Izglītības un zinātnes ministrija

Studiju un zinātnes administrācija

National Research Programme

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

Final report
1.06.2014-31.12.2017

ELEKTRONIKAS UN DATORZINĀTNU INSTITŪTS
INSTITUTE OF ELECTRONICS AND COMPUTER SCIENCE

LATVIJAS UNIVERSITĀTE
ANNO 1919

1862
RIGA TECHNICAL UNIVERSITY

Latvijas Universitātes
Matemātikas un informātikas institūts

Scientific report for the Program

PART 1 – INFORMATION ON PROGRAM

1.1. Title of the programme: „**Cyber-physical systems, ontologies and biophotonics for safe&smart city and society"**

1.2. Programme acronym: **SOPHIS**

1.3. Programme web page address: **http://sophis.edi.lv/**

1.4. Programme principal investigator: **Dr.sc.comp. Modris Greitāns**

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1.6. Final report for a period: **1 June 2014 – 31 December 2017**

1.7. The aim of the programme and objectives:

The goal of SOPHIS is development of the next generation ICT systems focused on solution of tasks crucial for Latvian society related to health, transport, security, bridging of digital gap, effective use of knowledge, as well as contributing to the economy transformation to products and services with high added value. SOPHIS is organized in four projects:

1. „Development of technologies for cyber physical systems with applications in medicine and smart transport";
2. „Ontology-based knowledge engineering technologies suitable for web environment";
3. "BIOPHOTONICS: imaging, diagnostics and monitoring";
4. "Development of technologies for secure and reliable smart-city".

SOPHIS is implemented by internationally recognized research teams with expertise in NRP and international projects from **IECS, UL FC, UL IAPS, UL IMCS, RTU FCSIT, RTU TI** and **RTU WRL**. The multidisciplinary team is well balanced and contains highly qualified researchers, young scientists, doctoral students and undergraduate students. The cooperation partners from economic sector represent end-users, producers and technology transfer companies. Strategic steering board includes the world-class scientists from the relevant areas as well as leading industry representatives.

Activities of the programme contain research, technology validation and transfer, investment in education, publicity and technological forecasting.

1.8. Executive summary of the programme:

Most significant achievements obtained during SOPHIS implementation are:

- Improved functionality (including mobile units(workstations) for WSN node tests in target environment) and effectiveness of wireless sensor and data network TestBed and its approbation in ICT industry, precise agriculture as well as licensing for use in study process in University of Latvia;
- Mobile body movement monitoring system and its approbation in several configurations and applications, including in rehabilitation center "Mēs esam līdzās";
- Self-driving full scale platform and software for autonomous collaborative self-driving approbated at Grand Cooperative Driving Challenge GCDC2016 and model collaborative driving test track is developed for improved algorithm development pipeline;

- Development of low-cost extremely high resolution monitor wall infrastructure which is compatible with standard PC software and applications. The infrastructure has been approbated in Faculty of Computing, University of Latvia;
- Development of reusable EAF (Environment-Action-Framework) configuration management approach, which allows automating different activities of IT project;
- Development of C6.0 machine learning algorithm which allowed to win the Horizon-2020 project "SUMMA" submission within H2020-ICT-16 BigData-research call; The algorithm approbated in the Latvian news agency - SIA “LETA”;
- Development and approbation of ontology- and web technology-based query language and data ontology depiction method on real CCUH (Childrens' Clinical University Hospital) medicine data;
- Technology for fast mapping of skin chromophores by single or double snapshot of color camera;
- Technology for remote control of anesthesia efficiency by means of photoplethysmography imaging and approbation and licensing of the technology for the hospital of Traumatology and Orthopedics;
- Implementation of the deep neural network for object counting in smart cities. The solution was approbated by the Turiba University;
- Advanced technology for data transmission in optical network using Wavelength-division multiplexing approach, approbated within the RTU research platform "ICT". Reconfigurable channel add-drop module was approbated by the company SIA "Affoc Solutions";
- Novel methods for remote sensing (include aerial and satellite images) signal and imaging processing in smart cities including approbation by Ādaži municipality. On the basis of these results the European space agency financed project DynLand has been won as well.
- Advanced ultra wideband radar technology , approbated by SIA “VPWash”;
- Online control system for detection of bacteriological contamination in water supply system including approbation by Liepāja municipality;

These achievements illustrate the potential of research results for bringing them in new products and service, which could be used in different fields of economy, including health, telecommunications, transport, logistics, water supply, security etc.

The main activities, fulfilled tasks and achieved results of the projects are summarized in the following tables:

Project 1:

Tasks	Main results
1. To research, develop and test innovative hardware and software platforms for smart sensors and embedded networks facilitating the development of cyber physical systems, including programming approaches targeted at non-professional users and economy; 1.1. Development of software platforms for more efficient and easier programming of sensor networks and related cyber physical systems, for developers and experts of such systems, as well as users from other fields of expertise. 1.2. Innovative modular platform for	*Information about all [Result] can be found within the corresponding subsection of the Scientific report (Appendix 1, Section 5).* Planned: Preparation of publications; Achieved: 5 scientific articles indexed by SCOPUS or Web of Science: • “A Realistic Evaluation and Comparison of Indoor Location Technologies: Experiences and Lessons Learned” [Result A.1.2.8]; • “EDI WSN TestBed: Multifunctional, 3D Wireless Sensor Network Testbed”

prototyping, profiling, debugging and evaluation of embedded systems. 1.3. Environment for testing, debugging and evaluation of wireless sensor networks, with more than a hundred nodes.	[Result A.1.2.9]; • "Network Data Traffic Management Inside a TestBed" [Result A.1.2.10]; • "Mobile wireless sensor network TestBed" [Result A.1.2.12]; • "Power Consumption Measurement of Tested Units in the WSN TestBed" [Result A.1.2.13]. Planned: Development of hardware and software prototypes. Achieved: 2 sets of software prototypes: • TestBed adapter management backend software set [Result A.4.1.3]; • TestBed user frontend and developments tools software set [Result A.4.1.5]. And 3 developed hardware prototypes: • TestBed adapter prototype [Result A.4.3.1]; • TestBed system prototype [Result A.4.3.4]; • Mobile TestBed adapter prototype [Result A.4.3.9]. Planned: approbated system prototype; Achieved: 3 approbations in enterprises: • TestBed approbation by "19 points" Ltd. [Result C.3.3]; • Mobile TestBed approbation at Dobele Institute of Horticulture [Result C.3.5]; • Mobile and stationary TestBed approbation at University of Latvia [Result C.3.6]. Planned: patent applications; Achieved: 2 Latvian patent applications: • "Mobile device for a more efficient development of wireless sensor networks and their nodes in target environment", [Result C.2.1.1]; • "Method of controlling of antenna radiation patterns by using transmission lines on printed circuit board", [Result C.2.1.2]. Planned: licensing of technology; Achieved: 1 license agreement with University of Latvia for TestBed system [Result C.4.1]. Planned: dissemination efforts; Achieved: 2 synergy international projects: • H2020 project ENACT [Result A.4.4.5]; • EU FP7 ARTEMIS project DEWI [Result A.4.4.8]. 4 courses improved by project results: • Introduction to digital design, University

	of Latvia [Result A.3.1]; • Concepts of Operating Systems, University of Latvia [Result A.3.2]; • Special course: cyber-physical systems, University of Latvia [Result A.3.3]; • Wireless sensor networks, University of Latvia [Result A.3.4]. Full list of dissemination activities can be found in Appendix 1, Section 5.
2. To research, develop and test cyber physical systems for healthcare uses in prevention, diagnostics, treatment and rehabilitation, which will improve health and wellbeing of individuals and the society as a whole. 2.1. The development of a smart clothing platform (architecture, hardware and software) for unobtrusive and wearable sensor networks. 2.2. Applications of the smart clothing platform to telemedicine – remote/virtual physiotherapy. 2.3. Big data collection and analysis in cyber physical systems for healthcare.	*Information about all [Result] can be found within the corresponding subsection of the Scientific report (Appendix 1, Section 5).* Planned: Preparation of publications; Achieved: 2 journal publications with high impact (SNIP>1): • "Acceleration and Magnetic Sensor Network for Shape Sensing" [Result A.1.1.1]; • "Architecture of smart clothing for standardized wearable sensor systems" [Result A.1.1.2]; and 9 scientific articles indexed by SCOPUS or Web of Science: • "Shape sensing based on acceleration and magnetic sensor system" [Result A.1.2.3]; • "Smart textiles for wearable sensor networks: review and early lessons" [Result A.1.2.5]; • "Wearable sensor grid architecture for body posture and surface detection and rehabilitation" [Result A.1.2.7]; • "Inertial sensors and muscle electrical signals in human-computer interaction" [Result A.1.2.11]; • "On improving gait analysis data: heel induced force plate noise removal and cut-off frequency selection for Butterworth filter" [Result A.1.2.14]; • "Amplitude Adaptive ASDM circuit" [Result A.1.2.17]; • "Knee Joint Dynamics Monitoring Using Wearable Sensor Network and Mobile Software During Rehabilitation" [Result A.1.2.18]; • "Human skin as n-th order passive filter" [Result A.1.2.20]; • "Smart textiles: efficient data collection grid architecture" [Result A.1.2.21]. Planned: Development of hardware and software prototypes. Achieved: 2 sets of software prototypes: • Head positioning monitoring mobile application [Result A.4.1.1];

