Appendix No.1

National Research Programme „Cyber-physical systems, ontologies and biophotonics for safe&smart city and society” (SOPHIS)

Project Nr.1 „Development of technologies for cyber physical systems with applications in medicine and smart transport (KiFiS)”

Scientific report

Period 1

CONTENT

Introduction

State research program “Cyber-physical systems, ontologies, and bio-photonics for safe&smart city and society” (VPP SOPHIS) ant 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, 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. The developed 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, will be approbated ir real or close to real conditions, in cooperation with partners from the economy. Potential use cases include intelligent transport systems, medical applications, wireless sensor network applications and others.

In the scope of CPS research the following research activities have been carried out:

- TestBed – testing environment for wireless sensor system development and testing;
- BoASen – Smart sensors for measuring human biomechanics;
- JoSen – Sensor system for rehabilitation of knee and other joints;
- MECG – Mobile smart sensor system for measurements of health paramters, including heart operation monitoring;
- ImPro – signal, including image, processing for environment evaluation of intelligent transport systems;
- GCDC – intelligent vehicle system for sager and more efficient driving.

All of these activities are targeted at reaching the goals of the project. These activities and their results are described in the following document, each in its own separate section.

1. Chapter. TestBed for Wireless Sensor Network design and profiling (TestBed)

Background

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 ar 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 mote 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.

Introduction

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

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

Design of WSN begins with definition of usage 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[?], XM1000[3], second – to build hardware from ground. The first option requires only adaptation of existing hardware to the desired operation and therefore requires less effort compared to the second option. However, 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.

Solution is to create a large (25+) WSN testbed were user can perform different tests at different levels of abstraction - from low to high.

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 compromise data acquisition, processing, structuring from testbed user point of view

Related work

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

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 [4] 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 [5], 102 eyesIFX.

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. 1 below.

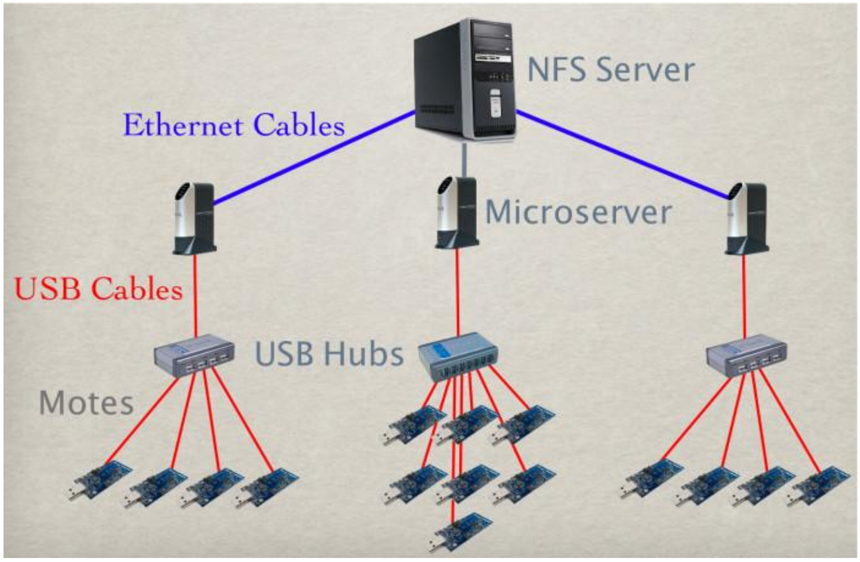

Figure 1: TWIST Testbed architecture

At the lowest level, sensor nodes are physically connected through USB interface to take sensor readings and/or perform actuation. They are connected to micro-servers through active USB hub. Communication can be established between sensor node and micro-server over this interface in both directions. The last level of connection is established between micro-servers and the central server, over Ethernet backbone. The central server is also used to provide workable interface between Testbed and end-users.

MoteLab

MoteLab [6] has been deployed on a network of 30 Ethernet-connected MicaZ "motes" [2] 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 it.

MoteLab was the first designed WSN testbed with reduced usage complexity. This was achieved due to the fact that was implemented 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,
- 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.

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 [7]. 100 TelosB [1] nodes and 25 Arduino [8] devices are used in INDRIYA testbed. The INDRIYA WSN testbed is build on TWIST architecture [4] 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.

Conclusions

There are many designed and deployed testbeds for WSN. Most of them are based on TWIST architecture [4]. All of WSN testbeds are freely available and their software is open source. None of mentioned WSN testbeds [4] [7] [6] solves all problems associated with WSN design. Mostly they have at least one unique feature. In our proposed work we try to solve all mentioned problems, regarding to WSN design. On the basis of conducted related work.

Our approach

EDI TestBed Architecture from hardware perspective

TWIST [4] was chosen as ground truth architecture for EDI Testbed, but with modifications:

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 Testbed adapter), is introduced. It is placed between micro-server and sensor node. Our developed module allows users accurately evaluate designed WSN performance. It provides with additional information: power consumption measurement, battery discharging emulation, real-world sensor data emulation, analog/digital signal debugging.

EDI Testbed architecture can be seen in Fig. 2.

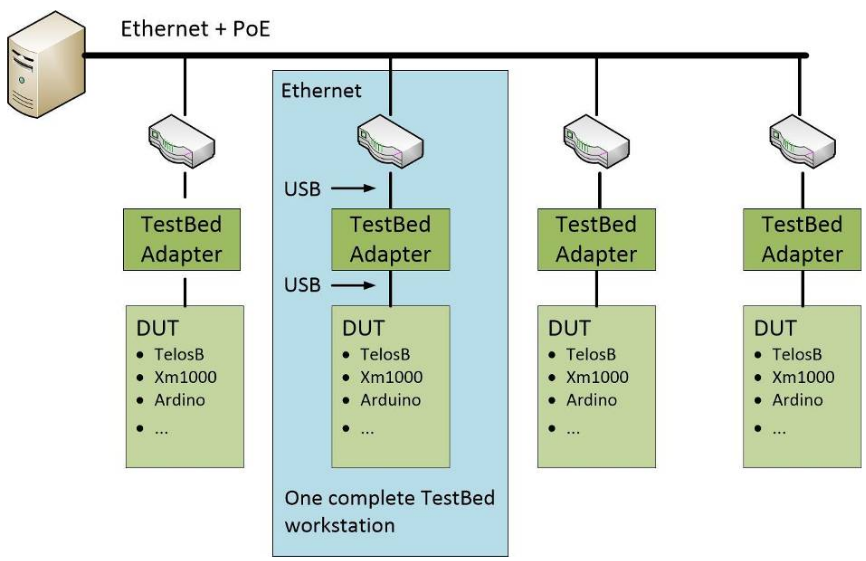

Figure 2: EDI TestBed Architecture

EDI Testbed Architecture from software perspective

WSN testbed design challenges (problems) from software perspective are:

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.

In the next sections each previously mentioned step will be explained in more details.

Evaluation

EDI Testbed infrastructure

Proposed Testbed architecture is currently being 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. It is intended that 100 Testbed workstations will be installed, 90 of them across five floors, and 10 outside of The EDI building. In figure below you can see Testbed workstation placement in the third floor, Fig. 3.

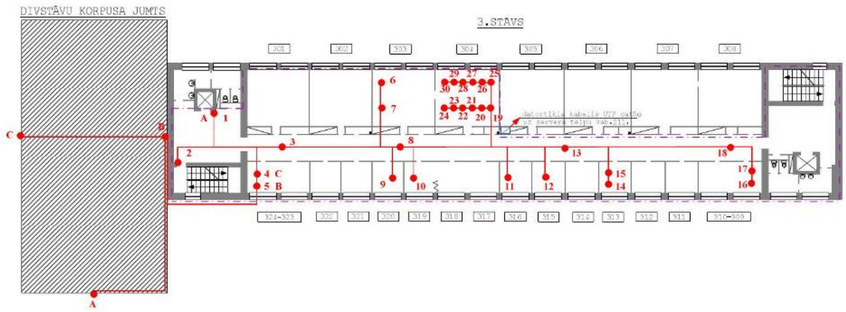

Figure 3: Sensor node placement in the 3rd floor

Testbed Adapter

EDI Testbed adapter is specifically designed for this particular Testbed. EDI Testbed Adapter is a result of previous research work, related to prototyping and profiling low power embedded systems [10][11]. 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, analog signals,
- measure - digital, analog signals,
- store measured data on local SD cards.

EDI Testbed Adapter is placed between router and sensor node.
To extend EDI Testbed Adapter life-cycle and support easy upgrade over time, for instance - adding extra functionality, replacing/upgrading old ones, and scalable architecture was chosen. Instead of one complex board, many divided functional boards were designed: communication, power metering, data acquisition modules. Each board has unified pin-out, and fulfills only one functional task, for instance, tasks that are related to power supply evaluation. In such approach computational power requirements for EDI Testbed Adapter won't increase, if extra modules are added, because all processing is done locally on each functional board. On functional modules that measures sensor node parameters, local data storage is used. Each designed module can be used as standalone device - connected through USB interface.

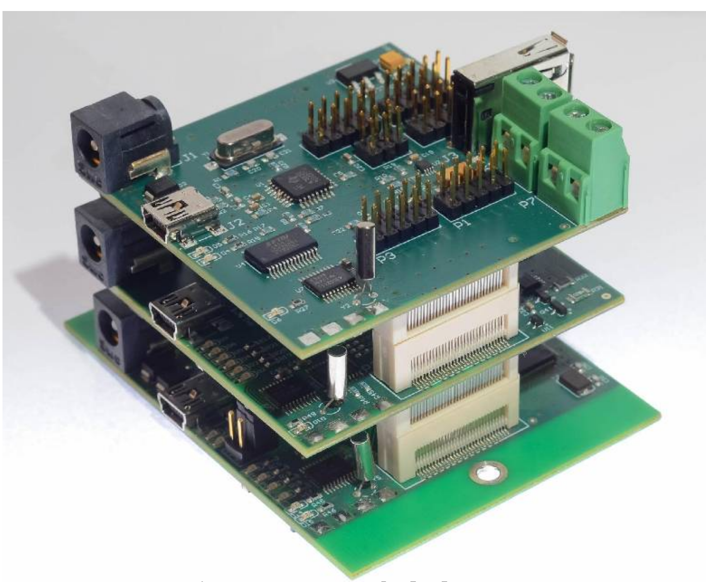

Figure 4: EDI Testbed adapter

Web interface

Web interface backend were programmed in Python using Django 1.8 framework. Python was chosen because MansOS operating system that is used in almost all levels of software in testbed design is programmed in Python and it makes easier interaction with it. Django framework was chosen because of its wide range of security and customizing features. One of the main goals in this stage of development for user interface was to make it as much AJAX base as possible. In different words to make all requests without refreshing web page. This way workflow is not unnecessarily interrupted and it feels much more like using a tool not surfing a web page.

