

EMG signal acquired from eye squeezing muscle during 4 subsequent eye squeezes was used as the test signal. All examined methods were able to successfully detect all 4 squeezing events. Judging from computational complexity the detector matched to MUAP shape was decided to be the most suitable for wearable systems and real time applications.

Research in EMG also provided beneficial in solving EEG problems, as shown in the co-publication with project No. 4 [Result A.1.2.17][47].

3.3.7 Signal processing of bio-mechanical signals

In addition to methods for general signal processing developed above a more specific method for gait analysis data filtering was also developed and published in [Result A.1.2.14] allowing for more precise future analysis of bio-mechanics while running resulting in potential health benefits.

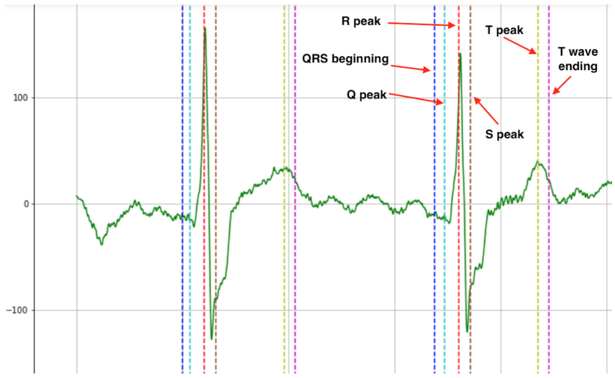


Figure 3.25: ECG signal with main variables

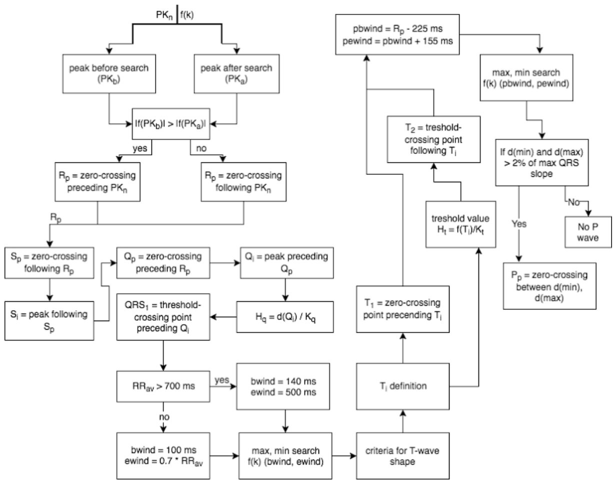


Figure 3.26: Algorithm diagram for finding key points in ECG

3.4 Applications of technologies developed in the project

The technologies developed in this project has been applied in several applications, initiated both by our research institute and approbated with external institutions, and also developed as contract research using knowledge and results reached in this research.

In the next subsections main examples of these applications are described.

3.4.1 Head position monitoring in therapy

There are patients with cerebral palsy or people after serious injuries who have difficulty maintaining vertical head position. In rehabilitation there are therapies to improve patient ability to maintain normal body position. Therapy with patients who suffer cerebral palsy can be problematic, because communication with some patients is troublesome or almost impossible. In collaboration with rehabilitation center ”MEL” idea emerged for system that could improve rehabilitation process for head position therapy. A prototype of wireless sensor module with single accelerometer/magnetometer sensor was developed adopting hardware used for shape sensing [Result A.4.3.2]. This prototype was attached to wearers head with elastic head band as seen in Figure 3.27 and used to determine head position.

Figure 3.27: Sensor module for head position monitoring.

By using sensor integrated in module it is possible to estimate tilt of the head relative to gravitation vector of earth.

A specialized software with simplified graphical user interface was developed. It was used to provide feedback about the head position to the wearer (Figure 3.28) [Result A.4.1.1]. The object, seen in application screenshot depicted in Figure 3.28, is controlled by wearers head movements. System is calibrated for preferred position of the head before the session. During session the task for the wearer of the sensor is to maintain the object in the marked area in the center of the screen. If object leaves marked area, feedback is triggered changing background of the screen to red color and producing sound alert. This simplified approach allows to perform therapy on patients who are hard to communicate with.

Posture and head position monitoring in therapy To obtain combined information about patients head position and posture, prototype was developed in collaboration with rehabilitation center ”MEL”, that combines head position and posture monitoring functions [Result A.4.3.5]. Specialized Vest was developed embedding 20 sensor nodes for posture monitoring and additional sensor for head position monitoring. Specialized application was developed for posture and head tilt monitoring providing feedback for the wearer of the system. Application also provides with data logging feature, that allows the data later to be visualized to provide better insight of the session as seen in Figure 3.29.

3.4.2 Head device for computer control

As mentioned in previous section, there are patients that are problematic to communicate with. For this reason the idea for system providing means of

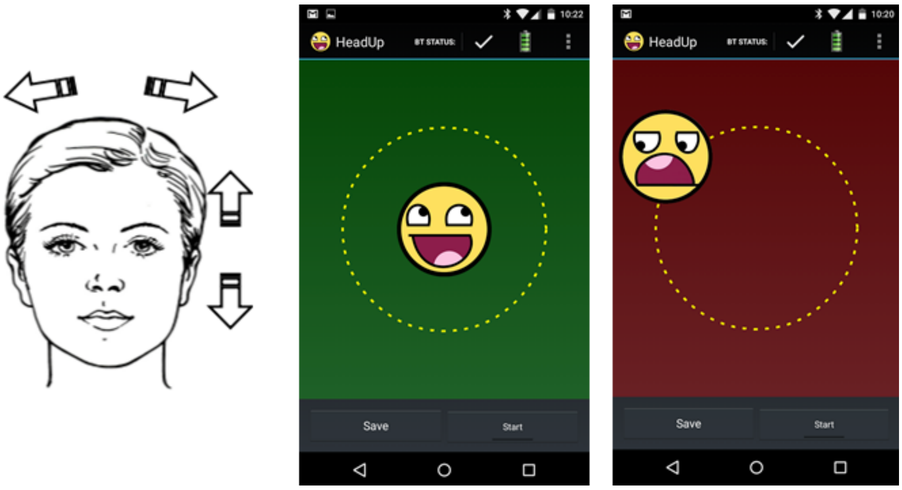


Figure 3.28: Head position monitoring application screenshot.

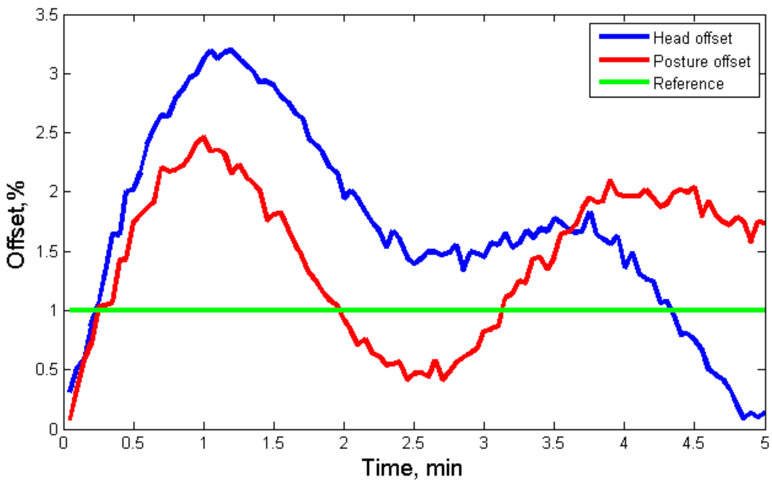


Figure 3.29: Head position and posture data visualization.

alternative communications emerged. Previously described system can be used as computer mouse like human-computer interface device, that is controlled by head motion.

In Figure 3.30. screen shot of smart phone/tablet application is shown used as tool for alternative communication. The application consists of moving object (yellow face) and two colored regions (red and green). Regions represent two options: yes/no type answers. The medical staff can ask yes/no type questions, and respondent can move the object to region representing corresponding answer by moving his head. In current implementation answer is accepted if yellow face marker has been in answer region for specified amount of time. The accept of answer is represented with sound alert.

Similarly head movements can be used for computer cursor control. To map head orientation (rotation angles) with cursor coordinates Bluetooth Low

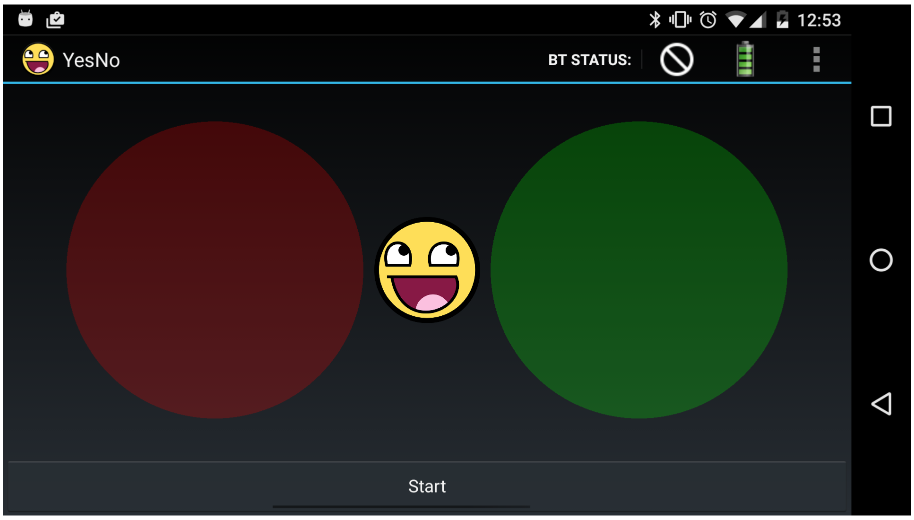


Figure 3.30: Application for alternative communication.

Energy HID-over-GATT profile can be employed. It provides standardized wireless protocol for cursor control which is supported by most of commonly used operating systems like Windows, Android, iOS and other.

Dwell time required for automatic target selection degrades interaction speed. To provide manual target selection mechanism head orientation sensor was combined with EMG sensor and master thesis was dedicated to research system application for alternative communication [Result A.2.2.1].

A wireless headband prototype (Fig. 3.31) with embedded single 9 DOF IMU (LSM9DS0) and single channel differential electromyograph, was developed [Result A.4.3.7]. Electrodes were placed on the inside of the headband, so that, when applied, sensing electrodes would rest on the right side of the forehead and DRL electrode would rest on the middle of the forehead. Sensing electrode placement allowed detection of facial muscle activation of right side of the face, mostly from eye squeezing or teeth clenching. With two sensing electrodes, signals emerging from multiple muscles could not be differentiated, however consecutive muscle activation events could be distinguished.

Prototype feasibility for human-computer interaction was tested with a group of participants. Two methods were used to quantify the system performance: *Grid task* and *Typing task*. The results showed, that developed system is feasible for hands-free computer control. Achieved interaction speed was close to other studies, which used inertial sensors for cursor control, but did not take into account target selection, showing that muscle electrical activity detection can be used for fast target selection. More detail about system design, experimental setup and results will be published in conference paper [Result A.1.2.11].

Headband prototype was improved significantly reducing power consumption and size of the hardware. Also rigid metal electrodes were replaced by textile electrodes to improve system wearability. The improved prototype was approbated in rehabilitation center MEL with patients suffering from cerebral palsy and autism [Result C.3.4].

Figure 3.31: Wireless headband prototype with (1) dry-contact electrodes, (2) reference electrode, (3) charging port

3.4.3 Knee device

Knee joint is the largest joint in the body, and one of the most easily injured. Knee injury is one of the most common reasons people see their doctors. In 2010, there were roughly 10.4 million patient visits to doctors' offices because of common knee injuries such as fractures, dislocations, sprains, and ligament tears. We propose a combination of a wearable sensor system prototype [Result A.4.3.3] and a mobile application [Result A.4.1.2] in order to help patients successfully complete rehabilitation procedure. Wearable system consists of 4 sensor nodes used for knee joint flexion/extension angle calculation. After successful vital signs data acquisition from sensor nodes, data is being transmitted to mobile application. As part of the project a mobile application was developed to make calculations, analyze collected data from sensor nodes, store and visualize it (Figure 3.32). Another important functionality of application - communication with a patient using developed notification system. Notification system was implemented based on health specialist – patient communication style aiming to create a similar feeling of safety when a patient is near physiotherapist. Patient is notified when exceeding the flexion limit threshold and also when reaching the end of rehabilitation session. Developed solution was tested in dynamic conditions – patients used the system during their rehabilitation session in real life. System received positive feedback from participants and rehabilitation specialists (Figure 3.33). During rehabilitation session developed prototype data was compared to industrial digital Precision of the implemented solution was calculated: 0.79 degrees, fulfilling the requirements received from doctors on current condition. Part of this work is described in publication [Result A.1.2.18] and is basis for the doctoral thesis [Result A.2.1.7] under development and also part of masters thesis [Result A.2.2.6] and bachelors thesis [Result A.2.3.1].

3.4.4 BT Smart Inhaler

Asthma patients use inhalers to deliver medication into the body via lungs. To help them to comply with their medication schedule and improve treatment, we

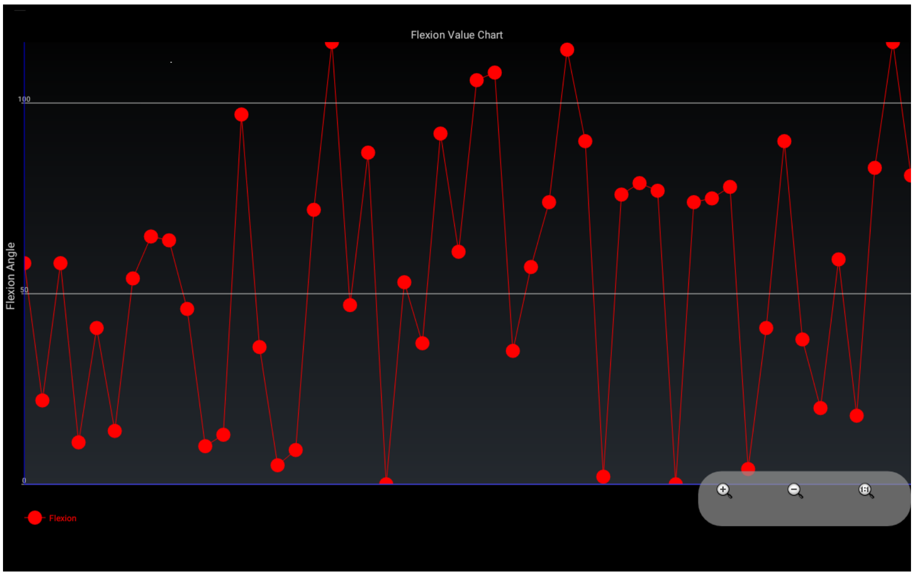


Figure 3.32: Knee flexion data visualization.