	• Knee joint monitoring mobile application [Result A.4.1.2]. and 6 developed hardware prototypes: • Head position sensor prototype [Result A.4.3.2]; • Knee joint sensor prototype [Result A.4.3.3]; • Body and head monitoring system prototype [Result A.4.3.5]; • Prototype for ECG data gathering [Result A.4.3.6]; • Headband for computer control prototype [Result A.4.3.7]; • Prototype 12-lead ECG data gathering and feedback device prototype [Result A.4.3.11]. Planned: approbated system prototype; Achieved: 3 approbations in enterprises: • Approbation at EuroLCDs Ltd. [Result C.3.1]; • Approbation at rehabilitation centre "Mēs esam līdzās" [Result C.3.4]; • Approbation at "Wide.Tech" [Result C.3.7]. Planned: spin-off company; Achieved: 1 spin-off company Hack-motion co-founded by project researcher [Result C.5.1]. Planned: dissemination efforts; Achieved: 2 synergy international projects: • Norway grants HIPPAC project [Result A.4.4.2]; • ERA-NET project CONVERGENCE [Result A.4.4.4]. Full list of dissemination activities can be found in Appendix 1, Section 5.
3. To research and develop uses of smart sensors and sensor networks for intelligent transportation systems for safe, efficient and convenient traffic. 3.1. Driver's personal assistant – research in image processing methodology for the monitoring of driver's attention and forecasting of reaction, as well as development of convenient feedback system between the system and the driver. 3.2. Extending the field of vision for the driver by 3D and 2D image processing for monitoring, interpretation and reaction to the surrounding environment. 3.3. Extending the spectrum of driver's vision beyond the range of visible light	*Information about all [Result] can be found within the corresponding subsection of the Scientific report (Appendix 1, Section 5).* Planned: Preparation of publications; Achieved: 2 journal publications with high impact (SNIP>1): • "Improved RGB-DT based face recognition" [Result A.1.1.3]; • "DIY Car Control System for Cooperative Driving" [Result A.1.1.4]. and 7 scientific articles indexed by SCOPUS or Web of Science: • "RGB-D-T based Face Recognition" [Result A.1.2.1]; • "Development of 802.11p Testbed – Experiences" [Result A.1.2.2];

by thermal image capture, processing and analysis, detection of hard to see objects during twilight and night time; 3.4. Communication methods for intelligent transportation systems for vehicle to vehicle and vehicle to infrastructure cooperation	• "Face recognition system on Raspberry Pi" [Result A.1.2.4]; • "Complex matched filter for line detection" [Result A.1.2.6]; • "Prospects of improving the selfdriving car development pipeline: transfer of algorithms from virtual to physical environment" [Result A.1.2.15]; • "Using virtual environment for autonomous vehicle algorithm validation" [Result A.1.2.16]; • "Scalable in-door positioning system for cooperative MicroIV algorithm development" [Result A.1.2.19]; Planned: Development of hardware and software prototypes. Achieved: 1 set of software prototype for autonomous collaborative self-driving car approbation at GCDC. and 2 developed hardware prototypes: • Prototype automatic collaborative self-driving car [Result A.4.3.8]; • Prototype mini collaborative driving infrastructure [Result A.4.3.10]. Planned: approbated system prototype; Achieved: 1 approbation in enterprise at GCDC challenge [Result C.3.2]. Planned: dissemination efforts; Achieved: 4 synergy international projects: • H2020 ECSEL project 3CCar [Result A.4.4.1]; • H2020 ECSEL project Autodrive [Result A.4.4.3]; • H2020 ECSEL project PRYSTINE [Result A.4.4.6]; • H2020 ECSEL project I_MECH [Result A.4.4.7]. Full list of dissemination activities can be found in Appendix 1, Section 5.

Project 2:

Tasks	Main results
I) To develop the technology of e-services and e-health data processing solutions to increase their security and availability.	
• To develop an ontology-based knowledge access rights modeling technology, which allows to use the semantic technologies in areas where the increased security level of data processing solutions is needed, e.g., data privacy in the e-health (A1.1). • To research and to develop the ontology-based linked data	Planned: 2 Methods. Achieved: Method developed. Described in the Scientific Report of stage 3, Appendix 2, Chapter 2.1.2. Achieved: Research on linked-data application in different domains. Description in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.4. Achieved: Overview of the state of Linked Data, analysis of considerations for applying Linked Data

technologies for applications of e-government and e-health (A1.5). • To develop the methodology and demonstration prototype of the framework for the integration of semantic web services in traditional websites for the usage in various problem domains such as e-logistics, that enables permanent control of structural quality and interoperability of systems; thus allowing avoiding unwanted side effects of changes by timely detecting their likelihood, as well as to ensure flow of knowledge adequate to changes (A1.9). • To develop the methods for accessing data of large volume that is based on models and domain-specific ontologies using a novel data query and visualization methods suitable for web environment (A1.10). • To develop the method for application of business process models in analyzing program run-time events to increase the level of information system security (A1.11).	to various domains, and a detailed survey of applications of Linked Data technologies in e-Government and e-Medicine. Method described in the Scientific Report of stage 4, Appendix 2, Chapter 2.1.1.5. Planned: 1 Method. Achieved: A methodology for integration of semantic web services in a web portal has been developed, which is described in scientific publication „Novickis L., Vinichenko S., Sotnichoks M., Lesovskis A. Graph Models and GeoData Based Web Portal in Cargo Transportation. Scientific Journal of Riga Technical University. Applied Computer Systems, 2015/17, RTU Press, Riga, 2015, pp. 34-39", Sections 2.2.4 and 2.2.5 of Scientific Report (Appendix 2) of stages 1-2, and Section 2.2.4 of Scientific Report (Appendix 2) of stage 3 Planned: 1 Software prototype. Achieved: Monitor wall created (hardware) Achieved: Data visualization and browsing software prototype developed. Available at FC UL upon request. Planned: 1 Approbated framework. Achieved: The developed methodology for development and integration of semantic web services has been approbated in improvement of the eLOGMAR portal and other software development projects, which is described in scientific publication „Bartusevičs, A., Lesovskis, A., Ponomarenko, V. Model-Driven Approach and Library of Reusable Source Code for Automation of IT Operations. Applied Computer Systems. Vol. 21, 2017, pp. 5-12" and Section 2.2.4 of the Scientific Report (Appendix 2) Planned: 2 Approbated prototypes. Achieved: At FC UL created and approbated prototype of monitor wall. Achieved: Data visualization and browsing software prototype approbated. Achieved: Runtime security model for bank transaction clearing process approbated at Bank of Latvia. Achieved: Runtime security model for ticket reservation system approbated. Achieved: Runtime security model for drone monitoring process approbated in the ARTEMIS project. Achieved: Results published in 26 scientific papers. Achieved: Defended 3 Doctoral Thesis.
II) To develop the ontology-based modeling technologies and tools for knowledge analysis suitable for web environment.	

• To develop ontology-based modeling technologies and tools that are suitable for web environment for creating ontologies of the domain knowledge presented in formal yet easily understandable way for the end user (A1.3). • To develop an ontology-based query language that allows the end user to build and understand queries easily (A1.2). • To develop the semantic web and computational linguistic methods to formalize data in the natural language form (A1.4).	Planned: 2 Methods. Achieved: Method developed. Description in the Scientific Report of stages 1-2, Appendix 2, Chapters 2.3.1-2.3.2, in the Scientific Report of stage 4, Appendix 2, Chapters 2.1.1.7, and publications of A.Sproģis. Achieved: Method developed. Description in the Scientific Report of stage 3, Appendix 2, Chapter 2.1.4, and publications of G.Bārzdiņš, D.Goško and P.Paikens Planned: 1 Language description. Achieved: Query language developed. Description in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.2. Planned: 2 Software prototypes. Achieved: Query language software prototype developed. Available at UL IMCS upon request. Achieved: Web-based modeling technologies building platform prototype (software) developed. Available at UL IMCS upon request. Planned: 2 Approbated methods. Achieved: Data ontology building method approbated at CCUH. Description in in the Scientific Report of stage 4, Appendix 2, Chapter 2.1.1.4. Achieved: Semantic formalization method approbated at LETA. Description in in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.10. Planned: 1 Approbated prototype. Achieved: Query language software prototype approbated at CCUH. Description in in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.7. Achieved: Submitted and won a Horizon-2020 project "SUMMA" under H2020-ICT-16 BigData-research call. Achieved: The first place in Task 8 of Semeval-2016 shared task competition. Achieved: We won the Generation track of the SemEval-2017 workshop Task 9: Abstract Meaning Representation Parsing and Generation. Achieved: Results published in 19 scientific papers. Achieved: Defended 2 Doctoral Thesis.
III) To explore and develop semantic web technologies for knowledge formalization, reuse and sharing.	
• To improve the automated analysis of knowledge structure models by extending the functionality of the I4S tool, which allows to make the acquired knowledge fully usable for the determination of the functional state of complex heterogeneous systems, risks associated with it and	Planned: 1 Software I4S 2.0 Achieved: Software tool for structural modeling I4S 2.0 with extended functionality has been developed (available upon request at the Department of Artificial Intelligence and Systems Engineering, Riga Technical University) Planned: 1 Software description,