Data visualizing

To make sensor nodes serial output monitoring easier two different views for visualizing data were made.
First view is plain text view in which data can be viewed by prefix in plain text. It is useful for looking at string or hex data. This visualizing mode is also comfortable for monitoring specific events outputted by sensor node. For example time of dawn (or smtn). Second is graphical view in which data is visualized using Google Charts API. As this API contains a lot of built in data representation styles data can be visualized in most convenient way possible. For example simple scalar data can be viewed as line graph, vector data can be viewed in plain etc. For now in graphical interface only line graph is fully supported. In future it is planned to support pie chart type, for displaying relations between values or percent data, plain type of visualizing vectors and graph chart type for visualizing networks or graphs. Timeline graphic may also be developed to more easily monitor specific event data.

Visualizing data the right way can save huge amounts of time created by large overhead of procedures necessary to understand the data better. For example if big sensor network with custom routing protocol is tested visualizing links between sensor nodes in real-time or after experiment can give a lot of understanding about protocol and possible problems connected to it. Using graph chart this type of data can be visualized.

Scheduling interface

To let the system be used by multiple users without disturbing each other scheduling system was made. Users can reserve time on specific sensor nodes in which they can reprogram the node and use it for intentioned purpose. In current state of development scheduling system works as follows:

- User can choose mote he/she wants to reserve;
- Time for reservation can be set it two fields – ’from’ and ’to’;
- Each time field can be filled using interactive calendar (Fig. 5), disabling and highlighting taken dates and times, for easier planning of reservation.

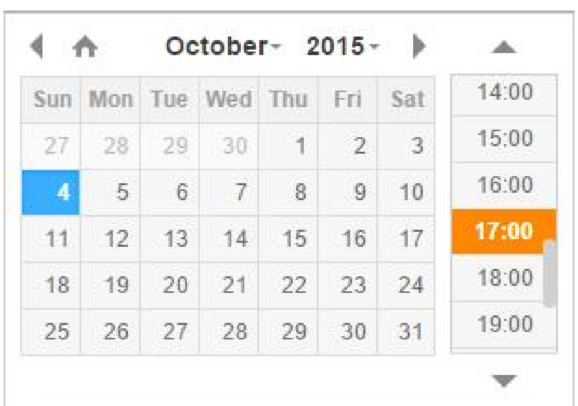

Figure 5: scheduling calendar

This sort of interface is handy, but only if couple of nodes needs to be reserved. In future feature called reservation groups will be developed. Allowing users to select all nodes they want to reserve and reserve them in one click, filling all desired time free gaps for all nodes. Another alterative view possibility can be tabular view (row for every sensor node and one column for one time unit) where user only needs to select area and reserve multiple nodes in one action.

Reprogramming interface

One of most time consuming operations in manual sensor network testing is sensor node reprogramming that is why every wireless sensor testbed addresses this problem. To reprogram sensor nodes in EDI testbed interface user first needs to upload .ihex file (compiled code) to server which can later be uploaded on sensor node. In present progress code compiling on server through web interface is not possible, but it is possible to implement it. When compiled code files are uploaded they are saved on the server and can be used by user to reprogram nodes any time. To start node reprogramming user must choose which file to use for reprogramming and choose group of nodes that should be programmed. Group reprogramming design was developed because most of wireless sensor network designs consist of main tower and leaf nodes or main tower, lower level towers, and leaf nodes and every group of them have different program. Using this interface user can choose group of nodes for every program needed and reprogram them all together (Fig. 6).

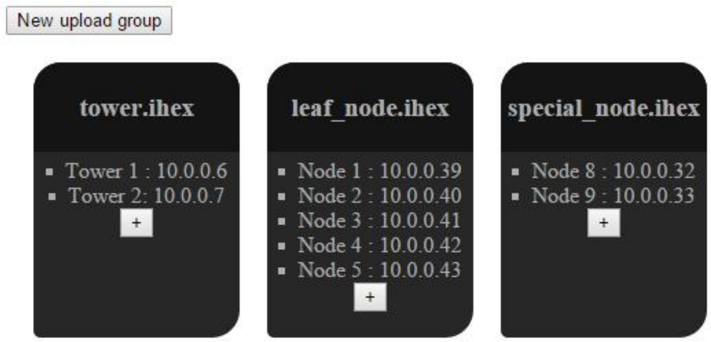

Figure 6: Sensor node upload interface

Uploading interface is made to save as much time as possible in setting up the experiment and to be as clear as possible.

In future it is planned to develop automatic reprogramming. For example if user reserves sensor node for whole day, but somebody has already reserved it for two hours in middle of the day, after two hours for different user have passed, node gets automatically reprogrammed to first user programs if he enables this setting. Also scheduled reprogramming is planned to be developed using which user can choose when to reprogram nodes and what to program on them. This way multiple experiments can be done autonomously and user can come back later to view results.

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[10] Leo Selavo Rinalds Ruskuls. Edimote: A flexible sensor node prototyping and profiling tool. In Real-World Wireless Sensor Networks, pages pp 194–197. Springer Berlin Heidelberg, 2010.

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2. Chapter Smart sensors for measurement of human biomechanics (BoASen)

Introduction

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, cardio- vascular system and other body functions. 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 system is being developed, which allows monitoring of human posture and different body part alignment in real time. Basing on the results, which were obtained in State research program "IMIS" project no. 2 „Innovative signal processing technologies for smart and effective electronic system development", in this reporting period a significantly improved posture monitoring system was developed. It is developed to enable monitoring of human posture during daily activities and provide posture biofeedback. Also data logging for later analysis is provided.

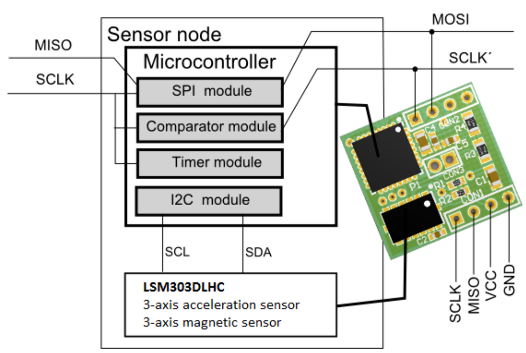
In addition, a new system for human head position monitoring and feedback was developed. This system is specifically designed for variety of patients with significant movement disorders. This system can help patient to train holding head in desired position, which improves human body functions. This can also improve ability to use specific equipment for alternative communication (for example, eye tracking devices), which can be used by patients that have speech disabilities.

Up to now several system prototypes have been developed and are being approbated in collaboration with rehabilitation centre "MEL" in Riga, Latvia.

Posture monitoring

Posture monitoring system was developed basing on wearable sensor network architecture developed in previous State research program. A sensor network was designed where each sensor node consists of different types of sensors (acceleration and magnetic field sensors). This network provides significantly improved information relating orientation and mutual location between sensors.

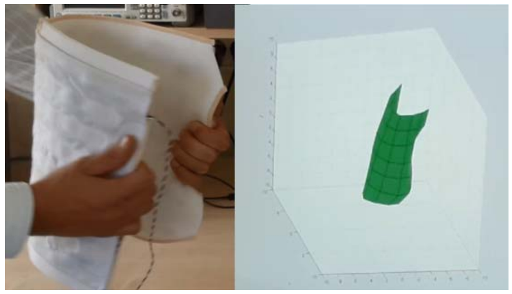
Each sensor node consists of three-axis acceleration sensor, three-axis magnetic field sensor and a microcontroller, which provides interface between the sensors and the network architecture. The application of these sensors enables to obtain full 3D orientation information of sensor node relative to global reference frame. Specific embedded software was developed to ensure effective data acquisition from sensors and transmission over the network to the processing module. A particular attention is paid to enable implementation all the required functionality utilizing low-cost, low-power electronics and limit the total size of hardware to be suitable for integration in fabric.



Structure of the sensor node

A close collaboration with project "VipTeh" (Nr. 2013/0008/1DP/1.1.1.2.0/13/APIA/VIAA/016) was established. In this project several methods for surface shape reconstruction basing on discrete orientation samples were developed.

Combining the mathematical method developed in “VipTeh” project and wearable sensor network developed in this project, a novel method for full 3d shape of fabric was obtained. Method allows to measure deformations around axis which is parallel to earth gravity field vector, which can not be obtained with accelerometer-only sensor network. Applying this method for human posture monitoring allows measurement of more detailed posture deviations and deformations.



Acquisition of full 3D deformations

Basing on this method a new human posture monitoring system prototype was developed. It consists of acceleration/magnetic sensor network for posture parameter measurements, wireless Bluetooth transmitter for data transfer and portable Android device. For Android device a specific application was developed. This application provides reconstruction of human posture model from sensor data and also several processing and logging features. Application also provides immediate biofeedback to the user, indicating posture deviations from desired position.

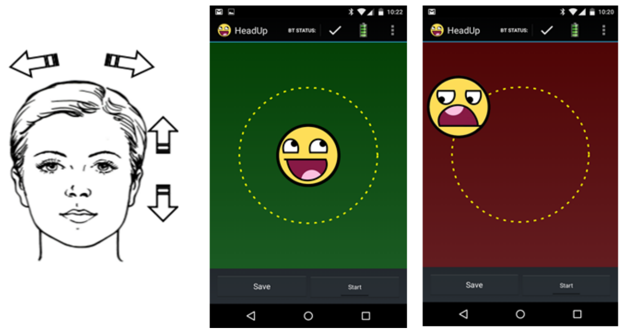
Head position monitoring

Measurement of head position

To monitor relative position of human head a custom sensor module was designed. Module consists of acceleration/magnetic field sensor node (same as being used in the sensor network of posture monitoring system), wireless Bluetooth transmitter for data transfer and battery pack. The module can be attached to patients head using elastic head band.