Figure 3.33: Patient participates in system prototype testing.

proposed to use BT Smart technology to send notifications from inhaler to a smartphone or a tablet.

We developed and tested a proof-of-concept prototype using TiWi-Ub1 BT Smart module with minimum circuitry required for device programming, registering push events and sending notifications to BT Smart enabled device (Figure 3.34). We also made an Android application, which logs received notifications and assigns corresponding time stamps (Figure 3.35). In current consumption test, logging averagely 4 push events every day, device could continuously operate for two weeks powered by two AA batteries in series.

This technology has lead to contract research [Result C.1.3] and in the future we are planning to improve device and application power efficiency to extend battery life to more than a month and implement time tracking into the inhaler device to eliminate necessity of connection to master device during push event to assign valid time stamp.

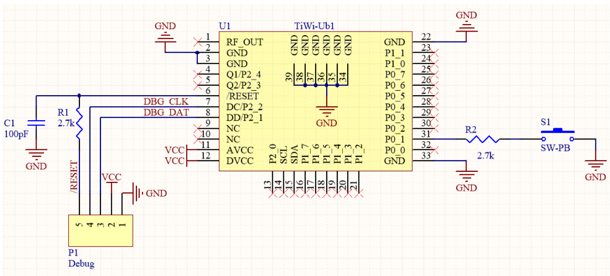


Figure 3.34: Proof-of-concept prototype schematic of inhalator monitoring device using TiWi-Ub1 module

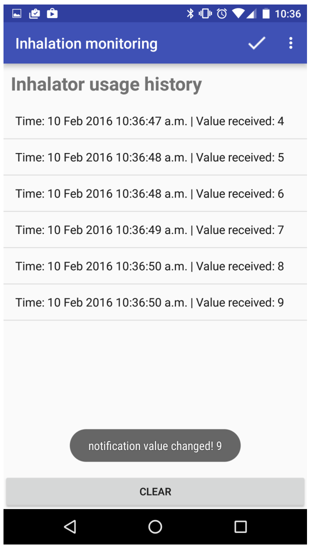


Figure 3.35: Inhalator monitoring device Android application screenshot.

3.4.5 Palm prosthesis dynamics monitoring in therapy (in cooperation with Wide.Tech)

During this project a wearable sensor system for prosthesis motion tracking in order to improve rehabilitation process was proposed. We developed a sensor system for prosthetics that will be able to track angle of a joint flexion/extension in real time. Acquired data will be used to monitor rehabilitation process and patient progress. For palm prosthesis flexion/extension angle calculation was used a network that consists of two 3-axial accelerometers and magnetometers on-board. Special cases were designed and printed to ensure sensors, master board and battery protection (mechanical influence etc.) and calculation precision 3.36. Position of sensors can influence on received data precision – sensor nodes should be located on one straight line (one plane). Sensors should be attached to the prosthetic in a way to minimize free movement inside the printed cases. As part of the project a mobile application was developed to make calculations, analyze collected data from sensor nodes, store and visualize it. Cloud services were used to provide data storage and communication between patient and health specialists, so that patient will be using up-to-date rehabilitation recommendations and health specialist will be informed on actual status of patient's rehabilitation progress. In the scope of this project, prototype version uses Microsoft Azure cloud services 3.37. Proposed prototype version was created in collaboration with and approbated by start-up company "Wide.Tech" [Result C.3.7], participating in "Fabulous" EU acceleration program.

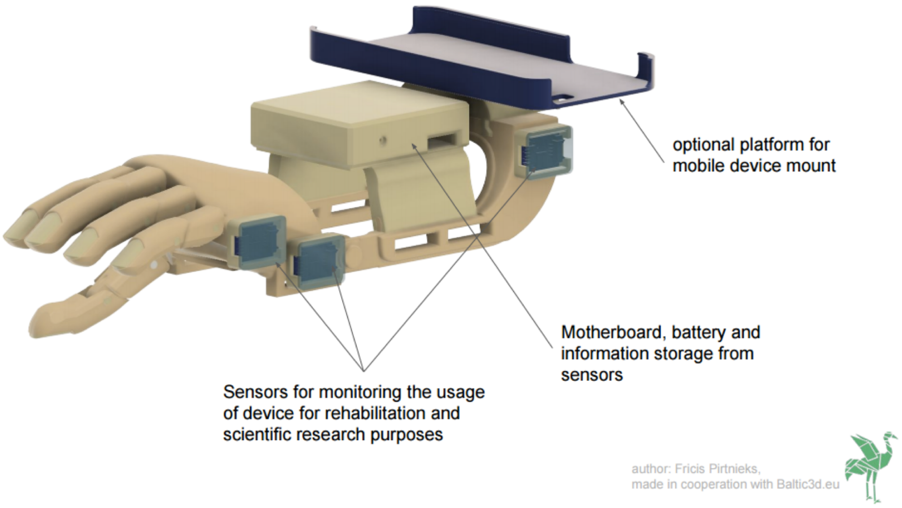


Figure 3.36: Palm prosthesis model with sensors attached.

3.5 Results

During the project a wearable sensor system is being developed, by both improving the architecture and developing new sensors for use in such system. In addition several of these results have been promoted to general public through dissemination efforts, and some have already attracted interested companies, thus resulting in contract research producing prototypes for specific applications.

Results of this research has also been presented in several conferences and published in 11 research papers, of which 2 are in high impact factor journals.

Based on this groups research 2 bachelors thesis and 3 master thesis have been developed and defended. Additionally 3 doctoral thesis are also based on this research of which 1 is already defended and 2 are still being developed.

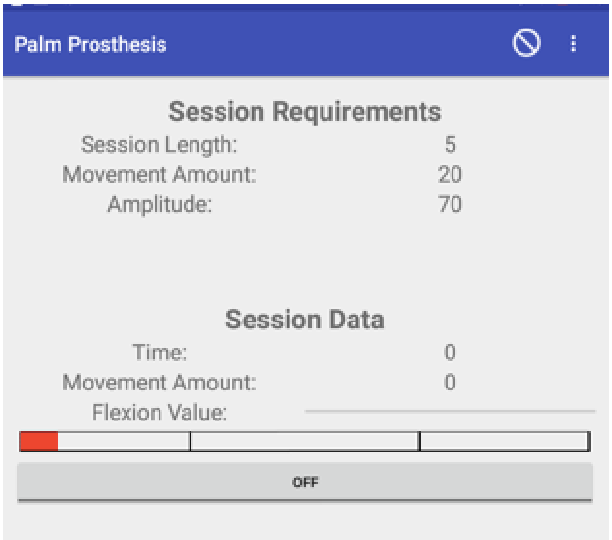


Figure 3.37: Prototype version of mobile application for palm prosthesis dynamics monitoring.

During the project this group has produced 2 software prototypes and 6 hardware prototypes three of which have been approbated for use in industry.

Additionally the research has already been the basis for 3 synergy projects and 1 spin-off company.

3.6 Discussion and future work

Authors see system future research as a part of global human vital signs monitoring solution – developed device can be used in synergy with other systems to get more data and provide them to health specialist to better diagnostics. We are planning to create cloud based solution to analyze data from various patients with sensor nodes attached, in order to define risk factors of rehabilitation process.

Chapter 4

SmartCar - Intelligent transport systems

4.1 Introduction

Automated driving systems have many potential benefits, such as improved safety and reduced environmental impact. It includes both fully automated driving and partially automated driving, such as advanced driver assistance systems (ADAS) ranging from purely informative to those completely taking over control in emergency situations. Even though purely autonomous driving can provide many of these benefits, as seen in self-driving cars [48], connected cars that do cooperative driving has the potential of extending these benefits even further, as evidenced by the move of European Commission to support it through Connected and automated driving (C-ITS) deployment platform [49].

Our main goal for the SmartCar - Intelligent transport systems project was to develop research expertise, prototypes and tools for boosting further development of vehicle systems dealing with cooperative and autonomous driving. Our work was focused mainly in the following more specific directions:

- Develop a car control system architecture and implement an universal car API;
- Develop a programmable car for development and testing self driving car applications using uniform car API:
  - Add a *drive-by-wire functionality to a real-scale car;*
  - *Develop a programmable mini-car (on 1/18 scale RC car basis) and in-door positioning system for it for development and testing of self-driving car algorithms in small-scale;*
  - *Prepare a software simulation platform for development and testing self-driving car applications using software car, environment and sensor models;*
- Develop stereo vision algorithms for object detection outside the car;

- Develop Deep Learning algorithms for automated driving based on video camera information;
- Develop sensor algorithms for driver's face recognition for ADAS applications;
- Develop a 5.8GHz network device for V2X data transfer in the network of cars and road-side units;

The work done in this project has provided synergy to project 3CCar [Result A.4.4.1][Result C.6.1].

4.2 Related research

Cooperative driving became an emerging research topic together with an expansion of computing technologies into automotive domain. The formulation of basic concepts was performed already in the 1990-ties [50]. Significant accelerating factors for further development of cooperative driving were the end of Global Positioning System (GPS) Selective Availability as well as the evolution of combined navigation solutions precise enough for road traffic scenarios [51]. The perception of external environmental objects, initially mainly based on analysis of passive information sources as general purpose cameras [52], during this time is transformed to a usage of multiple active information sources as RADAR and LiDAR systems [53]. The usage of multiple lines of evidence leads to the data fusion using techniques such as Kalman filters that take into account data particularities and inaccuracies [54]. The cooperation also means the communication, therefore, the standard for communication between separate vehicles (Vehicle-to-Vehicle, V2V) as well as between vehicles and road infrastructure (Vehicle-to-Infrastructure, V2I) was created [55]. Latest activities in the domain of cooperative driving are related to platooning including simulation [56] as well as real world controlled experiments as European truck platooning challenge 2016 [57].

4.3 Car Control System

4.3.1 Approach overview

The self driving car architecture we are focusing to is oriented on the following scenario:

1. a) The driver uses a software dashboard to choose a destination point on the map; b) A detailed route is computed using global map road data augmented with GPS routes on road lanes and other markup information, like traffic light and road sign positions;
2. When the route is set the driver press the "Start" button on the software dashboard. The car follows computed route until destination is reached. The primary driving method is the GPS path following. In time of driving

surroundings of the car (other cars, pedestrians, static objects etc.) are monitored. Driving is done at maximum possible safe speed. The car obeys the traffic rules and does not run on road obstacles.

4.3.2 Car API

Car control is done by actuators - steering, braking, throttle. The car actuator control functions are implemented on specific car hardware and encapsulated in a standard command set API. The API is also used to obtain information about car state as well (ie. speed).

The API is available by UDP protocol over Ethernet cable and is implemented in three environments: a) On the real-scale cars (like Mazda6, KIA Soul); b) On mini-cars (1/18 scale RC); c) On car software model in the Unreal Engine simulator.

The latter two development environments are critical to providing development and testing environment for cooperative driving algorithms at an affordable cost. Those algorithms involve several cars connected by a V2X network.

A server part of the API is implemented in C language. A client part of the API is implemented in C, Python and Erlang, and this list could be extended. That allows to do further development of car software using broad choice of programming languages.

4.3.3 Car control system architecture

The car control module (see Figure 4.1) is a combined hardware and software solution. It continuously obtains data about car state (as GPS position, direction, speed) and about its surrounding objects (positions and dimensions) from sensor devices. Data obtained from sensors is stored in the database. The system state is used to update motion plan of the car by *motion planning process* for some short future period (1 second) at a 5Hz frequency. Motion planning process describes the car's projected path in the future using a list of micro-goals for speed, steering angle, and relative position of the car.

Human-machine interface (HMI, software dashboard) sends commands initiated by driver to the car control module. For example car *operating mode* can be changed using *software dashboard*, emergency interrupt signal (*STOP* and *Resume* buttons on *control panel* could be pressed, etc.

Motion plan execution process performs step-by-step execution of current plan at a 25Hz frequency. The list of micro-goals describing the plan is converted to actuator control signals for throttle, steering and braking motors, and red/green beacon lights mounted on the car to inform outside observers whether car is controlled by human driver or self-driving.

Data from other cars (positions, directions, speeds) are received continuously at 25Hz frequency via *ETSI ITS G5 network*. The position of our car is sent to other cars at the same frequency. Data from the road infrastructure stations are received via the same network.

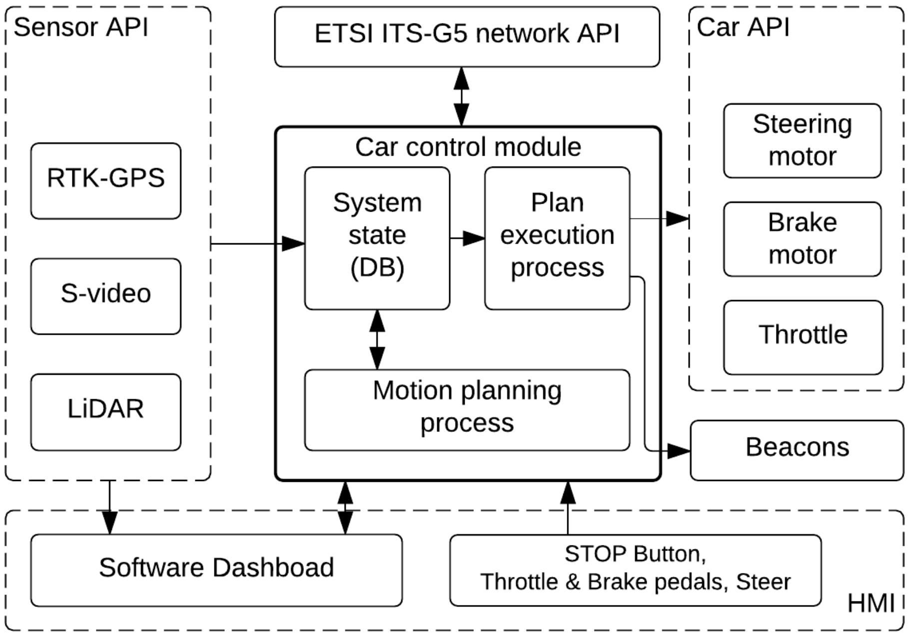


Figure 4.1: Car control system architecture

The software part of the car control system is developed in *Erlang* programming language and runs on *BEAM* virtual machine. Parts that deal with peripherals were written in C.