for the prediction of consequences caused by potential faults (A1.6). • To develop transformation methods for knowledge structure models to carry out the alignment of models, as well as methods for the analysis of models' syntax, semantics, and structure should be developed in order to determine the degree of overlapping and compatibility between models and, finally, methods are needed for the separation of specific models (A1.7) • To develop novel methods and algorithms for solving the following tasks: assessment of the importance of elements, representation of logical operators, and interpretation of inference rules for the analysis of the knowledge about complex heterogeneous systems structures. (A1.8)	Achieved: I4S User Manual v.1.0 has been written (available upon request at the Department of Artificial Intelligence and Systems Engineering, Riga Technical University) Planned: 3 Methods. Achieved: A method for autonomous introduction of changes in knowledge structures of multi-agent systems has been developed, which is described in scientific publication „Lavendelis E. A Cloud Based Knowledge Structure Update and Machine Learning Framework for Heterogeneous Multi-Agent Systems. International Journal of Artificial Intelligence, Vol. 14 (2), October, 2016. CESER Publishing, pp. 157-170” Achieved: An approach (method) for controlling legal states of business objects has been developed, which is described in scientific publication “Peņicina, L. Controlling Business Object States in Business Process Models to Support Compliance. PoEM 2016 Doctoral Consortium, Skövde, Sweden, November 8, 2016, CEUR Workshop Proceedings 1765, pp. 6-13” and in Master Thesis “Stanga, L. The Method Development of Continuous Business Process and Enterprise Architecture Correspondence Maintenance. Master Thesis, Riga Technical University, 2016” Achieved: A methodics (a simplified method) for requirements engineering knowledge/artefact maintenance and distribution has been developed, which is described in Section 2.2.3.6 of the Scientific Report (Appendix 2) Planed: 1 Approbated prototype. Achieved: Approbation of multi-robot simulation tool was done, which is described in the document „Lavendelis, E. Prototype of adaptive multi-agent system. Technical report, Riga Technical University, 2017” Planned: 2 Approbated methods. Achieved: Approbated methods for the work with knowledge structures allowing the creation of learning materials and methods for the automated development of tasks and knowledge assessment. Achieved: For approbation of the developed method for dynamic adaptation of emotion-based tutoring, an initial version of educational game has been created, which is described in scientific publication „Petrovica, S. Multi-level adaptation of an educational game to individual student’s gameplay, knowledge and emotions. Proceedings of the 9th Annual International Conference on Education and New Learning Technologies, Barcelona, Spain, July 3-5, 2017, pp. 2220-2230” Achieved: For approbation of the developed method for modeling of social effects of emotions, a game in

	form of a multi-agent system has been implemented, which is described in scientific publication „Pudane, M. Affective Multi-Agent System for Simulating Mechanisms of Social Effects of Emotions. Proceedings of Seventh International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), San Antonio, United States of America, October 23-26, 2017. San Antonio, 2017, pp. 129-134." Achieved: Results published in 20 scientific papers. Achieved: Defended 3 Doctoral Thesis.

Project 3:

Work tasks	Achieved*
1. To elaborate and approbate experimentally new imaging technologies: 1.1. Technology for obtaining several monochromatic spectral images from data of a single RGB image. 1.2. Video-imaging technology for non-contact monitoring of cardiovascular parameters at the near infrared spectral range. 1.3. Infrared imaging technology for quantitative estimation of tissue condition. 2. To develop methods, algorithms and programmes for operative and efficient processing of the obtained images, including calculations of the parametric maps. 3. To improve software of a prototype device for multimodal skin imaging, to approbate it clinically and to carry out technology transfer. 4. To develop new concepts, methods and technologies for non-contact, non-invasive and minimally invasive diagnostic imaging. 5. To approbate the developed methodologies, software and prototype devices pre-clinically in small groups of patients (20-50 persons).	1.1. Two technologies have been developed – single-snapshot for obtaining up to 3 monochromatic images and double-snapshot for obtaining up to 6 monochromatic images. 1.2. PPG video-imaging technology for monitoring skin blood perfusion was developed in 2 modalities – in the NIR range and at combined NIR+green illumination. 1.3. Near infrared (0.9-1.7 microns) imaging and spectroscopy methods have been tested for skin hydration estimation. 2. Efficient methods, algorithms and programmes for calculation of skin chromophore distribution and skin blood perfusion maps have been developed. 3. Software of the prototype device "SkImager" has been improved and clinically approbated for skin erythema estimation, technology transfer initiated. 4. Concepts of non-contact single- and double-snapshot skin chromophore mapping and remote anesthesia control have been developed. 5. Clinical measurements with the developed or improved prototype devices for skin chromophore mapping, skin tumor diagnostics, skin erythema and hydration estimation, skin blood perfusion mapping and remote anesthesia control have been carried out.

*) details are provided in the Annex and website of the Project, http://sophis.edi.lv/research/project-no-3-biophotonics-imaging-diagnostics-and-monitoring/

Project 4.

Tasks	Results
1. Development of the centralized monitoring approach for the city based on using the multi-sensor data acquisition points.	Developed "Smart city data collection point specification" (in Latvian, see http://www.edi.lv/media/uploads/UserFiles/Senso ru-specifikacija.pdf)
2. Development of highly efficient optical fiber transmission technology for transmission of high volume sensor data to processing centres.	Developed WDM-PON transmission technology with all optical channel add-drop function (see Appendix 4, section 4.5)

3. Development signal processing techniques and algorithms for recognition of predefined scenarios of actions or events related with the security in the city; implementation of algorithms by solving inverse problems and adapting for use of high-performance computing (HPC).	Developed deep neural network- based methods and software for video and other sensor data processing to target urban security problems (see Appendix 4, section 4.2)
4. Development of methods and algorithms for urban security monitoring based on RS data acquisition and processing; implementation of algorithms in HPC-oriented software.	Developed 3 novel methods and algorithms for processing of multispectral and hyperspectral RS data for land use monitoring. Developed software for simulation of flooding (see Appendix 4, section 4.3).
5. Development of urban infrastructure security monitoring technologies using UWB sensors and solving inverse problems for localization of objects.	Developed security monitoring technology using UWB sensors (see Appendix 4, section 4.4).
6. Development of the bacteriological quality control system for the city water supply network.	Developed online control system for detection of bacteriological contamination in water supply system (see Appendix 4, section 4.6).
7. Transfer of the developed technologies and solutions to end users to facilitate their uptake by the national economy.	1. WDM-PON transmission system with all optical channel add-drop function approbated in SIA "Affoc Solutions" (see Appendix 4.15). 2. Ultra wideband radar application for vehicle counting approbated in SIA “VPWash” (see Appendix 4.12). 3. Drinking water quality monitoring and contamination detection system approbated in SIA “Liepājas ūdens” (see Appendix 4.10). 4. Neural network for counting of moving objects approbated in SIA “Biznesa augstskola “Turība”” (see Appendix 4.13). 5. Flood simulation program “AdazuPludi” approbated in Adazi municipality (see Appendix 4.14).

The implementation of the programme has been performed in active collaboration with partners from industry and endusers, in particular:

• Children Clinical University Hospital (BKUS), where is approved performance of quick query language;

• SIA LETA, where is an approved the use of new effective semantics retrieval method;

• Consult Logitrans OU (Estonia), Tieto Latvia and Tartu University (Estonia) in parallel ongoing international project, resulting in synergies between research;

• SIA Eurolcds where is used segmentation algorithms for 3D imaging;

• SIA Pest Baltic, where is used wireless sensor networks and a small object detection algorithms.

• Hospital of Traumatology and Orthopaedics, where developed device for contactless monitoring of cardiac and circulatory parameters at near infrared spectral range is approved and compared with industrial device.

• Clinic of esthetical dermatology where experimental prototype of the device for imaging of tissue moisture distribution at near infrared range is tested.

• Laserplastic clinic where skin multimodal imaging by the prototype device "SkImager" is approved and tested.