Sensor module for head position monitoring

By utilizing the sensor node which is embedded into module, it is possible to obtain relative orientation of the patients head. A custom software was developed with easy to understand user interface, which provides biofeedback to the patient about head position. Patient with head movements can control an object that is visible on the screen. First the system is calibrated to desired position of the head. Then during rest of the training session patient has to hold the object within the area defined by medical specialist. If the head position changes, it is indicated with the movement of the object on the screen. If the object falls outside defined area a feedback signal is generated by changing the colour of application background and applying sound alert. This provides easy to understand goal and the feedback for patients exercise task and achieved performance.



User interface of head position monitoring application

Head position and back posture monitoring

To obtain additional information about state of patient head position and posture a custom system prototype was developed, which combine head position and posture monitoring functions. A specific vest for posture monitoring was designed with additional sensor that can be attached to patients head. A specific application was designed that provides both - reconstruction of posture model as well as feedback for head position. In addition during exercise session the system can log data about deviations from desired posture and head position. This data can be used to determine the mutual connection between head position and back posture for further analysis of biomechanics. Visual graphs can be generated to provide medical staff with detailed information about patient performance during exercise session.

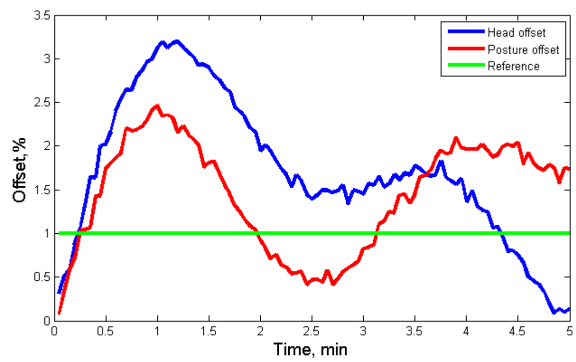
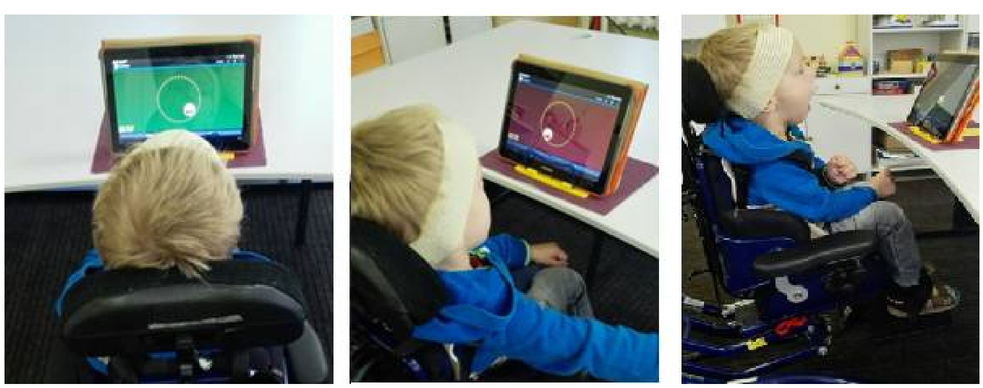


Illustration of head position and posture model data

Results

During this report period a number of different system prototypes were developed. Currently they are being approbated in rehabilitation centre "MEL" in Riga, Latvia, which deals with cerebral-palsy patients. Under the supervision of rehabilitation specialist the developed system prototypes are being tested as aiding technical apparatus facilitating the patient exercising to help them improve ability to hold desired head position and back posture.



Approbation of head position and back posture monitoring system in rehabilitation centre „MEL".

Published results

Presentations in conferences:

- 2015 IEEE International Symposium on Inertial Sensors and Systems (ISISS), 23-26 March, Hapuna Beach, HI, 2015.
- 14th International Conference on Information Processing in Sensor Networks (IPSN '15). ACM, Seattle, WA, USA, 2015.
- 4th International Doctoral School of Electrical Engineering and Power Electronics, 29-30 May, "Ronishi", Latvia.
- Summer school smart textiles for healthcare, Augsut 25-28, Riga, Latvia, 2015.
- 4th Baltic & North Sea Conference on Physical and Rehabilitation medicine, September 16-18, Riga, Latvia, 2015.

Publications:

- Hermanis, A.; Cacurs, R.; Greitans, M., "Shape sensing based on acceleration and magnetic sensor system," in Inertial Sensors and Systems (ISISS), 2015 IEEE International Symposium on , vol., no., pp.1-2, 23-26 March 2015
- Demo abstract - HERMANIS, A., CACURS, R., NESENBERGS, K., GREITANS, M., SYUNDYKOV, E., and SELAVO, L., 2015. 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 (IPSN '15). ACM, Seattle, WA, USA, 414-415.
- Abstract - A. Hermanis, A. Greitāne, S. Geidāne, A. Ancāns, R. Cacurs, M. Greitāns, „Wearable Head and Back Posture Feedback System for Children with Cerebral Palsy", Journal of Rehabilitation Medicine, p.777, Vol. 47., No 8, Sept, 2015.
- Submitted publication – A. Hermanis, R. Cacurs, M. Greitāns, „Acceleration and magnetic sensor network for shape sensing", IEEE Sensors Journal.

Presentations in other events:

- Exhibition "Skola 2015", 27 Feb – 1. March, 2015.g.
- Press conference of Riga IT Demo centre, 8. September, 2015.
- „Researchers night", 25. September, 2015.

3. Chapter JoSen for knee joint dynamic monitoring during rehabilitation

ABSTRACT

In this work the following problem was examined: patient vital signs monitoring during rehabilitation process. The goal of this paper is to present an approach for knee joint dynamics monitoring during post-operative rehabilitation by using specially developed architecture consisting of wired and wireless sensors.

Before the system development medical specialists as well as patients, who attend rehabilitation sessions after menisci surgeries were interviewed. This gave an opportunity to analyse the situation from the both sides – what difficulties face therapists during their work and what kind of problems do patients have during the rehab sessions. An analysis of existing system prototypes was made with an aim to define the pros and cons of used technologies.

Based on the previous information prototype version was built. Described system consists of combination of wearable sensor network for data gathering and transmission and mobile application for data analysis, visualization and communication with patient. System can notify a patient if there is a certain risk during the rehab session (when the prescription limits are being exceeded), by comparing an angle with a customizable threshold value.

Developed prototype version was tested in real life conditions by involving patients completing rehabilitation exercises with physiotherapist. Collected results were used to calculate described solution's accuracy and to get feedback about user experience from patients. During testing phase precision analysis was carried out to define if increasing sensor node quantity can lead to higher precision.

Introduction

Over the last decade there has been a rising interest in wearable and implantable biomedical sensors [1]. Researchers believe that long-term monitoring of physiological data could lead to significant improvements in the diagnosis and treatment of diseases (such as cardiovascular diseases, musculoskeletal disorders etc.) [2]. One of the cases are injuries of knee joint that are very common and occur in people of all ages. 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 [3].

Knee joint is composed of incongruent articular surfaces, therefore it relies on other structures to provide both static and dynamic stability. In scope of this project authors concentrated on injuries of menisci, that are the second most common injury of knee joint (61 cases per 100,000 persons) [4].

Figure 1. Rehabilitation procedure under control of health specialist

According to Ian D. McDermott et al. loss of the menisci leads to a significantly increased risk of developing degenerative changes in the long term [5]. In most of cases surgical assistance is needed for healing process. In case of menisci ruptures rehabilitation is aiming to minimize swelling and to return the range of movement, as well as to strengthen leg muscles by taking into account health specialist limitations (e.g. flexion limitation to 90 degrees, length of rehabilitation session etc.).

The most frequent cause why people choose not to come back to the same activity as before the surgery is feeling of uncertainty and fear to gain another injury. Overcoming these feelings during the rehab period is realy important. When a patient completes rehabilitation procedure, health specialist is also playing a role of psychologist by motivating patient to overcome fear and to continue working on rehab routine. Uncertainty about the right completion of the exercises can lead to another menisci injury as well as to chronical conditions [6].

Proposed solution

Our proposed solution consists of a combination of a wearable sensor system and a mobile application. Wearable sensor system consists of wired and wireless sensors and an embedded device, that is able to acquire vital signs data from sensor nodes attached to patient's knee joint. After data gathering device transfers data, using Bluetooth wireless communication channel. An important part of proposed system is a mobile application, that is used for received data analysis from wearable system. Connecting device to an application, that is installed on a smart device (such as smartphone etc.), will give an opportunity to a patient to view visualisation of his health indicators, as well as to receive notifications if these indicators will exceed certain limits (threshold value) defined by health specialist.

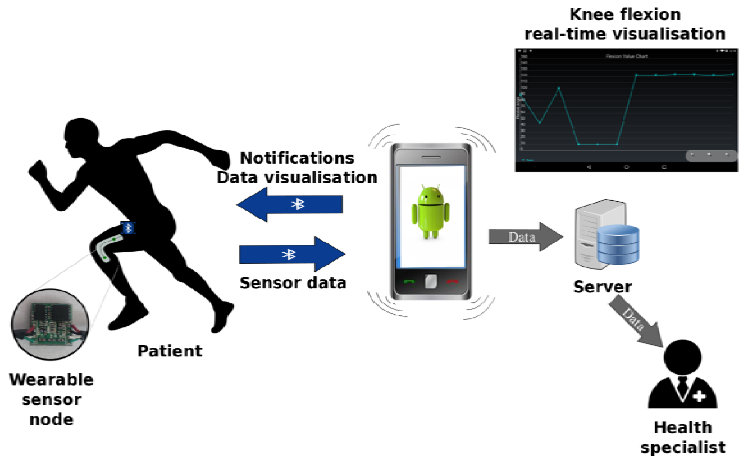


Figure 2. Structure of proposed system architecture

From other pespective, health specialist has an opportunity to view real-time and historical measurements of patient's knee joint dynamics. As a result, system will help physiotherapists to perform deeper analysis of patient's state of health and to monitor dynamics of convalescence - in this way doctor can timely make changes in treatment process. System would also help patients to complete rehabilitation process more effectively and increase the rate of successful rehabilitation after surgeries. Structure of described system is shown in Fig.1.

Wearable sensor system for knee flexion acquisition

One of the developed system's parts is wearable device used for data acquisition from patient in real-time during the rehabilitation sessions. Wearable sensor system consists of a circuit board with MSP430 microcontroller for data sampling with 50 Hz rate and 4 sensor nodes that include sensors (3-axial accelerometers and magnetometers). For knee joint flexion/extension angle calculation author used a network that consists of four 3-axial accelerometers.