The car control system has an architecture of several independent software processes (Erlang light-weight threads) that are executed concurrently. The processes interact with each other via the system state stored in the in-memory database server.

Some processes just receive data periodically from sensor devices and store them into the database (GPS data, surrounding objects, HMI events, and incoming network packets). Some other processes are reading system state data from the database and sending them to devices periodically (outgoing network packets, HMI updates, and the car's surrounding object data updates). Separate processes are allocated for motion planning and motion plan execution [Result A.4.1.4].

Part of this work is also being described in a doctoral thesis [Result A.2.1.4].

4.4 Real-size car adaptation (Mazda6)

As our base car (Mazda6) did not originally have drive-by-wire ability for steering and braking, we have added controllable actuator motors for steering column and brake pedal and made some changes to the car that are described here 4.2) [Result A.4.3.8].

Figure 4.2: Mazda 6

4.4.1 Steer control

Our base car has a hydraulic power assisted steering system. To add steer-by-wire functionality to it we use Electric Power Assisted Steering (EPAS) motor from *Renault Clio* that was integrated into our car's steering column (see Figure 4.3, left). This motor could be driven by 12V PWM. For steering angle feedback we use CAN angle sensor from *Renault* that also is assembled on the steering column.

Figure 4.3: EPAS motor and braking motor

4.4.2 Brake control

Brakes of our base car cannot be controlled by wire. Therefore we added a motor from Electric Parking Brake Module from *Renault Laguna* that is used to pull brake pedal using wire rope (see Figure 4.3, right). Parking brake motor is also driven by 12V PWM.

For brake position feedback we use voltage formed by rotary potentiometer connected to brake pedal and read by appropriate ADC device.

4.4.3 Throttle control

We have added input selection ability to the wired connection between the throttle pedal and car's ECU to enable feeding ECU throttle control input signal from either pedal or the DAC of our control system as necessary.

Our base car throttle signal from pedal to ECU is controlled by two voltages: V_1, V_2. V_1 must be in range from $1.57V$ to $3.3V$ and V_2 must be from $1.02V$ to $2.75V$. The difference between V_1 and V_2 must be exactly $0.55V$.

These voltages are linear to throttle pedal position and motor RPM value.

4.4.4 Emergency takeover mechanism

GCDC rules required that the control system should provide manual emergency takeover feature for driver to switch a car to manual mode in case if something goes wrong while the car is in AUTO mode or its sub-modes (for instance in case of a software error, a system error or power outage). After emergency takeover all automatic control should be removed and car must switch to the manual control.

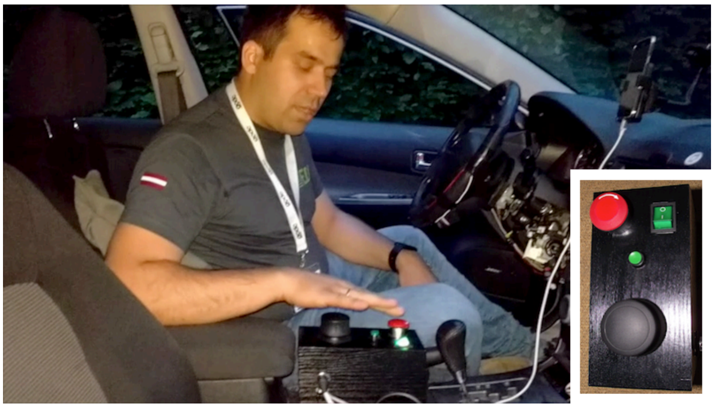


Figure 4.4: Control panel

Emergency manual takeover must be triggered by any of the following events:

- **By pressing the STOP button:** System must switch to manual mode if a special red button on control panel near driver's right hand (see Figure 4.4) is pressed.
- **By pressing any pedal:** System must switch to manual mode if throttle or brake pedal is pressed.
- **By moving the steering wheel:** System must switch to manual mode if steering wheel is touched.

4.4.5 Human-machine interface

In addition to control panel mentioned above the car control system's HMI includes a simple software dashboard — an application that shows current

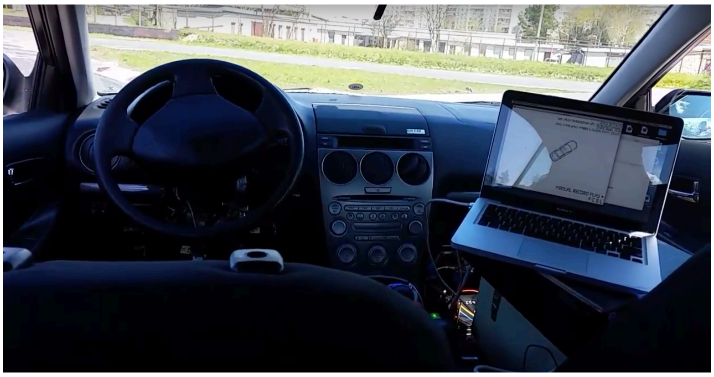


Figure 4.5: Software dashboard

car state parameters such as operating mode, speed etc. The dashboard also provides buttons for driver to change system operating mode or to adjust mode parameters (see Figure 4.5).

4.4.6 Car GPS position

We use a combined inertial and satellite-based navigation system *Oxts RT-3003* to obtain position, direction, speed and other parameters of our car. This device can be augmented optionally by ground reference station that allows to use RTK correction and provide position accuracy of 1cm at 100Hz. Data from *RT-3003* is received via Ethernet cable. Work on RTK GPS is partially described in bachelors thesis [Result A.2.3.4].

Figure 4.6: Self-driving car demonstration (Riga, May-2017)

4.4.7 Evaluation (GCDC)

Adapted real-size car platform was tested in the i-GAME *(interoperable GCDC*[1] *AutoMation Experience)* - a cooperative autonomous driving competition that took place in Helmond, Netherlands on May 23-31 of 2016 [Result C.3.2]. The final approbated solution is also described in journal article [Result A.1.1.4]

[1]Grand Cooperative Driving Challenge

Adapted real-size car platform was demonstrated in Riga at the track "Bikernieki" on May-2017 (see Figure 4.6) where a path following functionality was demonstrated.

4.5 Mini-car adaptation (1/18 scale RC)

4.5.1 Mini car

To create more affordable infrastructure for development of cooperative driving algorithms and to have an ability to test them with many cars simultaneously a mini cooperative driving infrastructure development was started (abstract cooperative driving algorithms are the same for real cars and for model cars). The infrastructure includes a track for specially equipped 1/18 scale model cars, positioning system infrastructure and control software.

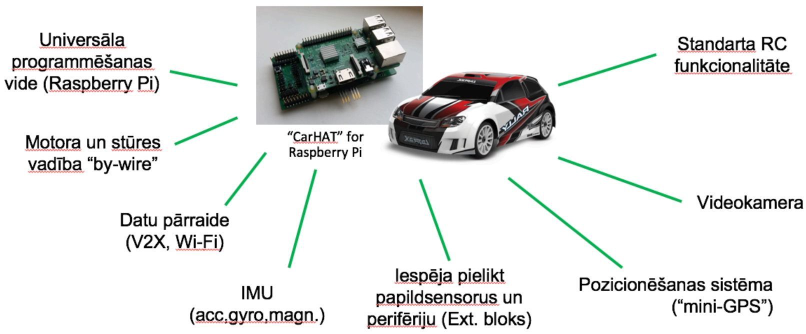


Figure 4.7: Mini car prototype

As a base for minicar we are using standard 1/18 scale RC car model. The model is equipped with an original control board and RaspberryPi 3 mini computer that allows to make custom development on car. The add-ons add drive-by-wire functionality, ability for the minicar to communicate via network, working with additional sensors, possibility to use video camera, IMU etc. (see Figure 4.7) [Result A.4.3.10]. This result is described in a prepared publication [Result A.1.2.19] and also part of masters thesis [Result A.2.2.7].

4.5.2 In-door positioning system for minicars

A positioning system prototype is developed (see Figure 4.8). It works like GPS system for real cars and provides positions and direction angles at 25Hz frequency for all cars on the track at the moment. Current precision of the system is around 1-2mm for position x, y coordinates and around 1 degree for direction angle.

4.6 Software simulated car model and environment

During the project, "virtual environments" capabilities were being used for validating algorithms, especially ground truth data was generated out, for

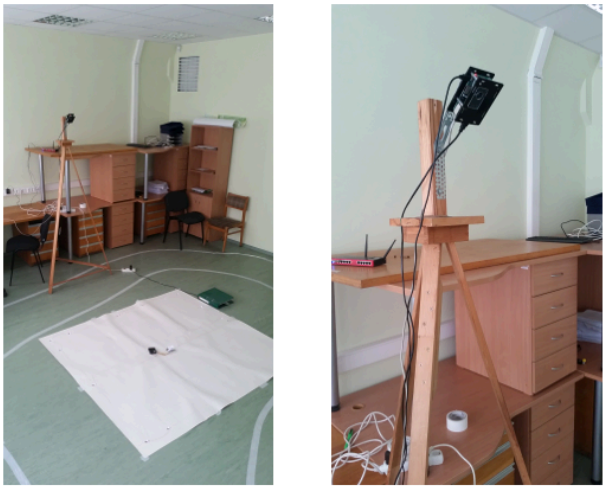


Figure 4.8: Mini-cooperative driving track and positioning system prototype

further analysis and comparison to algorithm output data. As it seems to be, ”virtual environments”, especially “game engines” are very convenient for research purposes. This enables variety of opportunities to test ideas and solutions in virtual reality before tests in the real world. This is the place where researcher can control entire environment, with physics included, generate event, and impact on the agent. In our case car models were used as agents. Such approach can be useful, since it can increase development and research productivity leading to resources decrease.

In particular, “Unreal Engine 4” game engine is used to simulate car, its sensors and its environment [Result A.4.1.4].

Figure 4.9: Camera placement

Additional research published in [Result A.1.2.16] was done on visual navigation with a downwards facing camera. Current work was done in the virtual environment, but it can be applicable to real self-driving cars in the future.

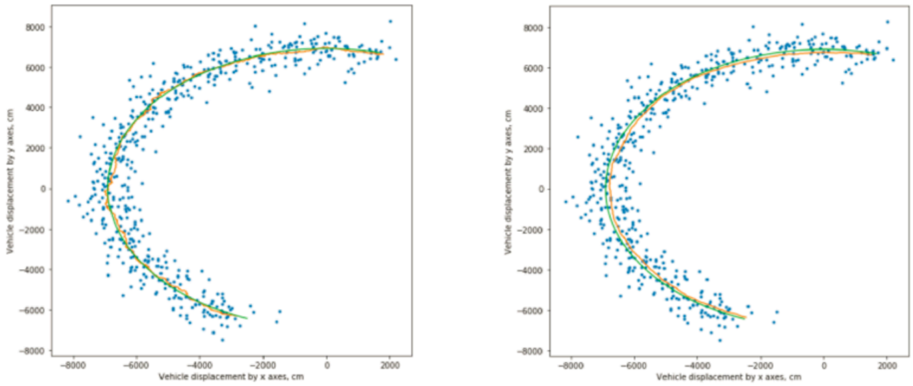


Figure 4.10: Position estimation without and with visual navigation

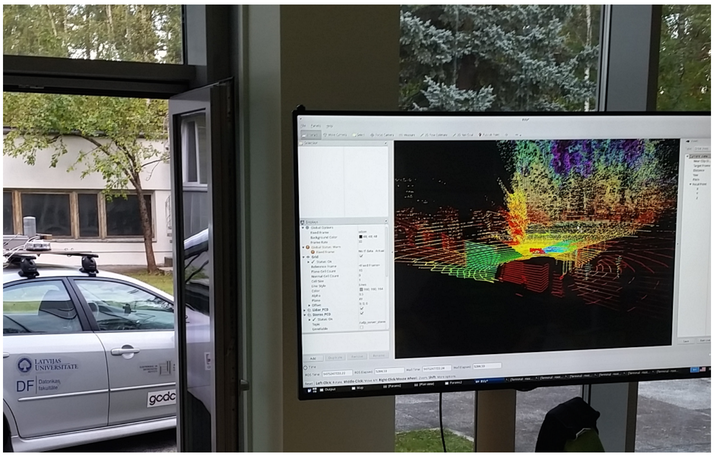


Figure 4.11: 3D point-cloud visualization on a common *ROS Rviz* scene from different data sources (LiDAR and stereo video)

4.7 Car sensors for stereo vision

Although it is not required by GCDC rules we added some sensors for detection of 3D point-cloud around our car and detecting objects such as pedestrians or road boundaries in them. Detecting other cars around our car might also be useful for additional correctness checks of data received from the network. 3D point-cloud is also used as stand by data source in moments of short interruption in network communication.

We use two independent sources for 3D point-cloud — LiDAR and stereo video camera (see Figure 4.11). Data from both data sources is sent to object processing PC where objects in point-cloud are detected and ”distilled” list of detected objects is sent to motion planning module of the car control system. Optionally a scene of car and its surroundings (car, 3D point-cloud, detected objects, other cars, planned path) could be visualized using *ROS Rviz* program or logged to file.

- 3D point-cloud from LiDAR: We are using a *Velodyne HDL-32E* device

Figure 4.12: Object detection example from road stereo-video [58]

to get cloud of distances to objects around the car. This device has 32 infrared 905nm lasers that measure a distance to objects from 1m to 70m with precision 2.5cm at 10Hz speed. Data from *HDL-32E* is sent to object processing computer via Ethernet cable where point-cloud data is extracted and processed. Work with the point cloud points was partially described in bachelors thesis [Result A.2.3.2].