• CSDD (Ceļu Satiksmes Drošības Direkcija/Road Safety Directorate) and Biķernieki Sports Center provided support in testing and validating the self-driving car platform and facilitating data gathering for training the system;

• "Latvijas Mobilais Telefons" SIA for providing a vehicle for additional testing and development of self-driving system;

1.9 Results of the programme:
Programme Activities:

No	Programme Activities	Results (expressed numerically)		
		Number (Planned)	**Unit of measurement**	**Number** (Achieved)
1.	Research	12	**Software prototypes** (contribution to tasks: 1., 3., 4., 5., 6., 7., 8., 10.)	23
		15	**Methodology, descriptions** (contribution to tasks: 2., 5., 6., 9.)	21
		21	**Mock-ups, prototypes, Technologies** (contribution to tasks: 1., 3., 4., 7., 8., 10., 11.)	25
		6	**Involvement in international projects** (contribution to horizontal tasks: 4.)	12
2.	Technology Transfer	15	**Approbated technologies and prototypes**	22
		12	**Patents** (contribution to horizontal tasks: 2., 5.)	14
3.	Investment in education	22	**Defended doctoral thesis**	14 (+11 predefined)
		52	**Defended Master thesis**	67
		13	**Improved courses** (contribution to horizontal tasks: 3.)	15
4.	Dissemination and long-term technological forecast	80	**Scientific publications**	140+3* are submitted and awaiting final review
		54	**Presentations in international conferences and seminars**	92
		4	**Participation in exhibitions** (contribution to horizontal tasks: 1.)	8
		25	**Organised public seminars**	27
		2	**Organised conferences**	3
		40	**Popular-scientific papers/events** (contribution to horizontal tasks: 6.)	81
		4	**Technological forecast** (contribution to horizontal tasks: 7.)	4

Results of the programme by performance indicators:

Performance indicator	Results					
	Planned	Achieved				
		Total	Period 1	Period 2	Period 3	Period 4
A. Scientific performance indicators						
1. Scientific publications:	80	140+3*	17	27	46	50+3*
1.1 number of original scientific articles (*SCOPUS*)(SNIP>1)	17	12+3*	0	2	4	6+3*
1.2 number of original scientific articles in journals or in proceedings of conferences in databases SCOPUS or Web of Science	63	108	13	22	34	39
1.3 number of reviewed scientific monographs	1	2	0	0	0	2
1.4 other original scientific articles	0	20	4	5	8	3
2. In the framework of the programme:						-

2.1 number of defended doctoral thesis	22	14+11*	1	4	3	6+11**
2.2 number of defended master's thesis	52	68	8	8	24	28
3. Number of improved courses	13	15	1	2	3	9
4. Research deliverables					-	-
4.1 Software prototypes	12	23	1	1	8	13
4.2 Methodology, descriptions	15	21	5	0	4	12
4.3 Mock-ups, prototypes, technologies	21	25	5	6	4	10
4.4 Involvement in international projects	6	12	1	2	2	7
B. Performance indicators of the promotion of the programme						
1. The number of interactive events to promote the process and results of the programme (target groups should include students):					-	-
1.1 Presentations in international conferences	50	83	13	15	23	32
1.2 Presentations in international seminars	4	9	0	1	3	5
1.3 organized seminars	25	27	5	8	6	8
1.4 popular-science publications, events, information in mass media	15	81	1	23	25	32
1.5 exhibitions	4	8	2	0	4	2
1.6 Organized international conferences	2	3	0	1	1	1
2. Press releases	0	9	2	3	2	2
3. Technological forecast	4	4	0	0	0	4
C. Economic performance indicators						
1. Amount of private funding attracted to the scientific institution in the framework of the programme, including:					0	-
1.1. co-funding from the private sector to implement the projects of the programme (EUR)	10000	70820	0	0	70820	0
1.2. income from commercializing the intellectual property created in the framework of the programme (alienation of industrial property rights, licensing, conferring exclusive rights or rights to use on a fee) (EUR)					-	-
1.3. income from contractual jobs that are based on results and experience acquired in the framework of the programme (EUR)	435000	1520346	232803	1198743	81800	27674
1.4 Co-funding from the scientific organizations to implement the projects of the programme (EUR)	368300	319768	22402	96730	200633	140432
2. Number of applied for, registered, and valid patents or plant varieties in the framework of the programme:	12	14	1	1	0	12
2.1 in the territory of Latvia	10	13	1	1	0	11
2.2 abroad	2	1	0	0	0	1
3. Number of new technologies, methods, prototypes or services that have been elaborated in the framework of the programme and approbated in enterprises	15	22	0	5	4	13
4. Number of new technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property)	3	3	0	0	0	3
5. Founded a new (spin-off) company	1	1	0	0	0	1
6. Earnings by the scientific institutions from other research projects in synergy (EUR)	4200000	4004006	0	108703	1288364	2606936

In case of deviation from planned justification of deviation.

The main problems in the first three phases of SOPHIS implementation are related to the considerable delays (five and seven months later than the planed start dates for the first and second stage) of a contract signing and receiving of funding. The workplans were necessary to adjust, which partly impacted timely achievement of the results. In addition, a reduction in funding for approximately 15% of the planed amounts for second period and approximately 25% of the planed amounts for third period led to necessity to release part of the employees, adjust workload of others. Due to such instability several employees have submitted resignations, including PhD students and young scientists. Instead PhD students of a lower level have been involved and therefore partly PhD theses are not defensed, but are predefined during SOPHIS implementation period. Some results had to be published at conference proceedings (SCOPUS and Web of Science indexed) not in journals with SNIP>1. One more PCT application was planned, based on LV patent, but due to misunderstandings the submission deadline was passed. Instead, two more LV patent applications are submitted. Earnings by the scientific institutions from other research projects in synergy with SOPHIS are still growing, because numerous project proposals are under evaluation.

1.10. List of results of the programme (*List of publications, conference thesis, etc.)*

Lists of results of the projects are in the project's full scientific annexes:
Appendix Nr1 Project No.1 Development of technologies for cyber physical systems with applications in medicine and smart transport";

Appendix Nr2. Project No.2 “Ontology-based knowledge engineering technologies suitable for web environment”;

Appendix Nr3. Project No.3.”Biophotonics: imaging, diagnostics and monitoring”;

Appendix Nr4 . “Development of technologies for secure and reliable smart-city”.;

.

PART 2: PROGRAMME PROJECT INFORMATION					
2.1.1.Project No. 1					
	Title		Development of technologies for cyber physical systems with applications in medicine and smart transport		
	Project leader's				
	name, surname		Leo Selavo		
	Degree		Dr.sc.comp.		
	Institution		Institute of Electronics and Computer Science, University of Latvia		
	Position		Institute of Electronics and Computer Science (EDI) Senior researcher, Head of Cyber Physical Systems Laboratory, University of Latvia, Faculty of Computing, Professor		
	Contacts		*Phone number*		+371 67558168
			E-mail		leo.selavo@edi.lv

2.1.2 Project goal and objectives

The overall goal of the project is to develop solutions and tools for cyber-physical systems (CPS), and in doing so, to make them usable and accessible for a wide user base and society in general. To help solve problems in medicine, intelligent transport systems and other fields important to the society, thus promoting economics based on production of competitive innovative CPS based products.

CPS unite components, which are capable of communication, sensing of the environment, evaluating the situation and make decisions and (hopefully in a positive manner) affect the physical environment. System aspects require coordinated and synergetic action form components both on high and low levels. To achieve this, sensor networks, embedded systems, computers, communication systems and control theory are used. To develop these CPS components, as stated in the project goals, the objectives of the project are to do research, analyse and check results and performance, both analytically and empirically, by developing prototypes and testing them in problem environments of the real world.

To achieve this goal, new and competitive solutions will be developed for integration of physical and virtual world in cyber-physical systems while developing competitive smart sensor and their network innovative hardware and software platforms and their applications for modern information, things and people network environments, while benefiting transformation of the economy into products with high added value and bridging the digital divide, allowing everyday users to use cyber-physical systems easier and more effectively.

In this scope, according to the goals of State research programme provisions for programme 2.2. “Next generation information and communication technology systems", specifically objectives 1, 3 and 4, specific work directions have been selected for the project, with specifically defined goals:

1. 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;
2. To improve the quality and ease of providing service in medical services, providing more effective prophylaxis, more timely diagnostics and more successful treatment and rehabilitation, based on innovative solutions, both locally and remotely in telemedicine;
3. To improve road traffic safety and ease of use of transport, by using intelligent transport system technologies;

While working on these goals, a strong connection between physical world, data gathered by smart sensors, processing and interpreting of this data as well as feedback back to physical world was emphasized. A special care was taken to improve efficiency and functionality of economic applications, through safe and autonomous measures, as well as a more convenient usage of CPS, and easier production of CPS based innovative systems.
During the project the project new technologies were developed, then these technologies were implemented into prototypes, tested, validated, approbated and prepared for industry approbation and/or patenting, and also research results were submitted for publication, presented in international conferences and popularized to general public.