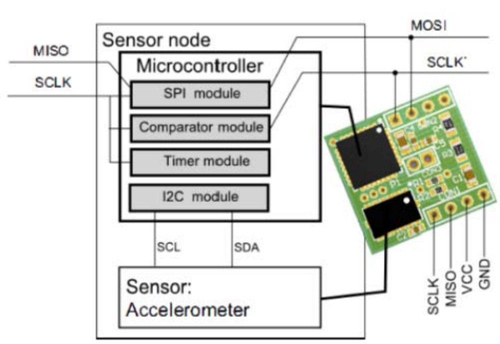


Figure 3. Structure of sensor node architecture

After successful vital signs data acquisition from sensor nodes, it is necessary to transmit it to mobile application for further storage, analysis and visualization. To achieve that a wireless communication channel should be chosen. Special emphasis should be taken on the safety and channel's reliability of broadcasted health data. This system sends acquired data to mobile application via Bluetooth BT-112 module using Serial Port Profile.

Mobile application for sensor data analysis

As part of the project a mobile application was developed to make calculations, analyze collected data from sensor nodes, store and visualize it. Another important functionality of application - communication with a patient using developed notification system. Mobile platform was chosen taking its availability, ease of use and good computing power into account. Mobile application was developed for Android OS, using Java programming language and MySQL Database technology.

Knee joint flexion angle calculation

After the connection between wearable system and mobile device is established, application will start to receive a data flow in real time, that consists of readings from 4 sensor nodes. Received raw data from wearable system can contain noises that can lead to errors during calculations. There can be several factors for noises in acquired data: patient movements, calibration of sensors etc. So the first step to calculate flexion/extension angular degree values is data normalization. After that system should calculate an angle between sensor nodes. To achieve that principles of vector algebra were used. Sensor nodes that include accelerometers can be represented as vectors in three dimensional space [7]. These vectors scalar product can be expressed as (Fig. 3):

$$\mathbf{a.b} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} * \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} = a_x b_x + a_y b_y + a_z b_z = |\mathbf{a}||\mathbf{b}| cos\alpha$$

Figure 4. Formula for vector scalar multiplication

Both vectors values (x,y,z) are corresponding sensor node's accelerometers readings. Based on this formula it is possible to calculate cosine of flexion/extension angle (Fig. 5):

$$cos\alpha = \frac{a_x b_x + a_y b_y + a_z b_z}{\sqrt{a_x^2 + a_y^2 + a_z^2}\ \sqrt{b_x^2 + b_y^2 + b_z^2}}$$

Figure 5. Angle's cosine value formula

By using (Fig. 5), it is possible to get needed angle's value [7]. To increase precision of calculations prototype version uses four sensor nodes with 3-axial accelerometers on-board. In case of four sensor nodes both vector coordinates are equal to arithmetic mean value of adjacent sensors.

Developed mobile application includes different types of calculations with the aim of receiving evidence that sensor nodes quantity increment can lead to better system's functionally accuracy.

Data storage and visualization

One of the important part of the application components is a database, that gives an opportunity to store data on patient state of health as well as to implement graphical visualization of vital signs. In case of this project MySQL relation database system was used. Following data is needed for system functionality:

Figure 6. Application database table description.

Name	Data type	Description
ID	Integer Primary Key	Indentification number
flexion_value	Integer	Calculated knee joint flexion value
flexion_time	Default current_timestamp	Timestamp of sensor reading

Application uses saved data for flexion angle visualisation and analysis. Developed prototype include chart for real-time and historical knee flexion values.

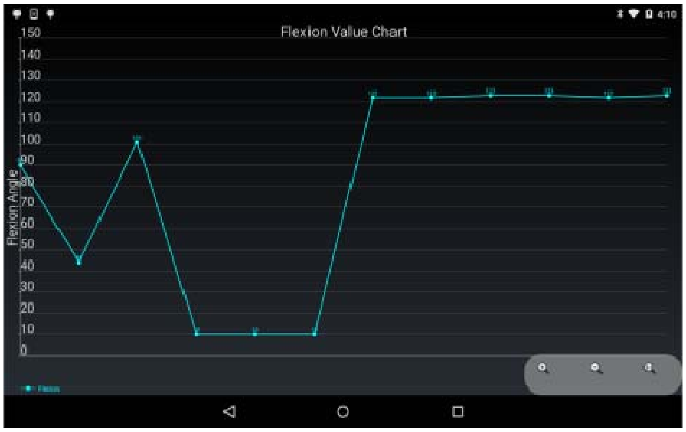


Figure 7. Calculated flexion angle value chart.

Acquired data analytics for communication with patient

Application functionality also consists of knee flexion value analysis and communication with patient. Alerting about the dangerous situations (exceeding doctor prescriptions) on-time can help to decrease the chance of repeated injuries.

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.

Testing

During the project author interviewed 20 patients, who completed the post-operative rehabilitation period and health specialists, who work with knee joint rehabilitation. The biggest part of patients admitted, that they felt fear and uncertainty about completing the doctor's prescriptions and doing rehabilitation exercises right. 70% of respondents noted, that they should monitor the flexion angle on their own during completing exercises. 3 patients had a repeated surgery (partial or full meniscectomy). In case of 2 patients repeated injury happened during rehabilitation period.

Before prototype development two health specialists were interviewed to receive valuable information on work process and problems happening during everyday work process with patients. One of the specialists ("Sporta Medicina 1" physiotherapist) was interviewed when author completed the rehab procedures by himself. Specialist stated, that patients frequently feeling fear and uncertainty, often because of healing dynamics changes – in the beginning they are having rapid results, later the progress is coming much slower and patients do not see it.

Figure 8. Patient participates in system prototype testing

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. During rehabilitation session developed prototype data was compared to industrial digital Precision of the implemented solution was calculated: 0.79°, fullfilling the requirements received from doctors on current condition.

Figure 9. Prototype calculated value and digital goniometer value comparison.

Exercise	Angle acquired from prototype	Angle acquired from digital goniometer
Nr. 1		
Knee flexion	102.2°	103.3°
	9.0°	10.0°
	74.7°	75.7°
	49.4°	51.4°
	50.1°	51.2°
Squats	104.0°	100.2°
	96.9°	97.8°
	10.0°	9.1°
	67.3°	68.9°
	66.8°	67.7°
Nr. 2		
Knee flexion	92.3°	93.2°
	47.8°	48.5°
	69.3°	70.3°
	13.3°	14.2°
	27.1°	28.1°
Squats	34.9°	35.7°
	89.5°	90.4°
	102.6°	103.7°
	76.9°	77.9°
	46.2°	48.9°

Results

Main result of this project is developed prototype, that consists of wearable device and mobile software for health data acquisition. Aim of developed system is to monitor patient knee joint movement angle in real time during rehabilitation procedures and assist in rehabilitation by providing feedback based on analyzed data. Wearable sensor system consists of a circuit board with MSP430 microcontroller for data sampling with 50 Hz rate and 4 sensor nodes that include sensors (3-axial accelerometers and magnetometers). Mobile application was developed to make calculations, analyze collected data from sensor nodes, store and visualize it. Another important functionality of application - communication with a patient using developed notification system. After comparison of developed prototype and industrial goniometer the precision was calculated: 0.79 grade (+/- 0.1 grade).

This project received the highest value and 2nd place in Best Student Paper competition in Computer Science. Project participated in international student conference "Health and Social Sciences", organized by Riga Stradins University. Prototype version was successfully presented at "IPSN 2015" conference demonstration session in Seattle, USA. Work is added to both conference proceedings [9,10].

Conclusion

Aim of the research project is to study the problems in patient state of health monitoring and opportunities during rehabilitation session. As a result, detailed analysis was made to define the difficulties occuring during post-operative knee joint rehabilitation period.

After completing market research, it was stated, that presented solutions are able to acquire data about knee flexions, but there is no analitics and notification system developed, which is very important for patients as well as helpful for physiotherapists.

Testing results gave an opportunity to receive developed system necessity and problems, that are existing in this sphere. After data analysis from interviews with health specialists author concluded, that patient monitoring topic is popular and such systems would provide help in rehabilitation process control.

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. Sensor data during dynamic conditions (like running, sports etc.) can lead to decrease of system's precision. This fact is not influencing system's ability to help during rehabilitation sessions, since such exercises are static. However, it is possible to broaden system use cases by using other sensor nodes combination.

Author sees system future extension 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.

Acknowledgement

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4. Chapter Embedded sensor system for health monitoring including ECG (MECG)

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. 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 is uncomfortable for patient because it is necessary to deliver this system back to doctor for analysis. 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.

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.

Our group is making an ECG system that includes, data gathering, analysis, and delivery to all interested parties using wireless radio. Using wireless radio eases work for doctors and patients. This functionality is ensured using wireless sensor network principles.

Related solutions

Related solutions for MECG group's activities are – Isansys Lifetouch sensor [1] and V-patch [2] wireless hearth monitoring device. In difference from those solutions ours is long term – 1 to 2 weeks. Also patient has the option to check his or her own health data.

Solution

Before the production of prototype we organized gatherings with Latvian cardiologists to get their view of the situation and requirements for the system. Summarizing the requirements we made a flowchart of the systems prototype.