- 3D point-cloud from stereo video camera: For detection of objects in front of the car we use stereo video camera *PointGrey Bumblebee XB3 1.3 MP*. Video shots are captured simultaneously by two cameras located in parallel at a fixed distance from each other ([58]). Pair of frames are sent via *Firewire* to object processing PC where 3D point-cloud is computed from them.
- Object detection in 3D point-cloud: After 3D point-clouds from LiDAR and Stereo Video devices is obtained/computed, road objects are detected (see Figure 4.12) in those point-clouds [58].

The next step to make the stereo vision more applicable in real-life automotive applications is to develop hardware stereo vision algorithm implementation. This work has been described in masters thesis [Result A.2.2.3] and masters thesis [Result A.2.2.4] describing the challenges of implementing such a solution on FPGA/SoC.

Additionally stereo-vision as an input for general autonomous robotic devices has been explored in bachelors thesis [Result A.2.3.8] and the results have synergy with project DIPA [Result C.6.9], project PRYSTINE [Result A.4.4.6][Result C.6.6] and project I-MECH [Result A.4.4.7][Result C.6.7]

4.8 Deep learning algorithms for driving

Developed a software and showed how radio-controlled car can learn drive in track by using only video images and neural networks. Showed that with this method car in a virtual environment can learn to drive in one track and that without any problems drive in completely different track. In-depth researched related works, reinforcement learning and positioning systems to keep work at which car would be able to learn drive by itself. The goal of this work is to create software which can be transferred to real self-driving car as described in publication [Result A.1.2.15]. Neural networks and especially reinforcement learning for self-driving cars have a crucial role in future development. Research in depth and testing is very important. This work is also published as a Master thesis [Result A.2.2.5].

4.9 V2X communication device

To get data via network about other cars position, speed etc. and to send our position to others we use *Cooperative awareness message (CAM)* and i-GAME *Cooperative lane change message (ICLCM)* formats. To receive messages from road infrastructure we use *Decentralized environmental notification message (DENM)* format. CAM and DENM packet formats are described in *ETSI ITS-G5* standard but ICLCM format was developed by organizers specially for GCDC competition.

A C function library was developed to encode/decode CAM, DENM an ICLCM payload using code generated by *ASN.1* compiler *asn1c*. Payload packet is sent and received using *IEEE 802.11p* at data-link level and is wrapped into simplified versions of *GeoNetworking* and *BTP* packets at network and transport levels respectively. A PC Engines APU platform board with Voyage Linux as network communication device is used. Some of the results are published in [Result A.1.2.2] [59] and provide synergy to project Autodrive [Result A.4.4.3][Result A.6.3]

4.10 ADAS systems

With the aim to promote the research in the mentioned domain, the second event of *Grand Cooperative Driving Challenge (GCDC)* was held as a part of the *i-GAME* project. Most of the participating teams were using existing drive-by-wire solutions which make it easier and more secure to focus on the cooperative part of the challenge. On the other hand, globally more than a billion cars are already on the roads, lacking this capability, so our team explored an alternative approach of outfitting a conventional vehicle for cooperative driving purposes. In this paper, we present our approach to tackling this challenge, to explore the potential to bring benefits of automated and cooperative driving to owners of existing cars.

Every year, many car accidents due to driver fatigue and distraction occur around the world and cause many casualties and injuries. Various studies have suggested that around 20% of all road accidents are fatigue-related, up to 50% on certain roads[60][61].

To reduce the number of these incidents, generally improve road safety and improve driving convenience Advanced Driver Assistance Systems (ADAS) can be used.

In this project existing ADAS systems were reviewed and analyzed, and several research directions were selected in which potential improvements can be achieved through research in the confines of this project. Also to test and validate the results of this research a test platform (self-driving car) with an innovative control platform was developed which will be used not only for running real-life tests, but also for validating the devices in actual competition environment in Grand Cooperative Driving Challenge (GCDC).

Below sections describe the current state-of-the art, our vehicle control/test platform architecture and specific research in ADAS systems.

4.10.1 Background and state of the art

Because many road incidents are a cause of driver error or drowsiness a significant part of ADAS systems is dedicated to driver monitoring and providing additional information to the driver, that normally is not accessible.

Some of the current systems learn driver patterns and can detect when a driver is becoming drowsy. Various technologies can be used to try to detect driver drowsiness[62] and generally assist driver in driving more safely and comfortably, thus improving road traffic safety through intelligent transport system technologies:

- **Steering Pattern Monitoring.** Primarily uses steering input from electric power steering system;
- **Vehicle Position in Lane Monitoring.** Uses lane monitoring camera;
- **Driver Eye/Face Monitoring.** Requires a camera watching the driver's face[63];
- **Physiological Measurement.** Requires body sensors for measure parameters like brain activity, heart rate, skin conductance, muscle activity;
- **Thermal imaging.** Requires thermographic camera to increase a driver's perception and seeing distance in darkness or poor weather.

4.10.2 Steering behavior

Features of steering wheel movement can be divided into time, frequency and state space domains. This assignment follows the first processing step of computing frame level descriptors, independent of feature characteristics of the second, contour describing, functional based processing step.

Time domain features: Within the time domain the following features can be extracted: regression descriptors (e.g. regression slope, intercept, maximum of regression error), class distribution measures (e.g. number of values within steering angle bin 0.0-0.1), peak amplitudes and distances (e.g. mean distance of peaks; maximum of peak amplitude), entropy, zero crossing distances and slope (e.g. maximum of distance between consecutive zero crossings; mean velocity of steering angle in zero crossings)

Frequency domain features: It is possible to obtain a set of frequency-related parameters. Usually a signal processing is applied to obtain signal spectrum which is evaluated in a frequency regions from which the descriptors are extracted. Frequency area is generally defined depending on the application. It is important how many samples will be used to calculate the spectrum of the signal and necessary descriptors will be extracted. Spectral features include: DCT coefficients, statistical moments, the standard deviation, the zero crossing frequency, etc.

State space: To extract the nonlinear properties of the steering angle signal, a three-dimensional state space (steering wheel position, steering wheel velocity, steering wheel acceleration) is computed, and a phase space is reconstructed. The geometrical properties of the resulting attractor figures can be described by trajectory based descriptor contours (angle between consecutive trajectory parts, distance to centroid of attractor, length of trajectory leg). The temporal information of the contours can be captured by computing functionals.

4.10.3 Signal and image processing for environment evaluation for intelligent transport systems

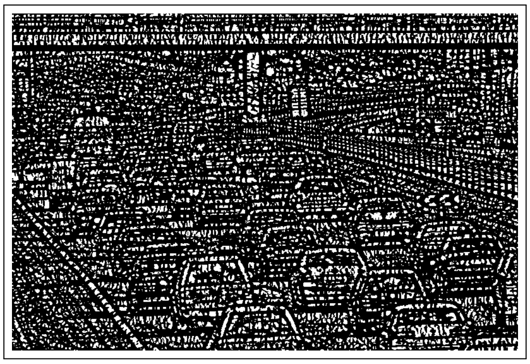
4.10.3.1 Introduction

Additional tasks that are usually performed by ADAS, like lane detection or traffic sign recognition, require fast and reliable low-level signal processing. In this project, as one of the activities, we have developed line extraction filter (Line Non-Halo Complex Matched Filter[64], L-NH-CMF), published in [Result A.1.2.6][65]. The main contribution of L-NH-CMF is fast, angle-invariant line-only detection with background-gradient-independent responses that contain additional line-direction information. The proposed L-NH-CMF can be used to extract object contours while ignoring gradients and edges, producing fewer seed pixels for the segmentation stage, c.f. Fig. 4.13 and Fig. 4.14.

Figure 4.13: L-NH-CMF improvements over NH-CMF for object contour extraction - black pixels in images (b) and (c) represent filter responses

(a) input image

(b) NH-CMF line-like object detection



(c) L-NH-CMF line only detection

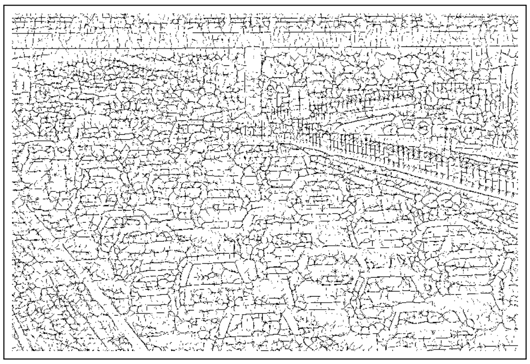
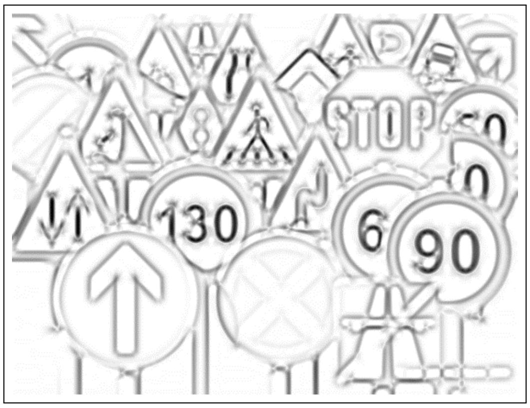


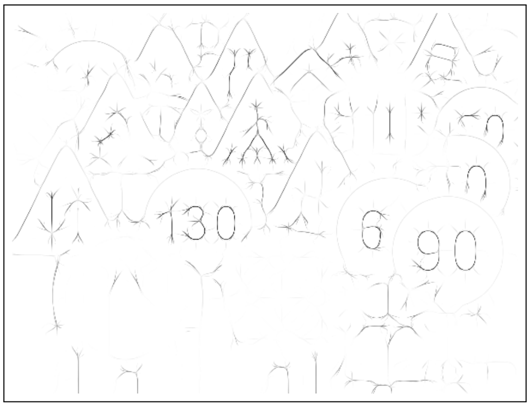
Figure 4.14: L-NH-CMF improvements over NH-CMF for traffic sign line extraction - black pixels in images (b) and (c) represent filter responses

(a) input image

(b) NH-CMF line-like object detection



(c) L-NH-CMF line only detection



The theoretical reasons behind the L-NH-CMF algorithm are discussed in depth in publication [Result A.1.2.6], therefore, only the main idea behind the algorithm will be mentioned here. The L-NH-CMF is based on detection of left and right edge profiles of the line object separately, providing left and right edge detector responses s_L and s_R, as illustrated in Fig. 4.15:

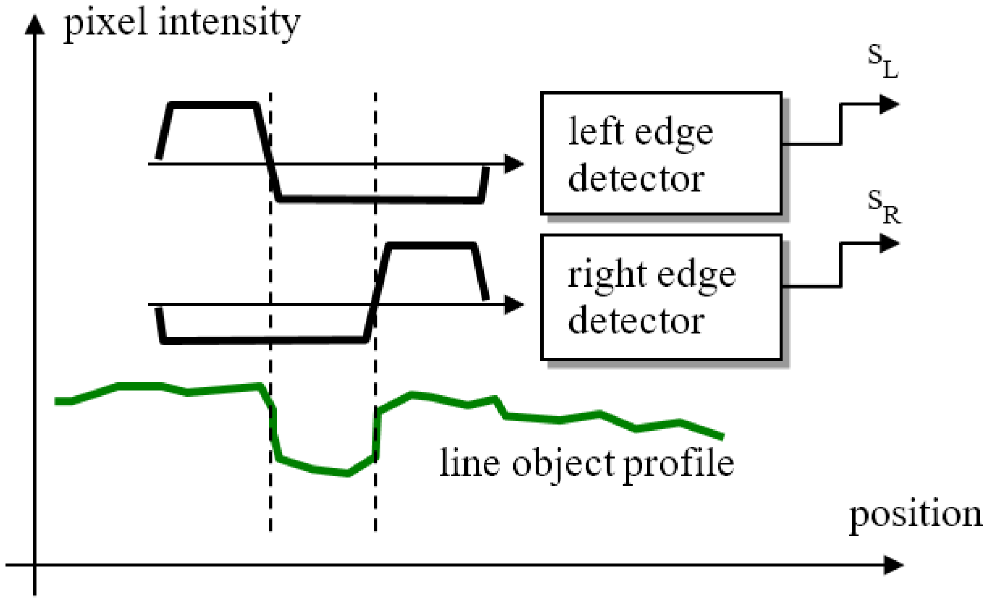


Figure 4.15: The principle of operation of left and right edge detectors of L-NH-CMF, shown using 1D pixel profile model

Then, the response of L-NH-CMF is calculated using $s = R[2 \cdot (s_L + s_R) - R[s_L] - R[s_R]]$, where $\forall x \in \mathbb{R} : R[x] \equiv \frac{x+|x|}{2}$. L-NH-CMF responses for different angles are combined using 2Φ algorithm, described in [66].

The rationale behind this algorithm is that when background gradient changes, the sum $s_L + s_R \approx const$, but in case of non-line object $|s_L| >> |s_R|$ or $|s_L| << |s_R|$, making $2 \cdot (s_L + s_R) - R[s_L] - R[s_R]$ negative or positive but small, see [65] for more details.

The developed filter might aid automated lane recognition for ACC systems, because road markings consists of line objects. Additionally, it might help detecting and recognizing road sign texts and in image segmentation tasks.

This work is also part of the doctoral thesis under development [Result A.2.1.3].

4.10.4 Vehicle Position in Lane Monitoring

The goal of the image processing is to extract information about the position of the vehicle with respect to the road from the video image. Two major processes are usually implemented: the pre-processing process and then the lane detection process. The goal of pre-processing is to remove image noise and make the images sharper. The goal of the lane detection is to detect the desired lane of the vehicle in order to obtain the look-ahead distance and the lane angle. This process is based on the real-time data of video sequences taken from a vehicle driving on the road. The processing steps of the example lane detection algorithm could be: image segmentation, edge detection, Hough Transform, and lane tracking.