Specific objectives for this project were defined as follows:

1. To research, develop and test innovative hardware and software platforms for smart sensors and embedded networks facilitating the development of cyber physical systems, including programming approaches targeted at non-professional users and economy;
   1.1. Development of software platforms for more efficient and easier programming of sensor networks and related cyber physical systems, for developers and experts of such systems, as well as users from other fields of expertise.
   1.2. Innovative modular platform for prototyping, profiling, debugging and evaluation of embedded systems.
   1.3. Environment for testing, debugging and evaluation of wireless sensor networks, with more than a hundred nodes.
2. To research, develop and test cyber physical systems for healthcare uses in prevention, diagnostics, treatment and rehabilitation, which will improve health and wellbeing of individuals and the society as a whole.
   2.1. The development of a smart clothing platform (architecture, hardware and software) for unobtrusive and wearable sensor networks.
   2.2. Applications of the smart clothing platform to telemedicine – remote/virtual physiotherapy.
   2.3. Big data collection and analysis in cyber physical systems for healthcare.
3. To research and develop uses of smart sensors and sensor networks for intelligent transportation systems for safe, efficient and convenient traffic.
   3.1. Driver's personal assistant – research in image processing methodology for the monitoring of driver's attention and forecasting of reaction, as well as development of convenient feedback system between the system and the driver.
   3.2. Extending the field of vision for the driver by 3D and 2D image processing for monitoring, interpretation and reaction to the surrounding environment.
   3.3. Extending the spectrum of driver’s vision beyond the range of visible light by thermal image capture, processing and analysis, detection of hard to see objects during twilight and night time;
   3.4. Communication methods for intelligent transportation systems for vehicle to vehicle and vehicle to infrastructure cooperation.

2.1.3 Description of gained scientific results

In depth project scientific results are described in the attached scientific report document (Appendix 1). Full list of specific numeric results of the project is also in this document (Appendix 1, section 5).

According to the goals of this project and specific objectives described in section 2.1.2. of this document, the work on these objectives within this project has been divided in three main groups:

1. **TestBed** (Appendix 1, section 2) – this group works on the objective of easing the development, programming and usage of CPS systems, by developing innovative hardware and software platform cyber-physical systems of smart sensors and their networks;

2. **MedWear** (Appendix 1, section 3) – this group works on the objective of improving the ease of serving and quality of medical services, by developing CPS for medical and telemedicine applications, and also by developing wearable sensor network technologies in general;
3. **SmartCar** (Appendix 1, section 4) – this group works on the objective of improving the read traffic safety and the ease of use of the cars, by developing uses of smart sensors in intelligent transport systems, as well as developing and testing advanced driver assistance systems (ADAS);

Below are the highlights of results of each of the groups together with the scientific and practical purpose as well as applications. For full list of results see table below and scientific report (Appendix 1, section 5):

1. **TestBed:** Wireless sensor TestBed adapter was improved, a mobile TestBed adapter was developed and full TestBed system concept and prototype was developed and approbated (including both test devices and software). The ease of use, stability and precision of the system was analyzed and approbated in industry, the results were published, as well as disseminated through thesis work, improved courses, presentations in international conferences and general popularization activities as well as served as a basis for synergy projects. *Scientific purpose of the work*: New types of technologies have been developed for sensor network testing and development, which also promote further scientific results in this field by making it easier and more productive to develop and test innovative sensor networks in target environment, the key results are published.
2. **MedWear:** Several wearable sensor systems were developed, data processing methods and prototypes were developed and approbated (including both devices and software). The results have been analyzed for ease of use and demonstrated for multiple different applications. The results are published as well as disseminated it through thesis work, presentations in international conferences and general popularization activities. These results also serve as a basis for multiple synergy projects and a spin-off company. *Scientific purpose of the work*: New medical data gathering methods and devices have been developed, on which new medical research can be based, also the key results have been published.
3. **SmartCar:** A prototype collaborative self-driving car and the accompanying car control system was developed and approbated in the international collaborative driving challenge (GCDC). For more rapid development of collaborative driving algorithms a specialized miniature modular self-driving car track was developed. Additionally multiple data acquisition and analysis methods were developed and improved (e.g. stereovision, lidar, face detection, line detection etc.) including deep learning methods for improving road safety through ADAS systems, better sensing and decision making and simulation. The results have been published, as well as disseminated through thesis work, presentations in international conferences and general popularization activities, as well as served as a basis for synergy projects. *Scientific purpose of the work*: Developed and approbated collaborative driving system, development platform and related algorithms, for use in the field of ITS and the key results have been publication.

The results achieved during this project were divided in specific activities – the overview of planned results and achieved results for each of these activates are below:

No	Activity of the project	Description	Result	Planned Number / Unit of measurement	Achieved results (See Appendix 1, section 5 for details on specific [Result])
A1.	Research				
A1.1	Research in development of smart sensors and sensor networks	In this activity hardware and software solutions for smart sensors and sensor	Software	1 set.	2 sets of software: • TestBed adapter management backend software set [Result A.4.1.3];

		networks will be developed, based on the foundation of previous experience (MansOS, SEAL, Testbed, EDIMote)	Methodology, descriptions	0 pcs.	• TestBed user frontend and developments tools software set [Result A.4.1.5]. 1 description of TestBed architecture concept [Result B.4.2.1].
			Developed experimental prototypes	2 pcs.	3 developed prototypes: • TestBed adapter prototype [Result A.4.3.1]; • TestBed system prototype [Result A.4.3.4]; • Mobile TestBed adapter prototype [Result A.4.3.9].
			Involvement in international projects	0 pcs.	2 synergy international projects: • H2020 project ENACT [Result A.4.4.5]; • EU FP7 ARTEMIS project DEWI [Result A.4.4.8].
A1.2	Research in development of cyber physical systems for uses in medicine and telemedicine	In this activity hardware and software solutions for telemedicine and medicine will be developed based on the foundation of previous experience	Software	1 set.	2 sets of software: • Head positioning monitoring mobile application [Result A.4.1.1]; • Knee joint monitoring mobile application [Result A.4.1.2].
			Developed experimental prototypes	2 pcs.	6 developed prototypes: • Head position sensor prototype [Result A.4.3.2]; • Knee joint sensor prototype [Result A.4.3.3]; • Body and head monitoring system prototype [Result A.4.3.5]; • Prototype for ECG data gathering [Result A.4.3.6]; • Headband for computer control prototype [Result A.4.3.7]; • Prototype 12-lead ECG data gathering and feedback device prototype [Result A.4.3.11].
			Involvement in international projects	0 pcs.	2 synergy international projects: • Norway grants HIPPAC project [Result A.4.4.2]; • ERA-NET project CONVERGENCE [Result A.4.4.4].
A1.3	Research in development of smart transport systems	In this activity hardware and software solutions for intelligent transport systems will be developed, based on the foundation of previous experience (Carmote, GCDC)	Software	1 set.	1 set of software for autonomous collaborative self-driving car approbation at GCDC.
			Developed experimental prototypes	2 pcs.	2 developed prototypes: • Prototype automatic collaborative self-driving car [Result A.4.3.8]; • Prototype mini collaborative driving infrastructure [Result A.4.3.10].

			Involvement in international projects	0 pcs.	4 synergy international projects: • H2020 ECSEL project 3CCar [Result A.4.4.1]; • H2020 ECSEL project Autodrive [Result A.4.4.3]; • H2020 ECSEL project PRYSTINE [Result A.4.4.6]; • H2020 ECSEL project I_MECH [Result A.4.4.7].
A2.	Technology approbation and transfer		Technology validated in companies		
A2.1	Approbation of prototypes and software	Approbation of prototypes and software	Software package validated in companies		
A2.1.1	Approbation of smart sensor and sensor network prototypes and software	In this activity the prototype of smart sensor and sensor network technology hardware and software will be approbated	Approbated prototype	1 pcs.	3 approbations in enterprises: • TestBed approbation by "19 points" Ltd. [Result C.3.3]; • Mobile TestBed approbation at Dobele Institute of Horticulture [Result C.3.5]; • Mobile and stationary TestBed approbation at University of Latvia [Result C.3.6].
A2.1.2	Approbation of smart clothing for medicine and telemedicine prototypes and software	In this activity the prototype of telemedicine and medicine system hardware and software will be approbated	Approbated prototype	1 pcs.	3 approbations in enterprises: • Approbation at EuroLCDs Ltd. [Result C.3.1]; • Approbation at rehabilitation centre "Mēs esam līdzās" [Result C.3.4]; • Approbation at "Wide.Tech" [Result C.3.7].
A2.1.3	Approbation of the prototype and software of intelligent transport system	In this activity the prototype of intelligent transport system will be approbated	Approbated prototype	1 pcs.	1 approbation in enterprise at GCDC challenge [Result C.3.2].
A2.2	Technology transfer	In this activity developed technologies will be patented and commercialized	Patents	2 pcs.	2 Latvian patent applications: • "Mobile device for a more efficient development of wireless sensor networks and their nodes in target environment", [Result C.2.1.1]; • "Method of controlling of antenna radiation patterns by using transmission lines on printed circuit board", [Result C.2.1.2].
			License agreement	1 pcs.	1 license agreement with University of Latvia for TestBed system [Result C.4.1].
			New company created	1 pcs.	1 spin-off company Hack-motion co-founded by project researcher [Result C.5.1].
A3.	Education				
A3.1	Use of results in courses	Use of project results and knowledge gained while executing it, for	Educational courses with content from	4 pcs.	4 courses improved by project results: • Introduction to digital design, University of Latvia [Result