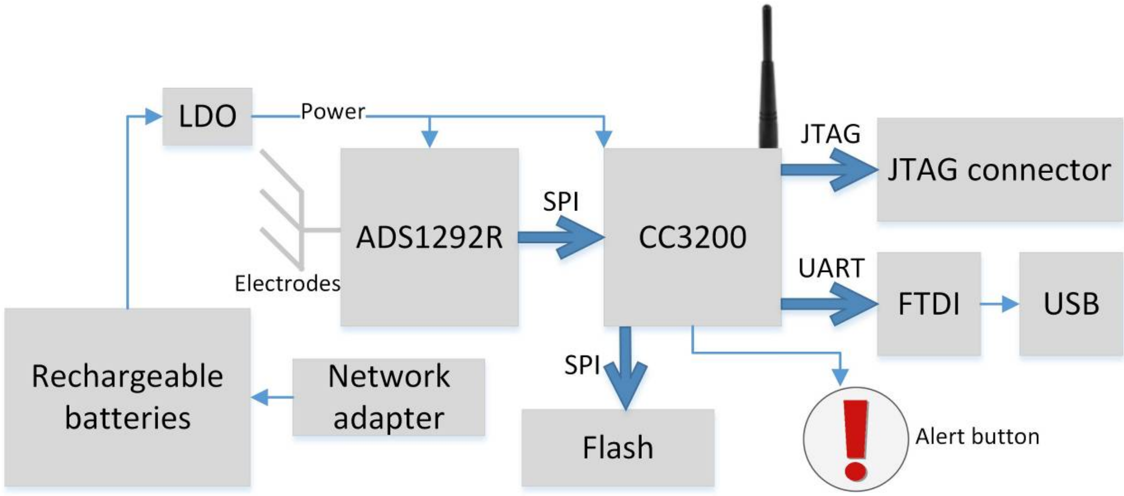
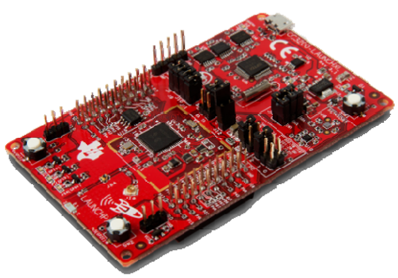


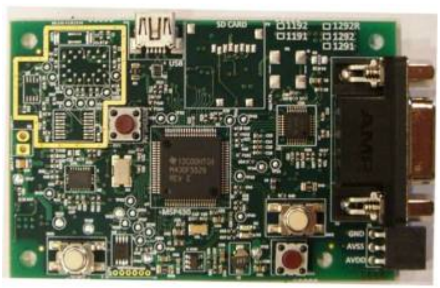
Fig. 0.1 Embedded device flowchart

To learn about the device we used various evaluation modules and development boards of components that are planned to be used in our system:

- CC3200 development board.
- ADS1292R development board.



CC3200 development board



ADS1292R development board

Continuing work we created prototype schematics.
The main component is CC3200 microprocessor, which has two integrated devices – powerful ARM Cortex M4 microprocessor and IEEE 802.11b/g standard WiFi wireless radio adapter. For gathering of heart signals we use ADS1292R analog to digital converter with integrated repertory function. For communication with USB devices we use Future Technology Devices International FT232RL component. To connect with embedded device we use RS232 interface.

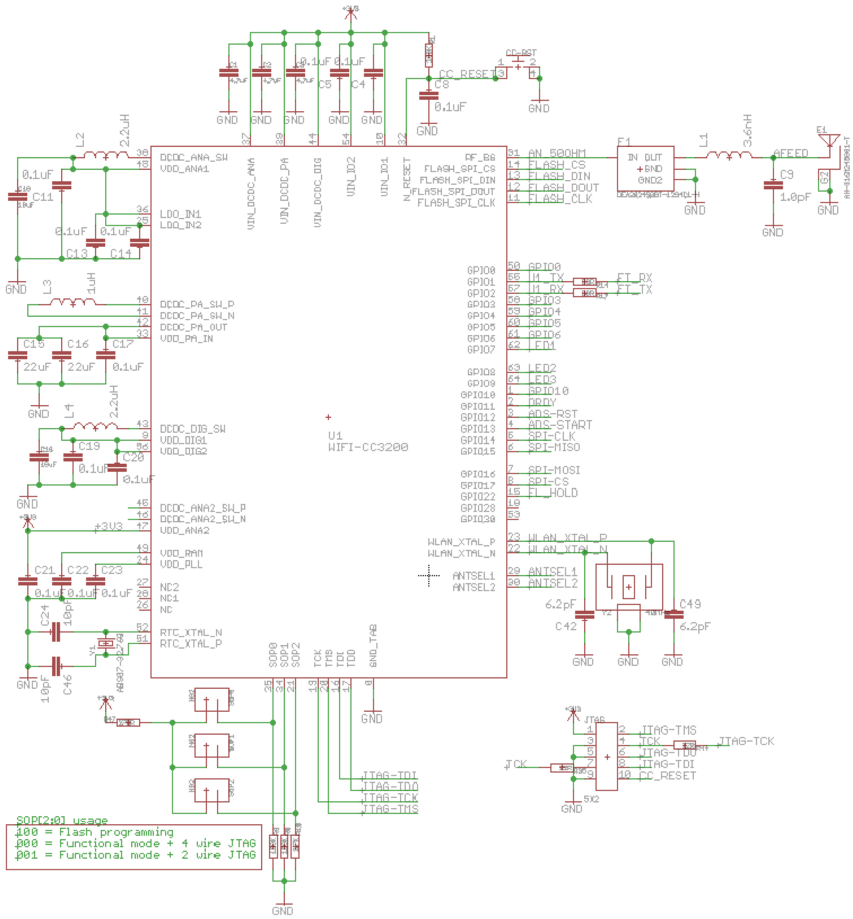


Fig. 0.2 CC3200 prototype schematics

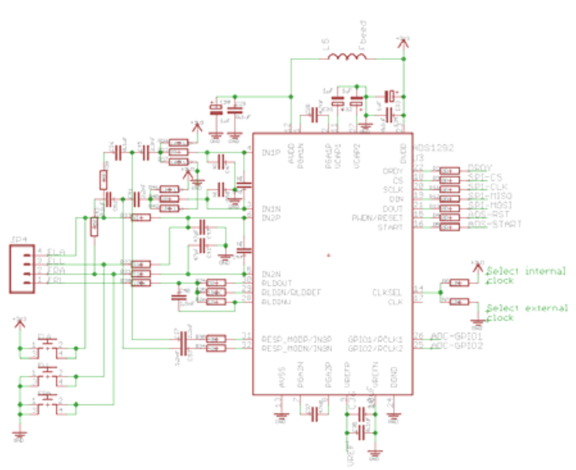


Fig. 0.3 ADS1292R prototype schematics

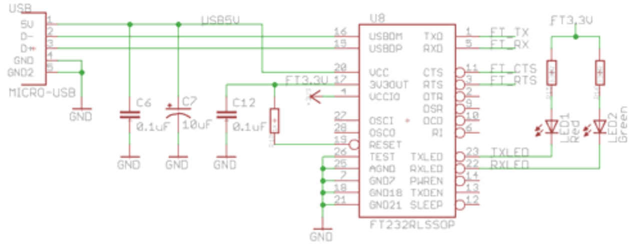


Fig. 0.4 FT232RL prototype schematics

We created and ordered prototype printed circuit board. The 3D model is seen in image bellow.

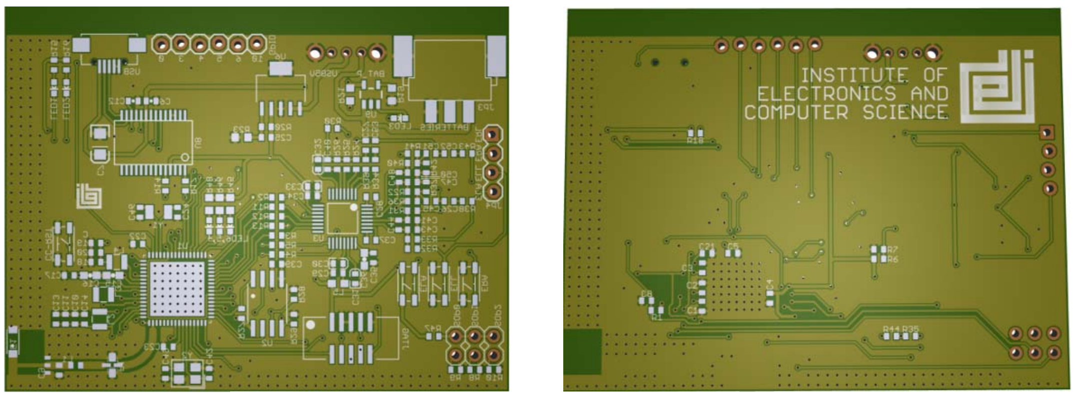


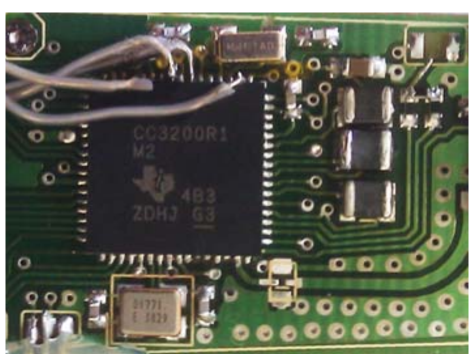
Fig. 0.5 Embedded device PCB 3D images

Experiments and tests

Tests were performed to check our device:

- Microprocessor test
- ADC test
- Wireless radio tests

For these tests we used development boards. Also for microprocessor we created standalone PCB that we also tested.



CC3200 microprocessor prototype PCB

Results

Conducting tests we confirmed that ADC provides data transmission that is needed for precise electrocardiogram. [Fig.0.6.]

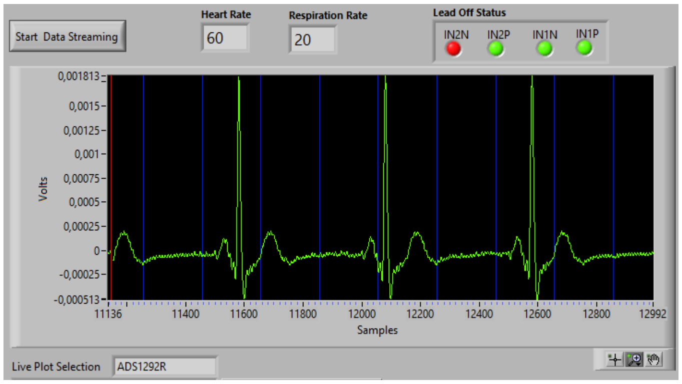


Fig. 0.6 ECG test results

We tested best possible connections of our components to microprocessor using CC3200 pinMux software.

Summary

Our team during project organized meetings with Latvian cardiologists and carried out research on electrocardiography and the possible applications for our system. We tested components and created a prototype.

Future

- Prototype tests.
- Improve data analysis by creating software for the system.
- Create database for data storage

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5. Chapter Signal and image processing for environment evaluation for intelligent transport systems (ImPro).

Image object detection process can be divided into following parts:

feature extraction about objects within image,

object classification using gathered features.

For both parts there exists many ways of data acquisition/processing and it is difficult to summarize all existing method in a short description. Information about each object in the image is formulated as a vector of numbers. When such approach is used and the number of features is N, then each object can be represented as a point in N-dimensional space, which is often referred to as "feature space". In ideal scenario, objects of different classes are separable in observed feature space, however, this is not always possible for any given set of objects or set of features. Therefore, the proper choice of features is essential. Work of many classifiers can be described by a given feature space model. However, other approaches exist as well, for example – point features. Here, the information about image objects is acquired in distinct image points and *template* (object of interest) search within the image can be accomplished by other means than using N-dimensional space. Thus, it becomes important to be able to extract point features with high repeatability, so that for different images one and the same scene points were extracted and described similarly.