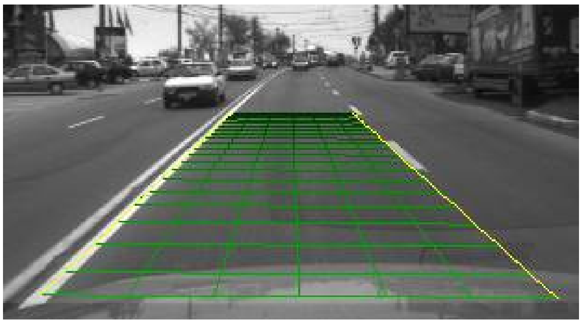


Figure 4.16: Lane tracking

4.10.5 Driver eye/face monitoring

Driver face monitoring: The driver face monitoring system is a real-time system that investigates driver physical and mental condition based on processing of driver face images. Driver status can be detected from eyelids closure, blinking, gaze direction, yawning and head movement. This system will alarm in hypo-vigilance states such as drowsiness, fatigue and distraction. The systems based on the driver face monitoring can be divided into two general categories. In first category, driver fatigue and distraction is detected only by processing of eye region. There are many researches based on this approach. The main reason of this large amount of researches is that main symptoms of fatigue and distraction appear in driver eyes. Moreover, processing of eye region instead of total face region has less computational complexity.

In the other category, symptoms of fatigue and distraction are detected not only from eyes, but also from other regions of face and head. In these approaches, not only activities of eyes are considered, but also other symptoms such as yawning and head orientation is extracted.

Software is the most important part of driver face monitoring system and is divided into two main parts: image processing algorithms and decision-making algorithms.

The main goals of image processing algorithms include preprocessing, detection and tracking of face, eyes and other facial components, and extraction of appropriate symptom from facial images.

After extraction of appropriate symptom from images, decision-making algorithms determine the level of driver alertness based on extracted symptoms. Finally, an appropriate output is generated for the system. In most of the driver face monitoring systems, face detection is the first part of image processing operations. In systems that fatigue and distraction is detected based on processing of facial region, face detection is considered as very important part of the system. Also in most of methods based on processing of eye region, due to difficulty of eye detection directly, face is detected at first and then eyes are detected. The most important problems of face detection are[67]:

- In-plane face rotation,
- Out-of-plane face rotation,
- The presence or the absence of makeup, beard and glasses,
- Mental conditions (happiness, crying, and etc.),
- Illumination conditions,
- Covering part of the face with an object,
- Real-time processing.

Face detection methods can be divided into two general categories[67]: (1) feature-based and (2) learning-based methods. Learning-based methods usually more robust than feature-based methods, but they often take more computational resources. However, these methods can achieve a detection rate about 80-90% or higher in laboratory conditions, but both of them usually fail in real conditions, especially in night light.

In feature-based methods, the main assumption is that face in the image can be detected based on some simple features, independent of ambient light, face rotation and pose. These methods are usually used for detection of one face in image. In noisy image or the environment with low illuminations, these algorithms have low accuracy[67].

Learning-based methods deal with face detection using a number of training samples. These methods benefit from statistical models and machine learning algorithms. Generally, learning-based methods have less error rates in face detection, but these methods usually have more computational complexity. Viola et al.[68] presented an algorithm for object detection, which uses very simple features named Haar-like features. In this algorithm, many Haar-like features are extracted from the image, and a number of effective features are selected using AdaBoost algorithm, and then these features are processed in a hierarchical structure similar to the decision tree. Due to the simple extracted features and selection of the best features, this algorithm is relatively fast and robust. Building on this work results in RGB-DT based face recognition was published as a result of this poject in [Result A.1.2.1] [69] and later improved in [Result A.1.1.3] [70]. Some of the face recognition algorithms were also implemented on low cost hardware [Result A.1.2.4] [71].

Driver eye monitoring: In all driver face monitoring systems, eye region is always processed for symptom extraction, because the most important symptoms are related to the eyes activity. Therefore, eye detection is required before processing of eye region. Eye detection methods can be divided into three general categories: (1) methods based on imaging in IR spectrum, (2) feature-based methods and (3) other methods.

Seeing Machines builds image-processing technology that tracks the movement of a person's eyes, face, head, and facial expressions. They've developed an ADAS technology which monitors driver fatigue and distraction events in real time, enacting an intervention strategy that improves driver and environmental safety.

Figure 4.17: Eye tracking device developed by Seeing Machines

4.10.6 Relationship between Physiological Signals and Drowsiness

Bioelectricity is generated on the cell level and acts as the charge flow on human surface. The electrical charges on the skin off the chest are mainly caused by the depolarization of heart muscles during each heartbeat cycle. In each cycle, nerve excitability is triggered by sinoatrial node, and then spreads through atrium, intrinsic conduction pathways and ventricles. As a result, it causes the change of action potential in cells manifested as the form of tiny rises and falls of potential on body surface. The electrical activity of heartbeat cycle is adjusted rhythmically by central and peripheral nervous system. Fatigue causes changes in spontaneous rhythmic activity, breathing, cardiovascular reflex activity, blinking, nodding, etc. The comprehensive regulation of these changes by the central nerve system will finally cause changes in the physiological signals.

A few physiological signals of drivers have been found to be good drowsiness indicators. It is generally believed that fatigue is the behavior of the central nervous system. When stress response of organs occurs during fatigue, cardiovascular nervous system will adjust accordingly. Therefore onset of fatigue causes changes in the bioelectrical signals, such as the electrocardiogram (ECG), a recording of electrical signals produced by the electro-dynamic functioning of the heart.

The methods for drowsiness identification based on ECG signal include Heart Rate (HR) analysis, Heart Rate Variability (HRV) analysis and amplitude analysis of T wave.

In period 1 and 2 of our research project we chose to use drivers face monitoring, because of the ease of use, non-intrusiveness and high reliability, based on the previous research results and commercial success.

This work is partially being described in the doctoral thesis [Result A.2.1.8].

4.10.7 Thermal imaging

An automotive night vision system uses a thermographic camera to increase a driver's perception and seeing distance in darkness or poor weather beyond the reach of the vehicle's headlights. Such systems are offered as optional equipment on certain premium vehicles. It is crucial to detect persons or animals on or on the side of the road before they appear in the drivers viewing range. This gives additional time for a driver to react and eliminate the accident. Many research groups have been working on this problem using methods like basic background subtraction, sliding window, keypoint detection and other approaches. In [72] researchers propose to use Maximally Stable Extremal Regions (MSER) to detect hot spots, verify detected hot spots using a Discrete Cosine Transform (DCT) based descriptor and a modified Random Naïve Bayes (RNB). Keypoint detection is prone to detect only few or no keypoints for low resolution objects. This leads to partial or missed detections. The sliding window approach is time consuming especially when many different object scale levels are considered. Background subtraction cannot be used with moving camera. Because of the low computational demand MSER method has been chosen for further research in the project. MSERs are the result of a blob detection method based on thresholding and connected component labeling[73].

This approach has been evaluated and described in bachelors thesis [Result A.2.3.3].

4.11 Results

The SmartCar group has developed multiple technologies related to ITS and self-driving cars, resulting in 9 publications of which 2 are in high impact factor journals.

The work in this group has been the basis of 4 defended bachelors thesis and 4 defended masters thesis. It is also part of 3 doctoral thesis currently under development.

As a result 1 software prototypes and 2 hardware system prototypes have been developed. The self driving car prototype together with the appropriate software prototype has been validated in the Grand Cooperative Driving Challenge.

The outputs of the work of this group as well as the gained experience has already provided synergy to 5 other projects and has the potential for much more in the future.

Chapter 5

Quantitative project results

This chapter contains the list of quantitative project results. These are referred in their respective sections in text as [Result X.1.1.1] and additional files can be appended to this report in filenames / folders with the respective naming convention.

A Scientific performance indicators

A.1 Scientific publications

A.1.1 Original scientific articles (SCOPUS) (SNIP>1)

1. Hermanis, A.; Cacurs, R.; Greitans, M., "Acceleration and Magnetic Sensor Network for Shape Sensing" in Sensors Journal, IEEE , vol.16, no.5, pp.1271-1280, March1, 2016 doi: 10.1109/JSEN.2015.2496283

2. Krisjanis Nesenbergs. "Architecture of smart clothing for standardized wearable sensor systems." IEEE Instrumentation & Measurement Magazine Volume 19, Issue 5 (2016), pp. 36-64. DOI: 10.1109/MIM.2016.7579068

3. Simón, M. O., Corneanu, C., Nasrollahi, K., Nikisins, O., Escalera, S., Sun, Y., Li, H., Sun, Z., Moeslund, T. B. & Greitans, M. (2016). "Improved RGB-DT based face recognition". Iet Biometrics, 5(4), 297-303.

4. I. Ribners, A. Mednis, K. Nesenbergs, R. Zviedris and L. Selavo "DIY Car Control System for Cooperative Driving", IEEE Intelligent Transportation Systems Magazine. Submitted for publication.

A.1.2 Original scientific articles in databases SCOPUS and Web of Science

1. Olegs Nikisins, Kamal Nasrollahi, Modris Greitans and Thomas B. Moeslund "RGB-D-T based Face Recognition", 22nd International Conference on Pattern Recognition (ICPR), Stockholm Waterfront,

Stockholm, Sweden, August 24-28, 2014, pp.1716-1721. DOI: 10.1109/ICPR.2014.302

2. Artis Mednis. “Development of 802.11p Testbed – Experiences”, Proceedings of the 14th Biennial Baltic Electronics Conference (BEC 2014), October 6-8, 2014, Tallin, Estonia, pp. 137-140.

3. A. Hermanis, R. Cacurs, M. Greitans, “Shape sensing based on acceleration and magnetic sensor system”, 2015 IEEE International Symposium on Inertial Sensors and Systems (ISISS), 23-26 March 2015. DOI:10.1109/ISISS.2015.7102383

4. O.Nikisins, R.Fuksis, A. Kadikis and M. Greitans. “Face recognition system on Raspberry Pi” 2015 5th International Workshop on Computer Science and Engineering: Information Processing and Control Engineering, WCSE 2015-IPCE; Bauman Moscow State Technical UniversityMoscow; Russian Federation; 15 April 2015 through 17 April 2015; Code 112346.

5. K.Nesenbergs, L. Selavo, “Smart textiles for wearable sensor networks: review and early lessons,” Medical Measurements and Applications (MeMeA) 2015 Conference on, Torino, Italy, 7-9 May 2015. DOI:10.1109/MeMeA.2015.7145236

6. Pudzs, Mihails; Fuksis, Rihards; Mucenieks, Agris; Greitans, Modris, “Complex matched filter for line detection,” in Image and Signal Processing and Analysis (ISPA), 2015 9th International Symposium on , vol., no., pp.93-97, 7-9 Sept. 2015 doi: 10.1109/ISPA.2015.7306039

7. Hermanis, A., Cacurs, R., Nesenbergs, K., Greitans, M., Syundyukov, E., & Selavo, L. (2015, April). “Wearable sensor grid architecture for body posture and surface detection and rehabilitation”. In Proceedings of the 14th International Conference on Information Processing in Sensor Networks (pp. 414-415). ACM.

8. Dimitrios Lymberopoulos and the participants of Microsoft Indoor localization Competition 2014 (including Leo Selavo), “A Realistic Evaluation and Comparison of Indoor Location Technologies: Experiences and Lessons Learned,” the 14th ACM/IEEE International Conference on Information Processing in Sensor Networks (ACM/IEEE IPSN), CPSWEEK, Seattle, USA, April 13-16, 2015. DOI: 10.1145/2737095.2737726

9. Ruskuls, R., Lapsa, D., & Selavo, L. (2015, November). “EDI WSN TestBed: Multifunctional, 3D Wireless Sensor Network Testbed”. In Advances in Wireless and Optical Communications (RTUWO), 2015 (pp. 50-53). IEEE.

10. J.Judvaitis, A. Salmins, K. Nesenbergs “Network Data Traffic Management Inside a TestBed”, RTUWO 2016 Advances in Wireless

and Optical Communications, 3-4. nov. 2016 Riga, Latvia., DOI: 10.1109/RTUWO.2016.7821874 ; ISBN: 978-1-5090-1535-1.

11. Ancans, A. Rozentals, K. Nesenbergs, M. Greitans. "Inertial sensors and muscle electrical signals in human-computer interaction", ICTA 2017, ICTA 2017 : 6th International Conference on Information and Communication Technology and Accessibility. December 19- 21, 2017, Muscat-Sultanate of Oman. Accepted for publication, presented.

12. A. Salmins, J. Judvaitis, R. Balass and K. Nesenbergs. "Mobile wireless sensor network TestBed". 25th Telecommunications Forum TELFOR 2017 on the 21st and 22nd November 2017,Belgrade, Serbia. Accepted for publication, presented.

13. D. Lapsa, R. Balass, J. Judvaitis, K. Nesenbergs and A. Skageris. "Power Consumption Measurement of Tested Units in the WSN TestBed". 25th Telecommunications Forum TELFOR 2017 on the 21st and 22nd November 2017,Belgrade, Serbia. Accepted for publication, presented.

14. V. Abolins, K. Nesenbers, E. Bernans. "On improving gait analysis data: heel induced force plate noise removal and cut-off frequency selection for Butterworth filter", 2017 9th International Conference on Signal Processing Systems (ICSPS 2017), AUT University, Auckland, New Zealand, November 27-30, 2017. Accepted for publication, presented.

15. N. Dorbe, I. Ribners, K. Nesenbergs. "Prospects of improving the self-driving car development pipeline: transfer of algorithms from virtual to physical environment", 2017 The 10th International Conference on Machine Vision (ICMV 2017), November 13-15, 2017 | Vienna, Austria. Accepted for publication, presented.

16. A. Levinskis "Using virtual environment for autonomous vehicle algorithm validation", 2017 The 10th International Conference on Machine Vision (ICMV 2017), November 13-15, 2017 | Vienna, Austria. Accepted for publication, presented.

17. Shavelis R., Ozols K., Greitans M., "Amplitude Adaptive ASDM circuit", 2017 3rd International Conference on Event-Based Control, Communication and Signal Processing, Madeira, Portugal, May 24-26, 2017, DOI: 10.1109/EBCCSP.2017.8022815 [1]

18. E. Syundyukov, A. Cirulnieks, K. Nesenbergs and L. Selavo. "Knee Joint Dynamics Monitoring Using Wearable Sensor Network and Mobile Software During Rehabilitation", Baltic Journal of Modern Computing, ISSN 2255-8942, Submitted for publication.

19. I.Drikis, I.Ribners, J.Ormanis "Scalable in-door positioning system for cooperative MicroIV algorithm development", Automatic Control and Computer Sciences, ISSN 1558-108X, Prepared for submission.