		development of course content	project results		A.3.1]; • Concepts of Operating Systems, University of Latvia [Result A.3.2]; • Special course: cyber-physical systems, University of Latvia [Result A.3.3]; • Wireless sensor networks, University of Latvia [Result A.3.4].
A3.2	Development of promotion and masters works				
A3.2.1	Development of masters works	Masters works will be developed with a partial support from the project	Developed masters works	6 pcs.	7 developed master's thesis: • Armands Ancāns [Reuslt A.2.2.1]; • Maksis Celitāns [Result A.2.2.2]; • Rihards Novickis [Result A.2.2.3]; • Aleksandrs Skripko [Result A.2.2.4]; • Nauris Dorbe [Result A.2.2.5]; • Emil Syundyukov [Result A.2.2.6]; • Reinis Ozoliņš [Result A.2.2.7].
A3.2.2	Development of promotion works	Promotion works will be developed with a partial support from the project	Developed promotion works	6 pcs.	9 developed doctoral thesis*: • Atis Hermanis [Result A.2.1.1]; • Krisjanis Nesenbergs [Result A.2.1.2]; • Mihails Pudžs [Result A.2.1.3]; • Ingars Ribners [Result A.2.1.4]; • Jānis Judvaitis [Result A.2.1.5]; • Rihards Balašs [Result A.2.1.6]; • Emil Syundyukov [Result A.2.1.7]; • Rihards Fuksis [Result A.2.1.8]; • Rinalds Ruskuls [Result A.2.1.9]. * Because of the relative length of average doctoral studies in relation to the project length and change of personnel during project, not all doctoral thesis were finished and defended. To mitigate this, in cases where it was not possible to replace the employee with another doctoral student, additional bachelors theses were developed during project. 8 developed bachelors thesis: • Emil Syundyukov [Result A.2.3.1]; • Voldemārs Smelēns [Result

					A.2.3.2]; • Mārtiņš Skudra [Result A.2.3.3]; • Henrijs Smelēns [Result A.2.3.4]; • Arnis Salmiņš [Result A.2.3.5]; • Niklāvs Barkovskis [Result A.2.3.6]; • Artis Rozentāls [Result A.2.3.7]; • Jānis Ārents [Result A.2.3.8].
A4.	Publicity and long term technology prognosis				
A4.1	Conference reports	Project results will be presented in international scientific conferences	Presentations	19 pcs.	21 presentations in international conferences: • EUSIPCO 2014 [Result B.1.1.1]; • KTI ARTEMIS "Brokerage event 2015" [Result B.1.1.2]; • 73rd conference of University of Latvia [Result B.1.1.3]; • ARTEMIS Co-Summit 2015 [Result B.1.1.4]; • CPSWEEK Microsoft Indoor Localization [Result B.1.1.5]; • IPSN 2015 [Result B.1.1.6]; • IPSN 2015 [Result B.1.1.7]; • 4th Baltic and North Sea Conference on Physical and Rehabilitation Medicine" [Result B.1.1.8]; • EWSN [Result B.1.1.9]; • RSU ISC 2016 [Result B.1.1.10]; • RTUWO 2016 [Result B.1.1.11]; • KTI ARTEMIS "Brokerage event 2017" [Result B.1.1.12]; • EWSN 2017 [Result B.1.1.13]; • EBCCSP 2017 [Result B.1.1.14]; • Erlang user conference [Result B.1.1.15]; • ICMV 2017 [Result B.1.1.16]; • ICMV 2017 [Result B.1.1.17]; • TELFOR 2017 [Result B.1.1.18]; • TELFOR 2017 [Result B.1.1.19]; • ICSPS 2017 [Result B.1.1.20]; • ICTA 2017 [Result B.1.1.21].
			and articles in conference proceedings	19 pcs.	21 scientific articles indexed by SCOPUS or Web of Science: • "RGB-D-T based Face Recognition" [Result A.1.2.1]; • "Development of 802.11p Testbed – Experiences" [Result A.1.2.2];

					• "Shape sensing based on acceleration and magnetic sensor system" [Result A.1.2.3]; • "Face recognition system on Raspberry Pi" [Result A.1.2.4]; • "Smart textiles for wearable sensor networks: review and early lessons" [Result A.1.2.5]; • "Complex matched filter for line detection" [Result A.1.2.6]; • "Wearable sensor grid architecture for body posture and surface detection and rehabilitation" [Result A.1.2.7]; • "A Realistic Evaluation and Comparison of Indoor Location Technologies: Experiences and Lessons Learned" [Result A.1.2.8]; • "EDI WSN TestBed: Multifunctional, 3D Wireless Sensor Network Testbed" [Result A.1.2.9]; • "Network Data Traffic Management Inside a TestBed" [Result A.1.2.10]; • ** "Inertial sensors and muscle electrical signals in human-computer interaction" [Result A.1.2.11]; • ** "Mobile wireless sensor network TestBed" [Result A.1.2.12]; • ** "Power Consumption Measurement of Tested Units in the WSN TestBed" [Result A.1.2.13]; • ** "On improving gait analysis data: heel induced force plate noise removal and cut-off frequency selection for Butterworth filter" [Result A.1.2.14]; • ** "Prospects of improving the self driving car development pipeline: transfer of algorithms from virtual to physical environment" [Result A.1.2.15]; • ** "Using virtual environment for autonomous vehicle algorithm validation" [Result A.1.2.16]; • "Amplitude Adaptive ASDM circuit" [Result A.1.2.17]; • *** "Knee Joint Dynamics Monitoring Using Wearable Sensor Network and Mobile

					Software During Rehabilitation" [Result A.1.2.18]; • **** "Scalable in-door positioning system for cooperative MicroIV algorithm development" [Result A.1.2.19]; • **** "Human skin as n-th order passive filter" [Result A.1.2.20]; • **** "Smart textiles: efficient data collection grid architecture" [Result A.1.2.21]. ** These publications are accepted for publication and are awaiting the publication and indexing. *** These publications are submitted for publication. **** These publications are prepared for publication, but have not been submitted yet.
A4.2	Scientific publications	Project results will be published in peer reviewed scientific journals	Articles	3. pcs.	4 journal publications with high impact (SNIP>1): • "Acceleration and Magnetic Sensor Network for Shape Sensing" [Result A.1.1.1]; • "Architecture of smart clothing for standardized wearable sensor systems" [Result A.1.1.2]; • "Improved RGB-DT based face recognition" [Result A.1.1.3]; • ***** "DIY Car Control System for Cooperative Driving" [Result A.1.1.4]. ***** This article has been submitted for publication and awaiting final acceptance notification.
A4.3	Dissemination of the results of the research	Scientific results of the project will be presented in annual seminars aimed at specialists of the field and students. Information for wider public about the scientific results of the project will be published in popular science articles and website of the project	Participation in exhibitions Organized seminars	2 pcs. 4 pcs.	6 exhibitions in which results demonstrated: • MINOX 2014 [Result B.1.5.1]; • Skola 2015 [Result B.1.5.2]; • RIGA COMM 2016 [Result B.1.5.3]; • ROBOTEX 2016 [Result B.1.5.4]; • Baltic Textile 2017 [Result B.1.5.5]; • RIGA COMM 2017 [Result B.1.5.6]. 6 organized seminars: • 2015-07-09 [Result B.1.3.1]; • (¼) 2015-10-07 [Result B.1.3.2]; • 2016-03-16 [Result B.1.3.3]; • (¼) 2016-03-30 [Result

					B.1.3.4]; • 2016-11-23 [Result B.1.3.5]; • (¼) 2016-12-07 [Result B.1.3.6]; • 2017-08-01 [Result B.1.3.7]; • 2017-11-30 [Result B.1.3.8]; • (¼) 2017-12-05 [Result B.1.3.9]. (¼) Some seminars are counted only as 0.25 because they were co-organized together with the other 3 projects from SOPHIS programme.
			Presentations in international seminars	0 pcs.	4 presentations in international seminars: • Gap Summit 2016 [Result B.1.2.1]; • GCDC developer seminar [Result B.1.2.2]; • IAA Cars 2017 and Udacity Seminar [Result B.1.2.3]; • ICT Proposers' Day 2017 [Result B.1.2.4].
			Popular science publications	4 pcs.	35 popular science publications in media (newspapers, portals, radio, television) – full list in Appendix 1, Section 5, subsection B.1.4 – marked with symbol [P].
			Other popularization events	10 pcs.	33 other popularization events and presentations – full list in Appendix 1, Section 5, subsection B.1.4 – all excluding publications marked with [P].
A4.4	Forecast of the technological development of the scientific direction	Forecasting of the project scientific direction technological development by following the development of the field	Forecast of the development of scientific direction of cyber physical systems	1 forecast	1 technological forecast for the future development of cyberphysical systems [Result B.3.1].