To summarize, it is often required to properly extract image primitives. An *image primitive* is a group of image pixels with predefined repeatable features. Image primitives can with different levels of complexity, beginning from simple ones – individual image pixels (directly), and up to complex ones, consisting of pixel groups.

One of the simplest image primitives is a region of image (image patch; including patches with size of 1x1, or individual pixels) and one of the simplest method of choice of image region is a sliding windows, when a program observes every possible region of the image, using a classifier to select only interesting regions. More complex approaches use complicated methods for selection and description of image patches before classification. However, it must be noted that even in these cases, often image primitive extraction is done by a sliding window approach (for example, when using a convolution/filtering).

In the first step of SOPHIS research of image processing methods, line detection and description algorithm (*Complex Matched Filtering*, CMF) was observed and improved.

Detector and descriptor

These two concepts must be properly identified:

- A *detector* is an algorithm that is able to recognize that a primitive of interest is present in the image.
- A *descriptor* is an algorithm that for a recognized image primitive can formulate a feature vector in the specified format.

Detector is usually assigned to a more complex task the descriptor. For example, the detector must be *transformation invariant* – able to detect (with high probability) the same image primitive independently of applied visual transformations (illumination, rotation, scaling, etc.). Detector is also commonly applied to the whole image using a sliding window, whereas a descriptor is applied only for those regions where detector reacted. In cases when one detector is not able to provide an invariance to the transformation of interest, multiple detectors might be used – each used to extract the same primitive with a specific deformation of appearance – and then all gathered information is combined.

Research

Complex Matched Filtering [1] can be used for detection of line-like objects (LLO) or detection of line objects, as well as for description of these objects in images. Traditionally, CMF consists of two parts (Fig. 1):

- many LLO detectors (each for a different interval of angular orientations),
- descriptor that combines all gathered information and describes detected LLO or line.

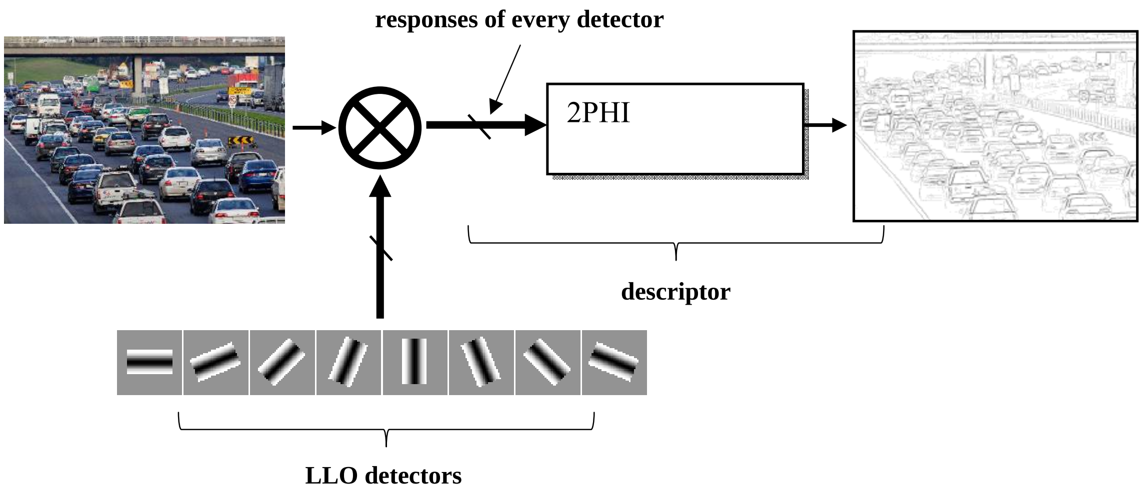

Fig. 1. CMF block diagram

LLO detectors that are used in CMF are based on convolution and “compare” observed image region with an LLO (filter kernel). The result of such operation is a scalar value that described similarity of image region and filter kernel and the intensity of LLO. The interpretation of this value is highly dependent on image region, therefore, multiple typical situations are considered:

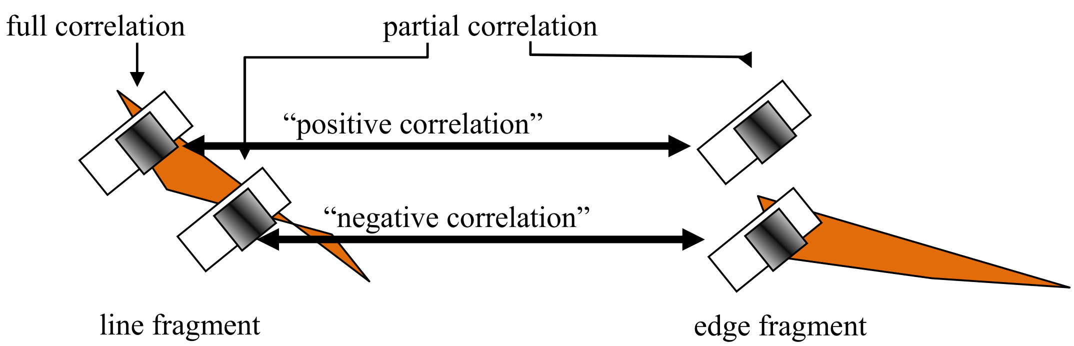

Fig. 2. Types of correlation

Many filter modifications exist, however, the most interesting here is *Non-Halo CMF* (NH-CMF) [2], where results of negative correlation are ignored. It must be mentioned that even in these conditions the positive correlation effect is quite widespread. Figure 3 on the left demonstrates the input image that is converted to Grayscale and the processed with NH-CMF, on the right side – image that represents using black pixels a places where at least one positive detector output is acquired.

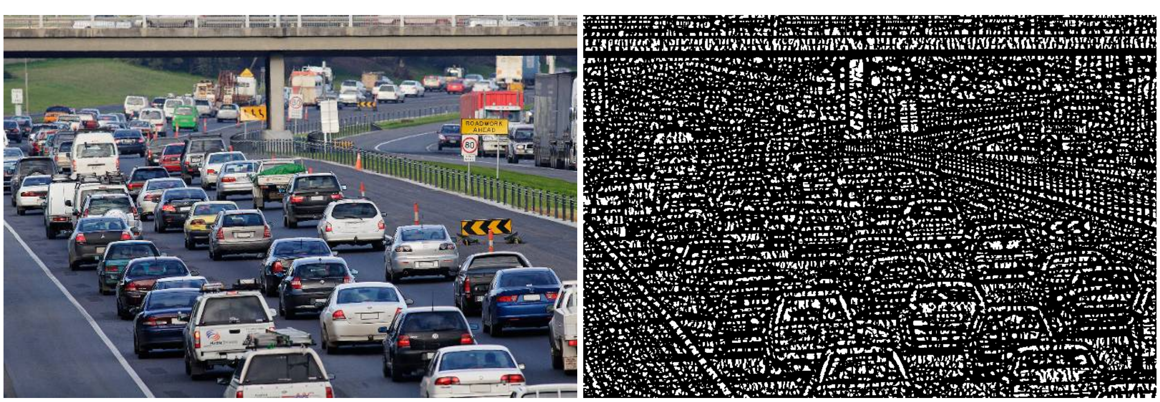

Fig. 3. Evaluation of CMF detectors

Such frequent response to image details might slow further processing of the image (because of too many generated initial points), as well as complicate the interpretation of processed data. As it can be seen in Figure 2, because of partial correlation effect, the detectors are reacting to object edges, even when only a slight gradient of light intensity occurs. Figure 4 demonstrates an example of road sign image processing using NH-CMF:

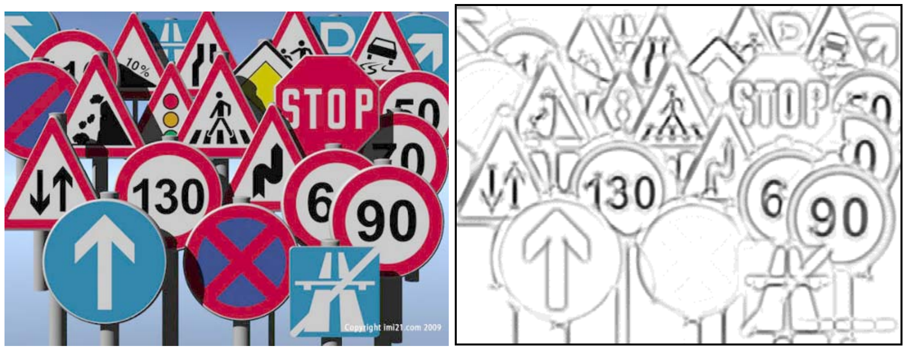

Fig. 4. Road sign image processing using NH-CMF (dark LLOs are detected)

It can be seen that because of partial correlation, image details that can be considered as road sign edges are extracted along with the road sign text.
The task can be formulated in the following way: to introduce a detector that does not detect object edges, but detects only lines with certain widths. Alternative approaches for the same task are:

Minima of "left" and "right" detected edges

In [3] the authors proposed a line detector, which detects the line profile of pixel intensities using two separate edge detectors (illustrated in Fig. 5):

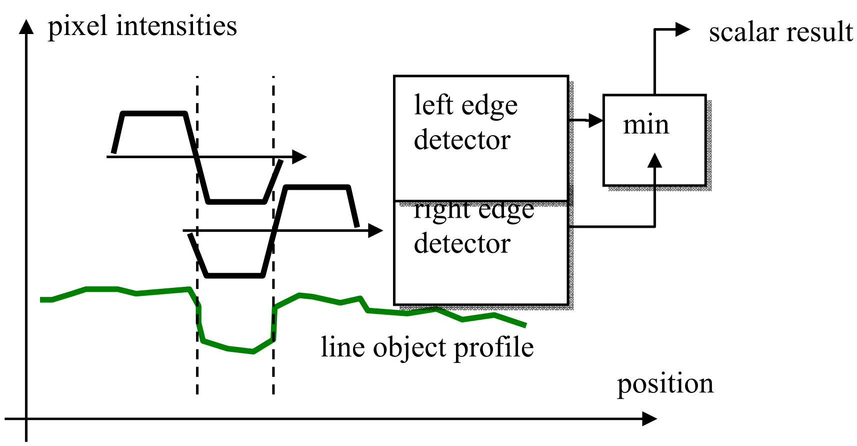

Fig. 5. Line detection using left and right edge detectors, method from [3]

This method is based on the fact that in case of absence of line, one of the edge detectors will react with a small response value and the result of min() will therefore also be a small value (illustrated in Fig. 6).