[1] This publication is only partly related to Project No. 1, and partly to Project No. 4.

20. J. Ormanis, A. Levinskis, K. Nesenbergs. “Human skin as n-th order passive filter”, Medical Measurements and Applications (MeMeA), 2018, IEEE International Symposium on, Prepared for submission.

21. K. Nesenbergs. “Smart textiles: efficient data collection grid architecture”, IEEE Transactions on Instrumentation and Measurement, Prepared for submission.

A.2 Prepared thesis in the framework of the programme

A.2.1 Doctoral thesis

As fully developing and defending a doctoral thesis might take longer than the duration of this project, both defended, pre-defended and prepared thesis are listed.

1. Atis Hermanis 25.11.2016. “Shape sensing based on embedded sensors for mobile cyber-physical systems” / “Formas noteikšana, izmantojot iestrādātus sensorus mobilām kiberfizikālajām sistēmām” Academic supervisors: Dr.sc.comp., senior researcher M. Greitāns, Dr.sc.ing., professor O. Krievs.

2. Krisjanis Nesenbergs, pre-defended, “On future smart textiles: distributed data acquisition architecture” / “Nākotnes viedie audumi: izkliedēta datu ieguves arhitektūra”, academic supervisor: Dr.sc.comp. Leo Seļāvo.

3. Mihails Pudžs, pre-defended[2], “Rakstur īgo pazīmju iegūšanas paņēmiens objektu detektēšanai un atpazīšanai attēlos” / “Method for Obtaining the Characteristic Features for Detection and Identification of Objects in Images”, academic supervisor: Dr.sc.comp., senior researcher M. Greitāns.

4. Ingars Ribners, thesis in preparation for defense in 2018, “Paplašināma daudzaģentu sistēmu modelēšanas vide” / “Extendable modelling environment for multi-agent systes”, academic supervisor: Dr.sc.comp. G. Arnicāns.

5. Jānis Judvaitis, thesis in preparation for defense in 2019, “Radiation diagram usage in wireless sensor network optimization” / “Bezvadu sensoru tīklu optimizēšana izmantojot radiācijas diagrammas”, academic supervisor: Dr.sc.comp. Leo Seļāvo.

6. Rihards Balašs, thesis in preparation for defense in 2020, “Lietu interneta drošība aparatūras līmenī” / “Hardware security for Internet of things”, academic supervisor: Dr.sc.comp, senior researcher M. Greitāns.

7. Emil Syundyukov, thesis in preparation for defense in 2020, “Lietotāja pieredzes modelēšana veselības informācijas sistēmu uzlabošanai iegulto iekārtu vidē” / “Modeling user experience for improving health information

[2] Left the project after pre-defense, but before defending the thesis

systems in the embedded system environment", academic supervisor: Dr. phil., professor, Jurģis Šķilters.

8. Rihards Fuksis, thesis in preparation[3], "Dažādos spektrālos diapazonos iegūtu attēlu apstrāde iegultās sistēmās" / "In different spectral bands acquired image processing in embedded systems", academic supervisor: Dr.sc.comp., senior researcher M. Greitāns.

9. Rinalds Ruskuls, thesis in preparation[4], "Dinamiski rekonfigurējami rīki iegulto sistēmu prototipēšanai" / "Dynamically reconfigurable tools for prototyping embedded systems", academic supervisor: Dr.sc.comp. Leo Seļāvo.

A.2.2 Masters thesis

1. Armands Ancāns (2016) "An Acquisition and Processing of Inertial Sensor and Electromyogram Signal for Alternative Communication Device" / "Inerciālo sensoru un elektromiogrammu signālu ieguve un apstrāde alternatīvās saziņas ierīcei". Academic supervisor: Dr.sc.comp. M.Greitāns.

2. Maksis Celitāns (2016) "Multi branch sensor network for human biomechanical monitoring" / "Daudzzaru sensoru tīkls biomehānikas novērošanai". Academic supervisor: Dr.sc.comp. M.Greitāns.

3. Rihards Novickis (2016) "Image Processing Using Heterogeneous Embedded Systems" / "Attēlu apstrāde lietojot heterogēnas iegultās sistēmas". Academic supervisor Dr.sc.comp. M.Greitāns.

4. Aleksandrs Skripko (2017) "Linking the stereo camera to SoC FPGA system for images further processing" / "Stereo kameras pieslēgšana pie SoC FPGA sistēmas, attēlu iegūšana tālākai apstrādei". Academic supervisor: G.Valters.

5. Nauris Dorbe[5] (2017) "Driverless cars tuition using reinforcement learning artificial deep neural networks within cooperate driving system" / "Bezpilota mašīnu apmācība, izmantojot stimulētās mācīšanās mākslīgos dziļos neironu tīklus kooperatīvās braukšanas sistēmā". Academic supervisors: Dr.sc.comp. G.Bārzdiņš and I.Ribners.

6. Emil Syundyukov (2017) "System for vital signs data acquisition and analysis" / "Sistēma veselības datu vākšanai un analīzei". Academic supervisor: Dr.sc.comp. L.Seļāvo.

7. Reinis Ozoliņš (2017) "Research and development of control unit for cooperative driving with miniature car" / "Miniatūra kooperatīvās

[3]Left the project during thesis preparation, but before defending
[4]Left the project during thesis preparation, but before defending
[5]Prize for best masters thesis in contest ZIBIT 2017

braukšanas automobiļa vadības bloka uzbūves izpēte un izstrāde". Academic supervisor: Dr.sc.comp. M.Greitāns.

A.2.3 Bachelors thesis

1. Emil Syundyukov[6] (2015), "Embedded hardware and software for health data monitoring during rehabilitation" / "Iegultās iekārtas un programmatūra veselības datu pārraudzībai rehabilitācijas laikā". Academic supervisor: Dr.sc.comp. Leo Seļāvo.

2. Voldemārs Smelēns (2016) "Point cloud extraction and processing in a specific space" / "Telpas punktu mākoņa ieguve un apstrāde". Academic supervisor: Mg.sc.comp. K.Nesenbergs.

3. Mārtiņš Skudra (2016) "Pedestrian detection for ADAS combining point cloud with thermal images" / "ADAS gājēju atpazīšana apvienojot punktu mākoni ar termiskām bildēm". Academic supervisor: Mg.sc.comp. K.Nesenbergs.

4. Henrijs Smelēns (2016) "RTK-GPS positioning system and its uses in self driving cars" / "RTK-GPS pozicionēšanas sistēma un tās pielietojums pašbaucošajās automašīnās". Academic supervisor: Mg.sc.comp. K.Nesenbergs.

5. Arnis Salmiņš (2016) "Wireless sensor network TestBed software" / "Bezvadu sensoru tīklu testēšanas vides programmatūra". Academic supervisor: Mg.sc.comp. J.Judvaitis.

6. Niklāvs Barkovskis (2017) "Train Integrity Control with Wireless Sensor Network Based on Accelerometer, GPS and RSSI Measurements" / "Vilciena integritātes kontrole ar bezvadu sensoru tīklu, kas balstīts uz akselerometra, GPS un RSSI mērījumiem". Academic supervisor: Dr.sc.ing. Kaspars Ozols.

7. Artis Rozentāls (2017) "Enerģijas iegūšana portatīvām ierīcēm" / "Energy Harvesting for mobile devices". Academic supervisor: Viktors Zagorskis.

8. Jānis Ārents (2017) "Industrial robot and computer vision solution integration research for automation of industrial processes" / "Industriālo robotu un datorredzes risinājumu integrēšanas iespēju izpēte rūpniecisko procesu automatizācijai". Academic supervisor: Armands Šenfelds.

A.3 Improved courses

1. "Introduction to digital design" / "Ievads digitālajā projektēšanā", University of Latvia, R. Ruskuls. Course demonstrates development of digital devices, and uses TestBed adapter as an example for specific lessons.

[6] Prize for second best bachelors thesis in contest ZIBIT 2015

2. “Concepts of Operating systems” / “Operētājsistēmu koncepcijas”, University of Latvia, K. Nesenbergs. Course demonstrates concepts of operating systems, including lessons from development of the operating system for wireless sensor networks (MansOS).

3. “Special course: cyber-physical systems” / “Specsemināri: Kiberfizikālās sistēmas”, University of Latvia, L. Selavo. Course demonstrates the workings of different cyber-physical systems including wireless sensor networks, demonstrating examples of systems developed in the project.

4. “Wireless sensor networks” / “Bezvadu sensoru tīkli”, University of Latvia, J. Judvaitis. Course teaches development and programming of wireless sensor network nodes and students use the TestBed environment for practical tasks.

A.4 Research deliverables

A.4.1 Software prototypes

1. Mobile application for head position monitoring prototype (Section 3.4.1).

2. Mobile application for knee joint monitoring prototype (Section 3.4.3).

3. TestBed adapter management and supporting backend software set (Section 2.3.6).

4. Software for autonomous collaborative self driving car approbation at GCDC (Section 4.3.3).

5. Testbed user frontend and development tools software set (Section 2.3.6).

A.4.2 Methodology, descriptions

1. Description of TestBed architecture concept (Appendix 1, annex A.4.2 and Section 2.3.1).

A.4.3 Mock-ups, prototypes, technologies

1. TestBed adapter prototype (Section 2.3.5).

2. Head position sensor prototype (Section 3.4.1).

3. Knee joint sensor prototype (Section 3.4.3).

4. TestBed system prototype with multiple adapters (Section 2.3.1).

5. Body and head monitoring system prototype (Section 3.4.1).

6. Prototype for ECG data gathering (Section 3.3.5).

7. Headband for computer control prototype (Section 3.4.2).

8. Prototype automatic collaborative self-driving car (Section 4.4). This together with software in [Result A.4.1.4] makes up the approbated system [Result C.3.2].

9. Prototype mobile TestBed adapter (Section 2.3.8).

10. Prototype Mini collaborative driving infrastructure (Section 4.5).

11. Prototype 12-lead ECG data gathering and feedback device (Section 3.3.5).

A.4.4 Involvement in international projects

1. 3CCar (`http://www.edi.lv/en/projects/international-projects/3ccar/`) - H2020 ECSEL project ”Integrated Components for Complexity Control in Affordable Electrified Cars” benefits from the knowledge developed by SmartCar group.

2. HIPPAC (`http://edi.lv/en/projects/international-projects/hippac/`) - EEA/Norway Grants “Research and Scholarship” programme project ”Health and Social Indicators of Participation in Physical Activities for Children with Disabilities” benefits from knowledge developed by MedWear group.

3. Autodrive (`http://www.edi.lv/en/projects/international-projects/autodrive/`) - H2020 ECSEL project ”Advancing fail-aware, fail-safe, and fail-operational electronic components, systems, and architectures for highly and fully automated driving to make future mobility safer, more efficient, affordable, and end-user acceptable” benefits from the knowledge developed by SmartCar group.

4. CONVERGENCE (`http://www.edi.lv/en/projects/international-projects/convergence/`) - ERA-NET project ”Frictionless Energy Efficient Convergent Wearables For Healthcare and Lifestyle Applications” benefits from knowledge developed by MedWear group.

5. ENACT (`http://www.edi.lv/en/projects/international-projects/enact/`) - H2020 project ”Trustworthy and Smart Actuation in IoT systems” benefits from the knowledge developed by TestBed group.

6. PRYSTINE - H2020 ECSEL project ”Programmable Systems for Intelligence in Automobiles” benefits from the knowledge developed by SmartCar group.

7. I-MECH (`http://www.edi.lv/en/projects/international-projects/i-mech/`) - H2020 ECSEL project ”Intelligent Motion Control Platform for Smart Mechatronic Systems” benefits from the knowledge developed by SmartCar group.

8. DEWI (`http://www.edi.lv/en/projects/international-projects/eu-fp7-artemis/`) - EU FP7 ARTEMIS project ”Dependable Embedded

Wireless Infrastructure" benefits from the knowledge developed by TestBed group.

B Performance indicators of the promotion of the programme

B.1 interactive events to promote the process and results of the programme

B.1.1 Presentations in international conferences

1. 2014-08-31...09-06 program manager M.Greitāns participated in European signal processing conference "EUSIPCO 2014", Lisbon, Portugal, where VPP SOPHIS ideas and results were discussed.

2. 2015-01-21...22 program manager M.Greitāns participated in KTI ARTEMIS "Brokerage Event 2015" Amsterdam, Netherlands, where VPP SOPHIS ideas and results were discussed.

3. 2015-02-20 project members participated in 73rd scientific conference of the University of Latvia, where they presented two reports: "Localization within buildings with digitally controllable antennas" (L.Seļāvo, I.Driķis, R.Balašs) and "Creation of heterogenous wireless communications range" (A.Mednis, J.Judvaitis, R.Ruskuls).

4. 2015-03-09...11 program manager M.Greitāns participated in an international event "ARTEMIS Co-Summit 2015" Berlin, Germany, where he presented and discussed VPP SOPHIS ideas and results.

5. 2015-04-14 Project team (Selavo et al.) participated in Microsoft Indoor localization Competition and presented article "A Realistic Evaluation and Comparison of Indoor Location Technologies: Experiences and Lessons Learned", CPSWEEK, Seattle, USA.

6. 2015-04-13...16 A. Hermanis presented article "Demonstration Abstract: Wearable Sensor Grid Architecture for Body Posture and Surface Detection and Rehabilitation," at the 14th ACM/IEEE International Conference on Information Processing in Sensor Networks (ACM/IEEE IPSN), CPSWEEK, Seattle, USA.

7. 2015-04-13...16 L. Seļāvo presented technical report "DiStAL: Digitally Steerable Antennas for Localization," at Microsoft Indoor Localization Competition, IPSN 2015, Seattle, WA,USA.

8. 2015-09-16 A. Hermanis presents at conference "4th Baltic and North Sea Conference on Physical and Rehabilitation Medicine" presenting the published abstract Atis Hermanis, Andra Greitane, Santa Geidāne, Armands Ancāns, Ričards Cacurs, Modris Greitāns, "Wearable Head

and Back Posture Feedback System For Children With Cerebral Palsy", Abstract: Journal of Rehabilitation Medicine (ISSN 1650-1977).