2.1.4. Further research and practical exploitation of the results

The further planned research activities and possibilities to exploit the results for each of the groups are described below:

TestBed:

Further research activities and solvable problems: In future projects the TestBed infrastructure requires upgraded hardware for even more precise power measurement, to more precisely be able to determine power consumption of low energy devices in sleep mode allowing for better analysis of their operation and required battery sizes. Additionally, the user interface for testbed management should be improved according to the suggestions from approbation, thus making it easier to use for the end users, and making it even easier to program and test wireless sensor networks.

Practical purpose and applications of the results: The results promote faster road to market of research intensive, sensor network based technologies, by increasing the speed of the development

cycle and making testing easier, even in target environments. Companies developing sensor network solutions are target exploitation audience, using the infrastructure for developing and testing their products.

MedWear
Further research activities and solvable problems: the developed technologies will be transferred to flexible substrates to improve their ease of use. Additionally, even more different types of sensors should be connectable to the developed architecture for more complicated data analysis and feedback. Telemedicine applications will be explored further.
Practical purpose and applications of the results: Wearable sensor platforms provide benefits to the field of rehabilitation and telemedicine, by reducing the time, that patient spends traveling to the doctor and by reducing the time, the doctor spends for patient monitoring, thus allowing one specialist to take quality care of more patients, and at the same time improving the quality of the service through regular measurements which provide basis for treatment and feedback to the patient. Potential exploitation channels are medical and rehabilitation institutions, as well as companies producing medical equipment.

SmartCar
Further research activities and solvable problems: In the future miniature collaborative driving test track should be improved and opened for wider audience as a service, as a kit or through events such as self-driving car programming competitions. Technologies, such as driver monitoring, expanding driver senses and V2V/V2X communication for coordinated route planning will be explored further in depth. Test track with smart infrastructure will be developed for future research needs.
Practical purpose and applications of the results: The smart car will be more secure and easier to use, because it can gather more data in a shorter period of time than the driver, thus allowing more efficient and more secure driving decisions. The developed technologies can prevent accidents on the road, both those caused by the external road conditions and other cars, and those caused by the tiredness or sleepiness of the driver. The developed smart car test platform and miniature test track will allow testing and validating of the developed technologies and to develop complex decision making algorithms for intelligent transport systems with minimal resource investment by utilizing development pipeline from pure simulation to tests in miniature track to full scale self-driving car tests.

All of these results will provide a stronger bond between the physical world, data gathered by smart sensors, processing and interpretation of this data, as well as providing real time feedback back to physical world and in doing so making it easier to develop CPS and use them as well as produce technology based on innovations, thus bridging the digital divide. Special attention is given to increase of efficiency and functionality of economy in a safe and autonomous way, for example, work in innovative bio-medical systems will allow for a timelier diagnostic, more efficient prophylaxis and more successful rehabilitation and treatment both in person and remotely, but work in Intelligent transport systems will allow safer traffic and more convenient use of the transport.

2.1.5. Dissemination and outreach activities
Full list of dissemination activities can be found in Appendix 1, Section 5.

2.1.6 The spent financing by Project #1 (*euro)*

		Planned 2014.–2017. g.	1st period	2nd period	3rd period	4th period	Sum
1000 – 9000	All expenses	434830	84889	110678	95060	174170	464797*
1000	**Salaries**	260040	61251	87324	80120	146719	375414
2000	**Goods and services** (2100+2200+2300)	60487	22187	4832	14940	27451	69410
2100	Travels	24150	13994	9115	4000	8941	36050
2200	Services	36322	8192	9405	10940	18510	47048
5000	**Assets**	0	1450	0	0		1450

*The part of the Project no. 3 Biometric assignments were carried out and implemented within the framework of Project No.1. Task financing was transferred to Project No.1.

2.1.7. The resulting indicators of Project #1

Resulting indicator	Results						
	planned	achieved					
	2014.–2017.	period					
		All	1st	2nd	3rd	4th	
Scientific results							
1. Number of scientific papers:	22	25	4	6	2	13	
1.1. Number of original papers (*SCOPUS*) (SNIP > 1)	3	4	0	1	1	2*	
1.2. Number of original papers included in databases IEEExplore, ACM DL, SCOPUS, Web of science	19	21**	4	5	1	10.5**	
1.3. number of peer-reviewed monographs	0	0	0	0	0	0	
1.4 number of other original research papers	0	0	0	0	0	0	
2. Number of defended theses:							
2.1. PhD theses	6	9***	0	0	1	8***	
2.2. Master theses	7	7	0	0	3	4	
2.3. Bachelor theses	0	8	1	0	4	3	
3. Number of improved study courses	4	4	1	1	1	1	
4. Research							
4.1 Software prototypes	3	5	2	1	1	1	
4.2 Descriptions of methodologies	0	1	1	0	0	0	
4.3 Prototypes, technologies	6	11	3	3	2	3	
4.4 involvement in international projects	0	8	1	1	0	6	
Results of the programme outreach							
1. Interactive events of programme implementation and outreach of the results where target groups include also students, number:							
International conferences	17	21	7	3	1	10	
International seminars	0	3	0	0	1	2	

Organized seminars	4	6	1.25	1.25	1.25	2.25	
Popularization (of which publications)	10 (4)	68 (35)	2 (2)	25 (9)	21 (13)	20 (11)	
Exhibitions	2	6	2	0	2	2	
2 Long-term technology prognosis for the research and technology direction developed in frame of the programme: Biophotonics	1	1	0	0	0	1	
National economy-related indicators							
1. Private funding attracted to the scientific institution, including:							
1.1. Private co-funding for implementation of the programme projects							
1.2. Income from commercialization of IPR created in frame of the programme (expropriation of industrial property rights, licensing, awarding of exclusive or usage rights for reward)							
1.3. Income from contract research, based on programme-created results and know-how (EUR)	95000	96782	7865	35743	35000	18174	
1.4 Co-funding of research institutions from own resources for implementation of the programme (EUR):	172000	177146	5639	45126	57279	69102	
2. Number of submitted, registered and active patents or breeds:							
In territory of Latvia	2	2****	0	0	0	2****	
Outside Latvia	0	0	0	0	0	0	
3. Number of new technologies, methods, prototypes or services created in frame of the programme and approbated in industry	3	7	0	1	1	5	
4. Number of implemented new technologies, methods, prototypes (contracts on IPR transfer)	1	1	0	0	0	1	
5. New spin-off created	1	1*****	0	0	0	1*****	
6. Earnings by scientific institutions from other research projects in synergy (EUR)	0	1886753	0	108702	227529	1550521	

* Of these one is submitted and awaiting final review.

** Of these one is counted as 0.5 because it is in collaboration with Project No.4, six are accepted for publication and presented, but awaiting indexation, one is submitted and awaiting final reviews and three are prepared for submission awaiting for a specific conference call.

*** Because of the relative length of average doctoral studies in relation to the project length and change of personnel during project, not all doctoral theses were finished and defended. To mitigate this, in cases where it was not possible to replace the employee with another doctoral student, additional bachelors theses were developed during project. Of these eight theses two are pre-defended, four are in development and will be submitted after the end of the project and two are on hold, as the employees have moved to other institution.

**** Patents are submitted and awaiting full evaluation.
***** Company Hack-motion co-founded by project researcher who technical know-how gained in this project, has allowed him to act as successful CTO for this newfounded company.

Leader of the project No.1. K.Nesenbergs 31.01.2018
(signature and transcript) *(date)*

2.2.1. Project No. 2

Title	Ontology-based knowledge engineering technologies suitable for web environment		
Project leader's name, surname	Janis BARZDINS		
Degree	Dr.habil.sc.comp.		
Institution	The Institute of Mathematics and Computer Science, University of Latvia (IMCS UL)		
Position	Senior researcher		
Contacts	*Phone number*		+371 67224363
	E-mail		Janis.Barzdins@lumii.lv

2.2.2. Project goal and objectives

(Describe the project goals and objectives so that the achievements reported below could be placed in context and evaluated)

Goals of the project No.2 are to develop the scientific expertise of the next generation ICT systems by researching and further developing novel competitive model-based information and communication technologies and their applications in modern web environment and to transfer the created expertise and technologies to concrete domains of Latvia's economics by developing and creating novel ICT methods and tools, as well as introducing them into the higher education study process.