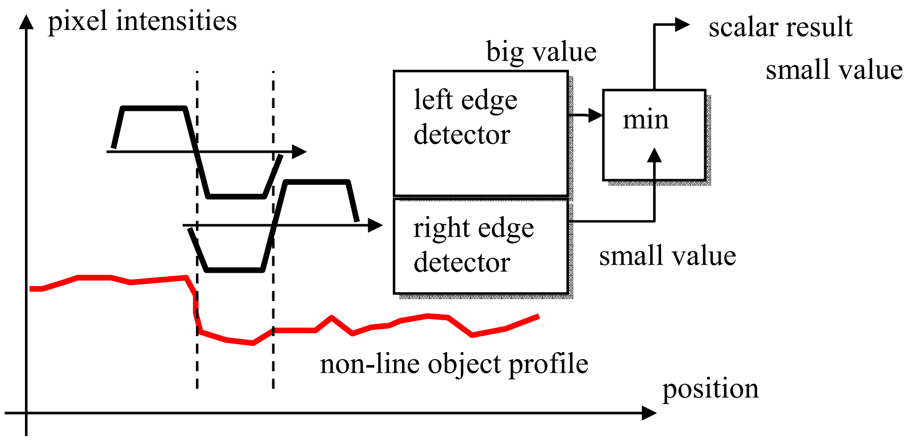

Fig. 6. Non-line rejection using method [3]

This approach is algorithmically simple, however, it has a drawback – intensity of detected line (after min() operation) depends on the background gradient.

Vein and crease filter

In [4] a more complex method of line detection was proposed, which could even distinguish between crease and veins of the palm. The method is based on LLO detection and result annihilation if observed image fragment will not pass additional gradient checks (illustrated in Fig. 7):

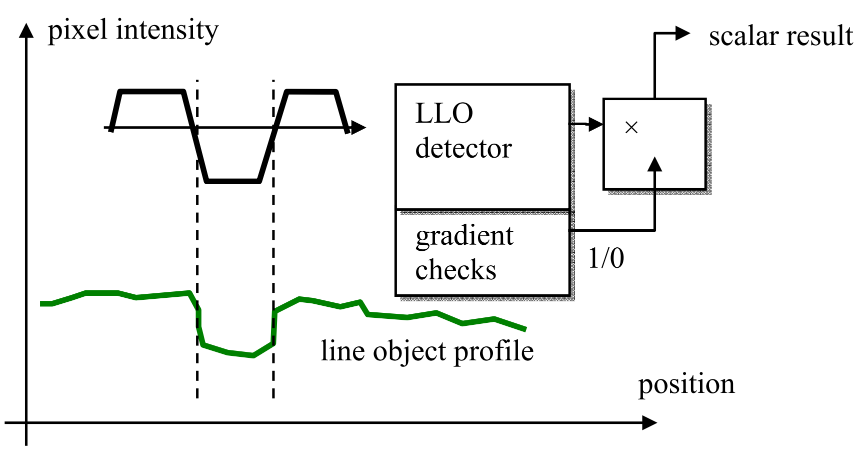

Fig. 7. Illustration of method [4]

Method [4] provides a more stable result, however, it is developed for a narrow usage in biometric field, therefore, it is complicated to adapt the filter for solving similar tasks.

Proposed filter

The following filter was proposed, illustrated in Figure 8:

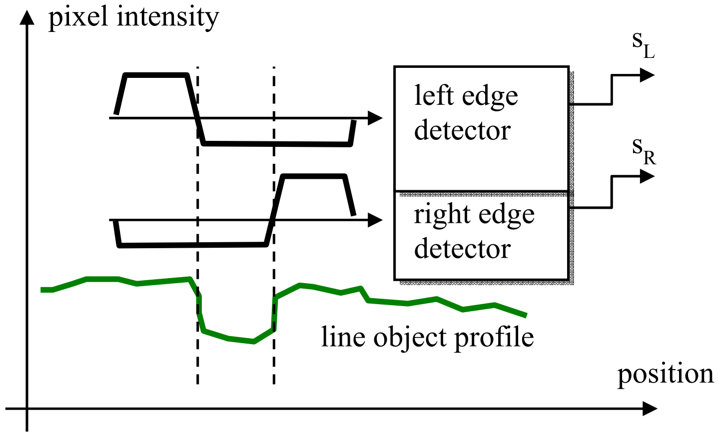

Fig. 8. Structural diagram and kernels of proposed filter

Edge detector filter responses are: s_L and s_R. When background gradient changes, the sum $s_L+s_R \approx const$, in case of non-line object $|s_L| >> |s_R|$ or $|s_L| << |s_R|$. Therefore, line detector response is calculated as:

$$s = \mathrm{R}[2(s_L + s_R) - \mathrm{R}[s_L] - \mathrm{R}[s_R]]$$

where $R[x] = 0.5 \cdot (x+|x|)$ (ramp function).

Results

Experiments with images showed that proposed approach provides a more stable filter response which depends more on the intensity and width of detected line and less on the background gradients. The theoretical derivations and experiments were described in a publication for ISPA 2015 conference.

Full name of the paper is: Mihails Pudzs, Rihards Fuksis, Agris Mucenieks, Modris Greitans, Complex Matched Filter for Line Detection, 9th International Symposium on Image and Signal Processing and Analysis, 2015.

Figure 9 ilustrates road sign image filtering with the proposed filter. As it can be seen, compared to image in Fig. 4. on the right side, Fig. 9 shows less unwanted details and text that consists of line objects is clearly visible.

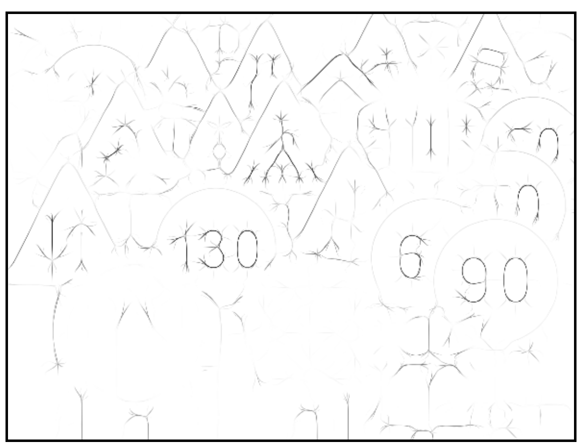

Fig. 9. Road sign image processing using proposed L-NH-CMF filter

Considering line detectors, Figure 10 ilustrates in which points at least one L-NH-CMF detector provided a positive response and can be compared with Fig. 3.
If these points are used as seed for line tracing algorithms, overall image processing time becomes less than in case of NH-CMF, because there are fewer seed points. However, working with L-NH-CMF one must be careful, because more image details are discarded and not all contours of objects are seen as clear line objects.

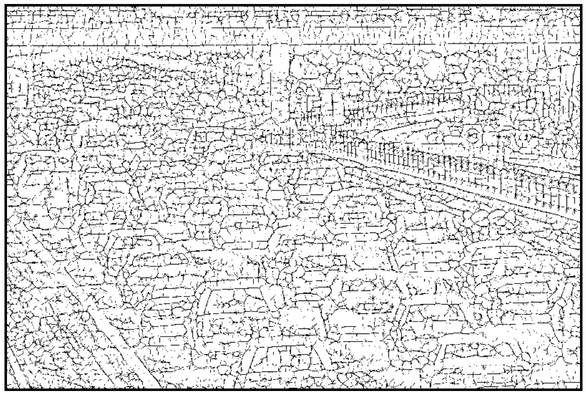

Fig. 10. Line detector evaluation

References

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6. Chapter Smart vehicle system for more secure and efficient driving (GCDC).

Abstract

This work contains activities related to preparation to i-GAME GCDC competition that will take place on 23-31 May 2016. Main results from 2015 are described, description of the proposed solution and future work plan are given.

Introduction

i-GAME (**i**nteroperable **G**rand cooperative driving challenge (GCDC) **A**uto**M**ation **E**xperience) is a cooperative autonomous driving competition that will take place in Eindhoven (Netherlands) on May 23-31 of 2016. Goal of the competition is to efficiently perform several scenarios that are typical for highway and city. This competition is different from other autonomous vehicle projects in sense that here scenarios should be performed efficiently not individually but cooperatively by the entire group of cars participating in maneuver. For this purpose cars involved in the competition will be equipped with communication infrastructure and every vehicle tells to others its coordinates and speed. So every vehicle knows about others and has a possibility to plan maneuvers without unnecessary stress and extremal damping.

In the GCDC-2016 competition[1] there will be following scenarios:

- Scenario 1: Cooperation on highway;
- Scenario 2: Cooperative intersection;
- Scenario 3: Emergency vehicle.

First GCDC competition took place on year 2011 and the team from Latvia (University of Latvia and Institute of electronics and computer science) participated.

In this year preparation and information exchange process for GCDC-2016 has started. Semi-monthly webinars for participants are organized. The first face-to-face workshop took place in Technical university of Eindhoven[2]. In this time also a team from Latvia is planning to participate and is preparing vehicle control solution.

This report consists of following parts:

- Introduction (this part);
- Solution and its parts;
- Results so far;
- Conclusion;
- Activity plan.

Solution

Dashboard

A simple dashboard will be developed as an addition to the vehicle dashboard. It will provide following functionality for driver:

1. Switching driving mode functionality that allows:
    - CACC mode – to turn on collective adaptive cruise control (a mode when vehicles drive in a column controlling distance and row behind a “head vehicle”). This includes also execution of specific scenarios;
    - Manual mode (the traditional way of vehicle control);
2. To set various CACC mode parameters (i.e. speed, distance to vehicles before and after, interval to adjacent vehicles);
3. To set various system-wide parameters.

Driver could use a dashboard developed to configure system settings and to switch CACC/manual mode. When CACC mode is on, vehicle actuators are switched to the command flow from Vehicle Control System, that is based on information from sensors and information received by the network from other vehicles and infrastructure.