9. 2016-02-15...18 Emil Syundyukov participates in conference and demo session with demonstration and poster "Wearable Sensor System for Human Biomechanics Monitoring", International Conference on Embedded Wireless Systems and Networks (EWSN) 2016, Graz (Austria).

10. 2016-03-17...18 Emil Syundyukov[7] participates in RSU ISC 2016 conference, with presentation "Wearable sensor network and mobile application for knee joint dynamics monitoring during rehabilitation".

11. 2016-11-04 A. Salmins presents article "Network Data Traffic Management Inside a TestBed" at RTUWO 2016 Advances in Wireless and Optical Communications, 3-4. nov. 2016 Riga, Latvia.

12. 2017-02-02 program manager M. Greitans participates in KTI ARTEMIS Brokerage Event 2017 and presents the achievements of SOPHIS, as well as discusses project synergy with future H2020 project PRISTYNA.

13. 2017-02-22 L. Seļāvo presents the developed directional communication antenna platform for wireless sensor networks at conference EWSN 2017 and heads the NextMote Workshop.

14. 2017-05-31 program manger M. Greitāns presents article "Amplitude Adaptive ADSM circuit" at conference EBCCSP'17 and chairs session "Event-Based Signal Processing".

15. 2017-06-08 at Erlang user conference, I. Ribners presents "Prototyping a self-driving car control system with Erlang".

16. 2017-11-14 N. Dorbe presents article "Prospects of improving the self-driving car development pipeline: transfer of algorithms from virtual to physical environment" at conference ICMV 2017.

17. 2017-11-14 A. Ļevinskis presents article "Using virtual environment for autonomous vehicle algorithm validation" at conference ICMV 2017.

18. 2017-11-22 A. Salmiņš presents article "Mobile wireless sensor network TestBed" at conference TELFOR 2017.

19. 2017-11-22 D. Lapsa presents article "Measurement of current consumption in a wireless sensor network TestBed" at conference TELFOR 2017.

20. 2017-11-28 V. Āboliņš presents article "On improving gait analysis data: heel induced force plate noise removal and cut-off frequency selection for Butterworth filter" at conference ICSPS 2017.

21. 2017-12-19 A. Ancāns presents article "Inertial sensors and muscle electrical signals in human-computer interaction" at conference ICTA 2017.

[7] Presentation was awarded 3rd place among conference presentations

B.1.2 Presentations in international seminars

1. 2016-04-04..06 Emil Syundyukov participated in GapSummit 2016, where he presented SOPHIS ideas and results, `http://www.df.lu.lv/zinas/t/39756/`

2. 2016-05-28 I. Ribners presents the Latvian Team self driving car solution, including user interface, in a developer seminar at GCDC competition.

3. 2017-09-14...17 A. Ļevinskis visits IAA Cars 2017 Exhibition and Udacity seminar, Frankfurt/Main, Germany, where he presented and discussed project ideas and results.

4. 2017-11-09...10 M. Greitans participates in ICT Proposers' Day 2017, Budapest, Hungary where he discussed project ideas and results with the goal of developing H2020 synergy projects and presented smart and flexible electronics results and capabilities.

B.1.3 Organized seminars

The seminars organized together with other projects from programme are counted as 0.25 for total results, as each of 4 projects contribute to them equally.

1. 2015-07-09 First stage seminar for Project no. 1 at EDI.

2. 2015-10-07 First stage joint SOPHIS seminar, with participation from all 4 projects.[8]

3. 2016-03-16 Second stage seminar for Project no. 1 at EDI.

4. 2016-03-30 Second stage joint SOPHIS seminar, with participation from all 4 projects.[9]

5. 2016-11-23 Third stage seminar for Project no. 1 at EDI.

6. 2016-12-07 Third stage joint SOPHIS seminar, with participation from all 4 projects.[10]

7. 2017-08-01 Fourth stage seminar for Project no. 1 at EDI.

8. 2017-11-30 Final seminar for Project no. 1 discussing overall results at EDI.

9. 2017-12-05 Final joint SOPHIS seminar and demonstrations, with participation from all 4 projects.[11]

[8] Counts as 0.25 for this project
[9] Counts as 0.25 for this project
[10] Counts as 0.25 for this project
[11] Counts as 0.25 for this project

B.1.4 Popular-science publications, events, information in mass media

Even though most of these popularization results are applicable specifically to Project No. 1, some of these are for SOPHIS programme in general. Entries, which are actual mass media publications (newspapers, portals, TV, radio) are marked with [P] to distinguish them from other popularization activities.

1. 2015-02-11 [P] Latvia Radio show "Monopols" interview with Leo Seļāvo `http://lr1.lsm.lv/lv/raksts/monopols/latvijas-universitates-datorikas-fakultates-profesors-leo-selavo.a48183/`
2. 2015-02-11 [P] Latvia Radio 1 show "Zināmais nezināmajā" interview with Modris Greitāns and Atis Hermanis `http://lr1.lsm.lv/lv/raksts/zinamais-nezinamaja/muguras-veseliba-un-stajas-problemas.a48109/`
3. 2015-05-05 [P] Latvia Radio 1 show "Zināmais nezināmajā" interview with Atis Hermanis `http://lr1.lsm.lv/lv/raksts/zinamais-nezinamaja/stastnieku-konkurss-jaunajiem-zinatniekiem.a51593/`
4. 2015-05-15 Atis Hermanis presented his work on wearable sensor systems in scientific research contest "Research Slam 2015" organized by RTU and gained 1st place, `https://m.diena.lv/raksts/sodien-laikraksta/researchslam-uzvar-prezentacija-par-korseti-14098776`
5. 2015-08-08 Researcher Atis Hermanis participated in Riga IT Demo center press conference and demonstrated wearable sensor system developed in EDI.
6. 2015-08-25 Junior Summer Entrepreneurship School 2015, Emil Syundyukov gives lecture presenting the project results. `http://www.sseriga.edu/en/news-and-events/news/news-archive/2015/09/yess.html`
7. 2015.08.27 Atis hermanis gives lecture at Summer School "Smart Textiles for Healthcare" about the technologies developed in the project.
8. 2015-09-25 Project results were presented in event "Scientist night 2015" at Institute of Electronics and Computer Science, `https://www.facebook.com/events/127213314299890/`
9. 2015-09-25 Emil Syundyukov presents at young researcher contest "Zinātnieku cīņas klubs" organized by University of latvia, `http://www.naba.lv/naba-zinas/nc/t/35410/`
10. 2015-09-30 Emil Syundyukov presented his Bachelors thesis "Embedded hardware and software for health data monitoring during rehabilitation" in the annual stipend contest for best IT bachelors thesis by company Exigen Services Latvia and RTU Development fund "ZIBIT 2015" and gained 2nd

place, https://www.fonds.lv/projekti/2015gads/datorikas-darbu-konkurss-2015/uzvaretaji/

11. 2015-09-30 [P] Article in portal “Izglītība un Kultūra” about project SOPHIS, http://www.izglitiba-kultura.lv/zinas/prezentes-valsts-petijumu-programmas-kiberfizikalas-sistemas-ontologijas-un-biofotonika-drosai-pilsetai-un-sabiedribai-pirmos-rezultatus

12. 2015-10-22 [P] Article “Zinātnieki drošai un viedai pilsētai un sabiedrībai” in newspaper “Izglītība un Kultūra” describes SOPHIS results.

13. 2015-10-26 [P] Radio NABA show “Studentu pietura” interview with Emil Syndyukov http://naba.lsm.lv/lv/raksts/studentu-pietura/studentu-pietura-studentija-neiespejamais-klust-iespejams.a58071/

14. 2015-11-04 [P] Journal “Ir” published interview with Emil Syundyukov, http://www.irlv.lv/2015/11/4/urki-kas-pasauli-ieliek-telefona

15. 2015-11-17 Emil Syundyukov in cooperation with “Health Hackers” organizes “Healthcare Technology and Enterpreneurship day” and presents results of the project.

16. 2015-11-17 Atis Hermanis presents project results at “Healthcare Technology and Entrepreneurship Day”, at Riga School of Economics, https://www.youtube.com/watch?v=bEr6ePKnEsM

17. 2015-12-13 [P] TV LNT News show the wearable systems developed in the project, https://skaties.lv/zinas/latvija/sabiedriba/petnieciba-latvija-uznem-apgriezienus-dzimst-jaunas-un-interesantas-idejas/

18. 2015-12-17 Emil Syundyukov presents at 38th discussion of DevClub.lv, subject of which is health, https://www.youtube.com/watch?v=YuccOEQOvi4 http://www.devclub.lv/announcement-of-health-focused-38th-devclub-lv/

19. 2016-01-16...28 Atis Hermanis presented project SOPHIS ideas and results while participating in international events “ARTEMIS Brockerage - Event for Call 2016” and “ECSEL Brokerage Event” at Strasbourg, fRANCE.

20. 2016-02-19 Emil Syundyukov as part of “Latvijas Informātikas Olimpiāde” event gives lecture to pedagogues in a seminar “Aktualitātes datorzinātnē, programmēšanā un to pielietošana mācību procesā”, introducting the latest achievements of the project, http://www.lio.lv/doki/LIO2016_seminara_progr.pdf

21. 2016-02-19 Atis Hermanis read a lecture at Latvian programmer day conference, https://youtu.be/yp0xhVOM1vE?list=PLxc2e81TLgVSqhXJCeehls8LLpJfs_pEz&t=4212

22. 2016-02-19 Emil Syundyukov recieved the Charles Babbage Award at the Latvian programmer day conference for contribution to computer science in Latvia, and presented a lecture about his work in the project, http://www.df.lu.lv/zinas/t/38682/

23. 2016-02-25 Emil Syundyukov presented his work at Riga Stradins University event “Zinātnes Pēcpusdiena”, https://www.facebook.com/events/350071191830237/

24. 2016-02-27 [P] Newspaper and portal “Diena” interview with Emil Syundyukov, https://www.diena.lv/raksts/latvija/zinas/studenti-kuri-patiesam-aizravusies-14131628

25. 2016-02-29 Emil Syundyukov presents the project results at Riga BioTech Meetup, https://www.meetup.com/Riga-Biotechnology-Meetup/events/228452747/

26. 2016-03-21 [P] Emil Syundukov interview at portal “db.lv”, http://www.db.lv/tehnologijas/programmatura/pulcesies-veselibas-tehnologiju-entuziasti-447088

27. 2016-03-29 [P] Article in portal “Izglītība un Kultūra” about project SOPHIS, http://www.izglitiba-kultura.lv/zinas/informes-par-programma-kiberfizikalas-sistemas-ontologijas-un-biofotonika-drosai-pilsetai-un-sabiedribai-paveikto

28. 2016-04-14 A. Ancāns presents his work “Smart mouse” in the contest “Research Slam 2016”, http://www.researchslam.com/2016/04/11/tresa-atlases-karta-14-aprili/

29. 2016-04-14 K. Nesenbergs presents his work “Universal smart clothing architecture” in the contest “Research Slam 2016” and advances to finals, http://www.researchslam.com/2016/04/11/tresa-atlases-karta-14-aprili/

30. 2016-04-15..16 Emil Syundukov organizes Garage48 HealthTech hackathon where project results are demonstrated, http://garage48.org/events/healthtech

31. 2016-04-28 [P] Latvijas Radio 1 show “Zināmais nezināmajā” interview with Krišjānis Nesenbergs, http://lr1.lsm.lv/lv/raksts/zinamais-nezinamaja/research-slam-2016-pastastit-par-zinatni-ta-lai-saprot-ari-abecn.a67395/

32. 2016-04-29 A. Ancāns presents his work “Inerciālo sensoru un elektromiogrammu signālu ieguve un apstrāde alternatīvās saziņas ierīcei” at 57th RTU student scientific and technical conference, https://www.facebook.com/ETF.RTU/posts/1700246346896312

33. 2016-05-05 [P] Radio Pieci.lv show “Domnīca” interview with Emil Syundukov, http://www.df.lu.lv/zinas/t/40289/

34. 2016-05-30 [P] Emil Syundyukov and his work in project is listed in journal “Forbes” as “Forbes 30 under 30” in science and medicine category: http://www.df.lu.lv/zinas/t/40692/ http://forbes.lv/30under30/talents-of-2016/

35. 2016-05-31 Emil Syundukov participates in “Upgraded Life Festival”, Finland, demonstrating project results, http://www.upgradedlifefestival.com/

36. 2016-09-28 [P] Portals kursors.lv and reitingi.lv publish article about project results, that will be presented at “Scientist night 2016”, https://kursors.lv/2016/09/28/edi-zinatnieku-nakti-aicina-iepazit-viedos-audumus-biometri/ http://www.reitingi.lv/lv/news/izglitiba/109998-edi-zinatnieku-nakti-aicina-iepazit-viedos-audumus-biometrijas-iespejas-iegultas-sistemas-un-viedo-transportu.html

37. 2016-09-30 - Project results have been demonstrated at event “Scientist night 2016” at Institute of Electronics and Computer Science, https://www.facebook.com/events/650870961744211/

38. 2016-10-17 [P] Portals delfi.lv, epadomi.lv and rigacomm.com have published articles about upcoming demonstration of self driving car developed in the project, http://www.delfi.lv/auto/zinas/sonedel-kipsala-vares-apskatit-latvija-raditu-pasbraucoso-auto.d?id=48034021 http://epadomi.lv/auto/17102016-kipsala_ieripos_latvija_radits_pasbraucos http://rigacomm.com/lv/kipsala-ieripos-latvija-radits-pasbraucoss-auto/

39. 2016-10-18 [P] Portal vipi.lv published article about self driving car demonstration in Exhibition Riga Comm, http://www.vipi.lv/kaleidoskops/latvija/idn61186/kipsala-ieripos-latvija-radits-auto-kurs-brauc-bez-vaditaja/

40. 2016-10-19 [P] Portals rus.db.lv and travelnews.lv published articles about self driving car demonstration in Exhibition Riga Comm, http://rus.db.lv/ekonomika/tehnologii/foto-drony-roboty-i-avtomobil-bez-voditelja-na-kipsale-75533 http://travelnews.lv/?m_id=18557&i_id=5&pub_id=101589&Kipsala-ieripos-Latvija-radits-pasbraucoss-auto-

41. 2016-10-20 [P] Portals apollo.lv and tvnet.lv published articles about self driving car demonstration in exhibition Riga Comm,http://www.tvnet.lv/apollo/arhivs/775400-kipsala_ieripos_latvija_radits_pasbraucoss_auto http://www.tvnet.lv/auto/auto_pasaule/630570-kipsala_ieripos_latvija_radits_pasbraucoss_auto?/auto/notikumi/630570-kipsala_ieripos_latvija_radits_pasbraucoss_auto

42. 2016-10-25 [P] Newspaper "Latvijas Avīze" published an article about Latvian innovations, including SOPHIS project results.

43. 2016-10-26 [P] Portal jauns.lv (online version of journal "Kas Jauns") published article reviewing the project result demonstration at Exhibition Riga Comm, including the self driving car, http://jauns.lv/raksts/bizness/12219-latviesu-zinatnieki-cer-atrisinat-sastregumu-problemu-kipsala-redzams-pasbraucoss-auto-foto

44. 2016-10-28 [P] Newspaper "Kas Jauns Avīze" publishes article about self driving car developed in the project.

45. 2016-11-08 Emil Syundukov received scholarship for his Masters work within projects, http://www.df.lu.lv/zinas/t/43098/

46. 2016-11-16 Emil Syundukov gave several presentations about his work in project at RSU, LU, Latvian schools, SSE Riga etc. as part of Global Enterpreneur week, http://www.sseriga.edu/en/news-and-events/upcoming-events/globalentrepreneurshipweek2016.html

47. 2016-11-30 [P] Latvian Television 1 "Lielais Jautājums", interview with Emil Syundyukov, http://www.lsm.lv/raksts/zinas/ekonomika/ka-apsteigt-igauniju-miljons-par-sasniegumiem-izglitibas-un-veselibas-aprupes-eksports.a212451/

48. 2016-12-02 [P] Portal "Izglītība un Kultūra" published adrticle about SOPHIS results in third year, http://www.izglitiba-kultura.lv/zinas/notiks-valsts-petijumu-programmas-sophis-tresa-posma-rezultatu-apspriesana

49. 2017-01-23 Leo Seļāvo presents "Internet of Things, Humans, or a Nervous System for Humanity," at 75th Annual Conference of the University of Latvia, Riga, Latvia, https://www.lu.lv/konference/programma/?session=318

50. 2017-02-06 [P] Article about project achievements in self-driving cars and collaboration with Pilot Automotive in journal "Deviņvīri" No.09 February 2017. Pages 74-78.

51. 2017-02-17 Leo Seļāvo presents "IoT as a Nervous System for Humanity" at Programmers Day Conference 2017, Riga, Latvia, https://www.df.lu.lv/par/latvijas-programmetaju-dienas/lpd-2017/

52. 2017-03-14 [P] Portals lza.lv and ecomedia.lv publish article about academic prize earned by SOPHIS project leader J. Bārzdiņš, http://www.lza.lv/index.php?option=com_content&task=view&id=3672&Itemid=43 https://ecomedia.lv/akademikiem-janim-barzdinam-un-baibai-rivzai-pasniedz-lza-lielas-medalas

53. 2017-04-05 Leo Seļāvo and Modris Greitāns presented project achievements at EBIT'2017, the Conference for Managers and Entrepreneurs, Riga, Latvia, http://www.vaditajukonference.lv/

54. 2017-04-28 Project achievements in self driving technologies demonstrated at Swedbank Digital Workshop by I. Ribners.

55. 2017-05-10 Live demonstration of self-driving capabilities at Biķernieki Complex Sports Base in cooperation with LMT, https://www.youtube.com/watch?v=KH2WTuZwgIc

56. 2017-05-10 [P] Portals delfi.lv, diena.lv and boot.lv published article about the self-driving capability demonstration, http://www.delfi.lv/auto/zinas/latvija-veidos-starptautisku-bezpilota-auto-izmeginajumu-trasi.d?id=48821261 https://www.diena.lv/raksts/tehnologijas/auto/latvija-veidos-starptautisku-bezpilota-auto-izmeginajumu-trasi-14171757 https://boot.ritakafija.lv/auto-moto/latvija-iesture-pirmais-bezpilota-auto/

57. 2017-05-10 [P] LNT television news broadcast the self-driving demonstration, https://skaties.lv/zinas/latvija/foto-un-video-unikals-notikums-bikernieku-trase-izmeginats-bezpilota-automobilis/

58. 2017-05-10 [P] National Television LTV news broadcast the self-driving demonstration, http://www.lsm.lv/raksts/dzive--stils/tehnologijas-un-zinatne/teste-pirmo-latvijas-bezpilota-auto.a235998/

59. 2017-05-11 [P] Portal kursors.lv published article about the self-driving demonstration, https://kursors.lv/2017/05/11/latvija-ir-sapnis-izveidot-starptautisku-bezpilota-auto-izmeginajumu-trasi/

60. 2017-05-15 [P] Portal automedia.lv published article abpout self-driving demonstration, http://automedia.lv/vieglie-auto/foto-ari-latvija-nak-klaja-ar-iestradem-bezpilota-auto-vadibas-sistemas-radisana-un-sola-veidot-starptautisku-izmeginajumu-trasi/

61. 2017-06-16 M. Greitāns participates in ECSEL 2017 Symposium where he discusses SOPHIS results and their potential synergy with future projects.

62. 2017-06-29 Leo Seļāvo speaks at festival LAMPA about smart homes and wireless sensor networks.

63. 2017-06-30 Leo Seļāvo speaks at festival LAMPA, about potential for technology transfer of project results.

64. 2017-09-29 In the event of "Scientist night 2017" at Institute of Electronics and Computer Science, the project results were presented, `https://www.facebook.com/events/491333651204841/`
65. 2017-10-17 [P] Portal delfi.lv published article about the successfully ending SOPHIS programme and future of state research programmes, `http://www.delfi.lv/news/national/politics/puse-bada-vai-jauna-politika-varetu-iznicinat-atseviskas-zinatnes-nozares.d?id=49343091`
66. 2017-11-13 [P] Portal ecomedia.lv published article about the final results of SOPHIS, `https://ecomedia.lv/decembra-sakuma-prezentes-rezultatus-nakamas-paaudzes-ikt-sistemu-attistiba/`
67. 2017-11-14 [P] Portal kursors.lv published article about the final results of SOPHIS, `https://kursors.lv/2017/11/14/latvijas-zinatnieki-aicina-iepazities-ar-vinu-sasniegumiem-informacijas-tehnologiju-joma/`
68. 2018-01-04 [P] Latvia Radio 1 show "Zināmais nezināmajā" interview with discussion about final SOPHIS results, `http://lr1.lsm.lv/lv/raksts/zinamais-nezinamaja/robots-sofija-pasbraucosie-auto-un-kripto-valuta-aizvaditais-gad.a97486/`

B.1.5 Exhibitions

In each of these Exhibitions the latest project results were presented.

1. 2014-10-10...11 A.Mednis participated in Exhibition "MINOX 2014" organized by Riga Technical University.
2. 2015-02-27...28 Participation in exhibition "Skola 2015", Riga.
3. 2016-10-20...21 Participation in exhibition "RIGA COMM 2016", Riga.
4. 2016-12-02...04 Participation in exhibition "ROBOTEX", Tallin, Estonia.
5. 2017-03-31 Participation in exhibition "Baltic Textile 2017", Riga.
6. 2017-11-9...10 Participation in exhibition "RIGA COMM 2017", Riga.

B.2 Press releases

The following press releases were sent out informing the media of project results. These were in Latvian language only, so the title is not translated. All of these releases were indexed by at least one press release aggregator service, such as leta.lv or bns.lv.

1. 2015-07-03 "Projekta "Kiberfizikālo sistēmu tehnoloģiju attīstība un to pielietojumi medicīnā un viedā transporta jomā" seminārs par 1. posmā veiktajiem darbiem un iegūtajiem rezultātiem".

2. 2015-10-02 “Prezentēs valsts pētījumu programmas ”Sophis” pirmos rezultātus”.
3. 2016-03-10 “Elektronikas un datorzinātņu institūts aicina uz semināru”.
4. 2016-03-16 “Notiks viedajai pilsētai, tehnoloģijām medicīnā un transportā veltīti semināri”.
5. 2016-03-22 “Notiks valsts pētījumu programmas SOPHIS otrā posma rezultātu apspriešana”.
6. 2016-03-30 “Prezentēs valsts pētījumu programmas SOPHIS otrā posma rezultātus”.
7. 2016-09-28 “EDI Zinātnieku naktī aicina iepazīt viedos audumus, biometrijas iespējas, iegultās sistēmas un viedo transportu”.
8. 2016-10-17 “Ķīpsalā ieripos Latvijā radīts pašbraucošs auto!”.
9. 2016-12-02 “Notiks valsts pētījumu programmas SOPHIS trešā posma rezultātu apspriešana”.
10. 2016-12-02 “Prezentēs valsts pētījumu programmas ”SOPHIS” trešā posma rezultātus”.
11. 2016-12-07 “Apspriedīs valsts pētījumu programmas SOPHIS trešo posmu”.
12. 2017-11-13 “Iepazīsti nākotnes IKT sistēmu attīstībā sasniegto noslēdzoties valsts pētījumu programmai SOPHIS”.
13. 2017-12-04 “Prezentēs rezultātus nākamās paaudzes IKT sistēmu attīstībā”.

B.3 Technological forecast

1. A technological forecast for the future development of cyberphysical systems (Appendix 1, annex B.3).

C Economic performance indicators

C.1 Private funding attracted to the scientific institution in the framework of the programme

C.1.3 Income from contractual jobs that are based on results and experience acquired in the framework of the programme (EUR)

At the moment the income from contractual jobs based on the project results and experience amount to 96782.40 EUR, which exceeds the planned 95000.00 EUR by 1782.40 EUR. This income can be related to project periods thus:

1. Period 1 = 7865.00 EUR.
2. Period 2 = 35743.40 EUR.
3. Period 3 = 35000.00 EUR.
4. Period 4 = 18174.00 EUR.

C.1.4 Co-funding from the scientific organizations to implement the projects of the programme (EUR)

The total amount of co-funding from the Institute of electronics and computer science for Project No. 1 is 177146 EUR, thus surpassing the planned goal of 172000 EUR by 5146 EUR. This amount was divided by period as follows:

1. Period 1 = 5639 EUR.
2. Period 2 = 45126 EUR.
3. Period 3 = 57279 EUR.
4. Period 4 = 69102 EUR.

C.2 Applied for, registered, and valid patents or plant varieties in the framework of the programme

C.2.1 In the territory of Latvia

1. 2017-11-02 Submitted Latvian patent application No. P-17-69. Name of invention “Mobile device for a more efficient development of wireless sensor networks and their nodes in target environment” / “Mobila ierīce bezvadu sensoru tīklu un to mezglu efektīvai izstrādei mērķa vidē”. Inventers: Leo Seļāvo, Krišjānis Nesenbergs, Jānis Judvaitis, Didzis Lapsa, Rihards Balašs, Arnis Salms, Modris Greitāns.
2. 2017-12-29 Submitted Latvian patent application No. P-17-97. Name of invention “Metohod of controling of antenna radiation patterns by using transmission lines on printed circuit board” / “Metode antenas virziendarbības nodrošināšanai, izmantojot tikai spiesto plašu celiņus ar pielāgotu garumu”. Inventor: Ivars Driķis.

C.3 New technologies, methods, prototypes or services that have been elaborated in the framework of the programme and approbated in enterprises

1. 3D clothing technology with 3D information segmentation algorithms was approbated at EuroLCDs Ltd. on their volumetric displays (Section 3.3.4)
2. Self-driving car technology approbated at GCDC challenge (Section 4.4.7)
3. TestBed approbation by “19 points” Ltd. (Section 2.4.6)

4. Device for head control of computer approbated at rehabilitation center ”Mēs esam līdzās” (Section 3.4.2)
5. Mobile TestBed approbation at Dobele Institute of Horticulture (Section 2.4.6)
6. Mobile and stationary TestBed approbated by students at University of Latvia as part of a Wireless Sensor Network hands on course (Section 2.4.6)
7. Palm prosthesis monitoring system was approbated by start-up ”Wide.Tech” (Section 3.4.5)

C.4 New technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property)

1. Licensing agreement contract No. 1.1.1.-5/23-17, with University of Latvia, about licensing the TestBed system for student use as part of course material.

C.5 Founded a new (spin-off) company

1. HackMotion (`https://hackmotion.com/`) is a start-up co-founded by researcher in SOPHIS project, Atis Hermanis, whos technical know-how gained in this project, has allowed him to act as successful CTO for this newfounded company. Licensing agreements for any specific technologies developed within project are still under discussion.

C.6 Earnings by the scientific institution from other research projects in synergy (EUR)

Multiple projects have provided earnnings to the scientific institution from research in synergy with the project results. The total amount of earnings from these projects is 1886753.00 EUR (Which added to contract research projects in [Result C.1.3] of 96782.40 EUR results in 2 million EUR in earnings to institution from synergy projects), which consist of these projects and amounts:

1. 3CCar = 293219 EUR (`http://www.edi.lv/en/projects/international-projects/3ccar/`).
2. HIPPAC = 82775 EUR (`http://edi.lv/en/projects/international-projects/hippac/`).
3. Autodrive = 295868 EUR (`http://www.edi.lv/en/projects/international-projects/autodrive/`).
4. CONVERGENCE = 200000 EUR (`http://www.edi.lv/en/projects/international-projects/convergence/`).

5. ENACT = 136250 EUR.
6. PRYSTINE[12] = 200000 EUR.
7. I-MECH = 323000 EUR (`http://www.edi.lv/en/projects/international-projects/i-mech/`).
8. 3D clothing = 25000 EUR (`http://www.edi.lv/en/projects/ec-co-financed-projects/3d-audums/`).
9. DIPA = 227529 EUR (`http://www.edi.lv/en/projects/ec-co-financed-projects/dipa/`).
10. DEWI = 103112 EUR (`http://www.edi.lv/en/projects/international-projects/eu-fp7-artemis/`).

[12] The total income from this project is 323000 EUR, but 123000 EUR are attributable to Project No. 4 of SOPHIS, thus only 200000 EUR are attributed to this project.

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