There will be implemented following indicator lights on the vehicle roof with following meaning:

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1 More information about GCDC-2016 – http://gcdc.net

2 Technical university of Eindhoven (TU/e) is one of the organizators of the competition. The others – TNO (https://www.tno.nl/en/), IDIADA (http://www.applusidiada.com) and Viktoria Swedish ICT (https://www.viktoria.se)

- green light – vehicle operating in CACC mode;
- red light – vehicle operating in manual mode;

A special functionality for fast returning to manual operating mode will be implemented. The vehicle will be switched to manual mode when in CACC steering wheel or gas/brake pedal is touched or when special “red” button is pressed.

Vehicle control model

Vehicle control system providing automatic CACC driving mode and execution of competition scenarios consists of Control center that provides decision making and driving commands issuing and of periphery that provides sensor data perception and actuator control (see figure).

Control center is a decision maker module that:

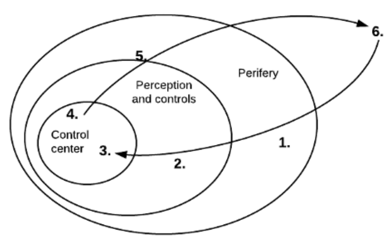
1. receives from periphery information about situation around vehicle;
2. takes decisions according to information available, its goals and “principles”;
3. sends control commands to periphery that implements decisions.

Periphery is a connection between Control center and vehicle physics and it consists of:

1. sensors that read data about vehicle position and surroundings;
2. communication module for exchange of vehicles positions and speeds;
3. actuators that move gas and brake pedals and steering wheel.

Perception and controls – middle-layer between control center and periphery that consists of:

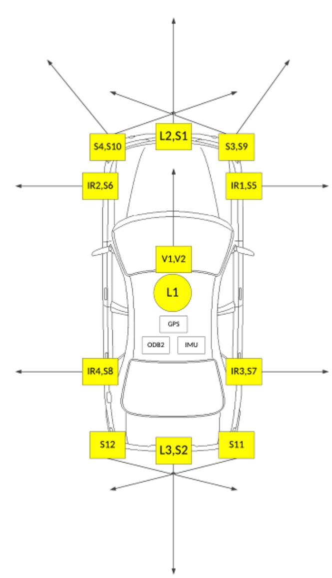
1. perception that does sensor data reading, filtering and other processing necessary to translate raw sensor data into information usable for decision process;
2. actuator controls that takes driving plan from control center and is converting it in real-time manner into micro commands that are understandable by actuators.



Vehicle sensors and communication

Vehicle sensor data and data from other vehicles will be filtered and consolidated into unified and periodically refreshed data model. The data model consists from:

1. Vehicle parameters (speed, acceleration, coordinates) will be obtained from diagnostic interface OBD2, inertial measurement unit IMU Xsens MTi-G and GPS receiver Oxts RTS-GPS (precision 1cm).
2. Visible surroundings model of the vehicle will be created from data received from following sensors:
   - Velodyne Lidar HDL-32E (L1) that by using infrared 905nm laser beam can measure distance from 1m to 70m (precision 2.5cm). HDL-32H will provide a basis for vehicle world model that will be supplemented by data from other sensors.
   - Ultrasound sensors is one of additional methods that helps to confirm information about objects provided by HDL-32E, for example vehicles before and after (S1-S2) (sensors MB7383). It helps also to check for obstacles that are invisible by HDL-32E, for example road borders nearest than 1m from vehicle (S3-S12) (sensors HC-SR04.
   - Infrared sensors IR1-IR4 (Sharp GP2Y0A02, GP2Y0A710) will be used to check distance to adjacent vehicles.



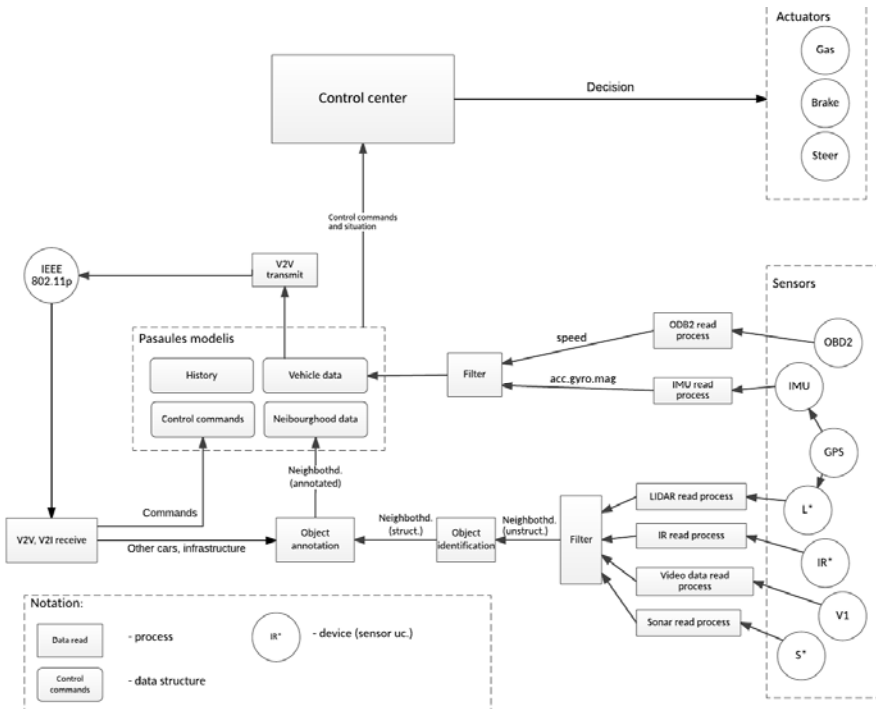
- Stereo video (two 5MP Omnivision 5647 cameras) (V1,V2) also will be used to detect distance to objects in front of the vehicle.

3. To provide vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data exchange requirements from ITS-G5 a PCEngines Alix APU1D computer with Athero9 network card will be used. It will support protocols BTP/GeoNetworking at the network level and protocol IEEE 802.11p.

Actuator control

For GCDC-2016 scenarios execution actuator control will be provided for gas and brake pedals and for steering. It will be implemented by connecting to CAN interface of the vehicle.

Dataflow model



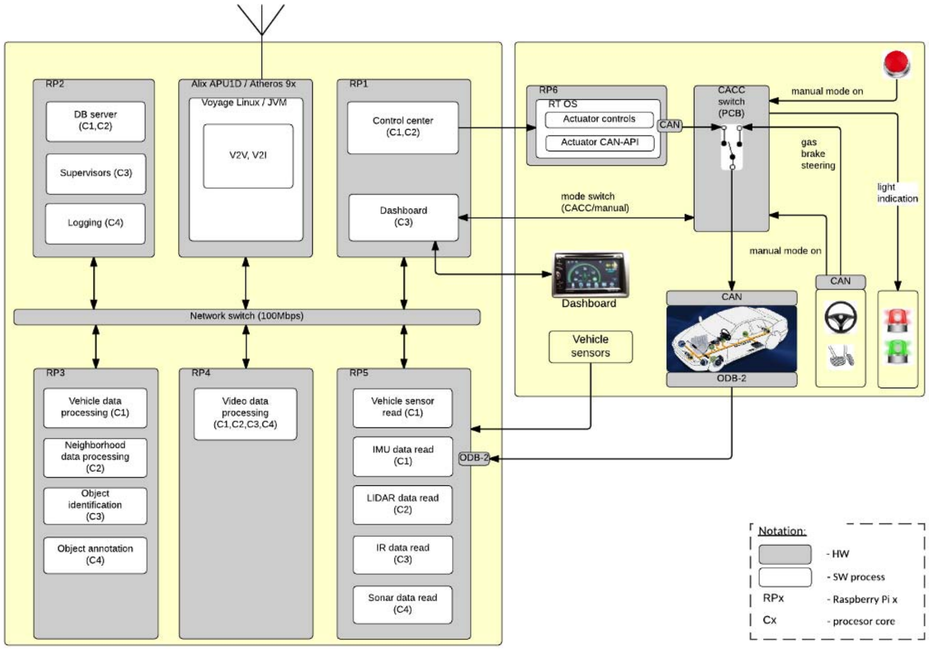
Technical solution

Vehicle control system will be implemented using the following approach: the system will consist of several independent processes residing on several compact computation devices like PC or Raspberry Pi running Linux. Devices will be connected to common Ethernet network segment.

There are following kinds of processes in the vehicle control system:

1. Sensor data readers and filters (for each sensor);
2. Processes that send and receive data over the network BTP/GeoNetworking/IEEE 802.11p;
3. Processes that implement control of vehicle actuators and implement a dynamical model of the vehicle;
4. Database processes for storing data and performing queries over data;
5. Motion planning processes that perform decision making, execution of scenarios and maneuvers;
6. Dashboard user interface control process;
7. Supervisor processes for monitoring and recovering of the system.

Processes above will be distributed over several computing device cores. One example of such distribution is shown in the figure below. Processes will be isolated each from other. Data exchange will be provided via message sending mechanism and usage of shared memory areas between processes will be minimized.



Results so far

Other results so far:

1. GCDC-2016 requirements and other documentation studied;
2. Development of software started for reading data from sensors;
3. Participation in GCDC-2016 webinars (08-09.2015 I.Ribners, before that – A.Mednis);
4. Participation in the GCDC-2016 workshop in the Technical university of Eindhoven (Netherlands) 28-29.09.2015;
5. Vehicle control system prototype design and implementation started.

Conclusion

At this time clarity is obtained about architecture of the system to be built. The activity list of research, programming and other tasks is developed.

Activity plan

Due date	Activity
30.11.2015	- To choose the appropriate model of vehicle for participation in the competition; - To become familiar with the rest of hardware and software that will be used.
31.12.2015	- To prepare a prototype version of the Vehicle Control Center; - To prepare a prototype version of the Vehicle Dashboard; - To prepare network stack for vehicle communication (BTP/GeoNetworking/IEEE 802.11p)
31.01.2016	- To prepare low-level interfaces: - for sensor data receiving; - for vehicle actuator control. - To install the GCDC interactive testing infrastructure; - To prepare prototype implementations of GCDC competition scenarios.
28.02.2016	- To test low-level interfaces including tests necessary for necessary vehicle safety level (provided by IDIADA)
(03-04.2016)	To do vehicle safety testing in IDIADA testing infrastructure (Spain) and to fix issues found.
30.04.2016	- To test GCDC scenarios using interactive testing infrastructure: - individually; - cooperatively with other participants. - To fix issues found.
23-31.05.2016	Grand Cooperative Driving Challenge 2016 (Helmond, Netherlands)