The objectives of the project No.2 in the 4th stage of the SOPHIS program are:

1. Further development of data ontology depiction methods and approbation on real medical data.
2. Research of ontology-based linked data and further development of their application in e-Government and e-Medicine domains.
3. Fast query language usage testing on Children's Clinical University Hospital data.
4. Further development of web-based methods for modeling of hard-to-formalize systems
5. FrameNet micro-relation ontology formalization in the form of AMR (Abstract Meaning Representation) and development of appropriate machine learning methods for semantic analysis of text. Research of application of these innovative methods in other areas, e.g., text generation and robotics.
6. Long-term technological prognosis for R&D directions developed in the project (IMCS, UL)
7. Development of methods for transformation of knowledge structures and approbation of the prototype of intelligent structural modelling tool I4S 2.0 in the study process for working with knowledge structures (concept maps)
8. Development, combination, and usage of knowledge structure models for decision making in multi-agent systems and intelligent tutoring systems
9. Model, process, enterprise architecture and other knowledge/artefact amalgamation in FREEDOM framework and development of the methodics for requirements engineering knowledge/artefact maintenance and distribution
10. Improvement and approbation of the framework and methodology for integration of semantic web services in traditional web portals for usage in various problem domains
11. Long-term technological prognosis for R&D directions developed in the project (RTU FCSIT)
12. Development of experimental data visualization and browsing software accordingly to the capabilities of the infrastructure of the monitor wall.
13. Further development of the runtime verification methods by building the ticket reservation system's runtime verification model.

14. Long□term technological prognosis for R&D directions developed in the project (UL FC)

2.2.3. Description of gained scientific results

Planned activities and achievable results of the project No. 2:

No	Activity of the project	Description	Result	Planned Number / Unit of measurement	Achieved results
A1	**Research**				
A1.1	Development of methods for modelling security and availability of ontology-based data processing	Ontology-based methods of modelling knowledge access rights will be developed in the activity, such that will allow in knowledge processing tools graining every user access to only those data, for which he/she has access rights.	Method	1 pc.	Method developed. Described in the Scientific Report of stage 3, Appendix 2, Chapter 2.1.2.
A1.2	Development and implementation of ontology- and web technology-based query languages	Firstly, based on data ontologies, rapid querying language necessary for organization management will be developed in the activity, such that will be usable by branch experts (without the mediation of programmers). Secondly, an intelligent access rights mechanism to sensitive data will be developed by using the mentioned querying language in the web environment.	Language description Software prototype	1 pc. 1 pc.	Query language developed. Description in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.2. Software prototype developed. Available at UL IMCS upon request.
A1.3	Development of web-based modelling technologies	Firstly, web-based data ontology visualization methods will be developed in the activity that will be easy perceptible by the branch experts.	Method Software prototype	1 pc. 1 pc.	Web-based modelling technologies building platform prototype (software) developed. Available at UL IMCS upon request. Method developed. Description in the Scientific

		Secondly, modelling methods and their applications of hard-to-formalize systems will be developed.			Report of stages 1-2, Appendix 2, Chapters 2.3.1-2.3.2, in the Scientific Report of stage 4, Appendix 2, Chapters 2.1.1.7, and publications of A.Sproģis.
A1.4	Development of ontological semantic theoretic base of FrameNet micro-relations	Ontological semantic theoretic base of FrameNet micro-relations will be developed in the activity.	Method	1 pc.	Method developed. Description in the Scientific Report of stage 3, Appendix 2, Chapter 2.1.4, and publications of G.Bārzdiņš, D.Goško and P.Paikens Submitted and won a Horizon-2020 project "SUMMA" under H2020-ICT-16 BigData-research call. The first place in Task 8 of Semeval-2016 shared task competition. We won the Generation track of the SemEval-2017 workshop Task 9: Abstract Meaning Representation Parsing and Generation.
A1.5	Further development of researching web-based linked data	Research and further development of ontology-based linked data technologies for applications of e-management and e-health will be performed in the activity.	Method	1 pc.	Research on linked-data application in different domains. Description in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.4. Overview of the state of Linked Data, analysis of considerations for applying Linked Data to various domains, and a detailed survey of applications of Linked Data technologies in e-Government and e-Medicine. Method described in the Scientific Report of stage 4, Appendix 2, Chapter 2.1.1.5.
A1.6	Development of automated methods and algorithms for the system's structural model analysis and their implementation in I4S	During this activity, the structural modelling tool I4S 2.0 for the acquisition of knowledge about complex heterogeneous systems will be	Software I4S 2.0 Software description	1 pc. 1 pc.	Software tool for structural modelling I4S 2.0 with extended functionality has been developed (available upon request at the Department of Artificial Intelligence and Systems Engineering, Riga Technical University)

		developed so that functional state of industrial control systems and risks associated with them could be determined and consequences caused by potential faults could be predicted as a result of these systems' analysis			I4S User Manual v.1.0 has been written (available upon request at the Department of Artificial Intelligence and Systems Engineering, Riga Technical University)
A1.7	Development of methods for the knowledge structures combination and separation, as well as the development of methods for the models' transformation and for the analysis of models' syntax, semantics, and structure	During this activity, first of all, methods for the knowledge structures combination and separation will be developed; secondly, methods for the models' transformation and for the analysis of models' syntax, semantics, and structure will be developed aiming to automate the development of learning materials and students'/pupils' knowledge assessment.	Method	1 pc.	A method for autonomous introduction of changes in knowledge structures of multi-agent systems has been developed, which is described in scientific publication „Lavendelis E. A Cloud Based Knowledge Structure Update and Machine Learning Framework for Heterogeneous Multi-Agent Systems. International Journal of Artificial Intelligence, Vol. 14 (2), October, 2016. CESER Publishing, pp. 157-170”
A1.8	Development of approaches and methods for the control of models, processes, enterprise architectures, and knowledge structural compatibility	During this activity, approaches and methods for the control of models, processes, enterprise architectures, and knowledge structural compatibility will be developed that will facilitate the incorporation of regulatory aspects in organization's business processes and enterprise architectures	Method	2 pcs.	1) An approach (method) for controlling legal states of business objects has been developed, which is described in scientific publication “Peņicina, L. Controlling Business Object States in Business Process Models to Support Compliance. PoEM 2016 Doctoral Consortium, Skövde, Sweden, November 8, 2016, CEUR Workshop Proceedings 1765, pp. 6-13” and in Master Thesis “Stanga, L. The Method Development of Continuous Business Process and Enterprise Architecture Correspondence Maintenance. Master Thesis,

					Riga Technical University, 2016” 2) A methodics (a simplified methodology) for requirements engineering knowledge/artefact maintenance and distribution has been developed, which is described in Section 2.2.3.6 of the Scientific Report (Appendix 2)
A1.9.	Development of the methodology and framework for semantic web services integration.	During this activity, the methodology and framework for the integration of semantic web services in traditional websites will be developed for the usage in various problem domains	Methodology	1 pc.	A methodology for integration of semantic web services in a web portal has been developed, which is described in scientific publication „Novickis L., Vinichenko S., Sotnichoks M., Lesovskis A. Graph Models and GeoData Based Web Portal in Cargo Transportation. Scientific Journal of Riga Technical University. Applied Computer Systems, 2015/17, RTU Press, Riga, 2015, pp. 34-39”, Sections 2.2.4 and 2.2.5 of Scientific Report (Appendix 2) of stages 1 and 2, and Section 2.2.4 of Scientific Report (Appendix 2) of stage 3
A1.10	Development of technology for browsing and visualising large volume NoSQL databases	NoSQL databases and their applications will be explored in the activity, as well as experimental tool for data browsing and visualizing will be developed.	Software prototype	1 pc.	Monitor wall created (hardware) Data visualization and browsing software prototype developed. Available at FC UL upon request.
A1.11	Development and verification of business process run-time security models	Business process run-time security models will be developed in the activity and their verification will be performed.	Business process run-time security model	2 pcs.	Runtime security model for bank transaction clearing process developed. (Available upon request at SIA “DIVI grupa”). Runtime security model for ticket reservation system developed. (Available upon request at SIA “DIVI grupa”). Runtime security model for drone monitoring process developed in the ARTEMIS

					project. (Available upon request at IMCS UL).
A2	**Technology transfer and approbation**				
A2.1	Approbation of technology developed in activity A1.2	Mentioned technology will be approbated in some Latvian hospital (currently planned hospital is Children clinical university hospital, from which a support letter has been obtained).	Approbated prototype	1 pc.	Approbated at CCUH. Description in in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.7. [Aprobacija_LUMII_1]
A2.2	Approbation of data ontology building method developed within activity A1.3	Mentioned method of data ontology building will be approbated on real data of health branch (currently planned data are to be from National Health Service, a collaboration agreement has been signed between NHS and IMCS).	Approbated method	1 pc.	Approbated at CCUH. Description in in the Scientific Report of stage 4, Appendix 2, Chapter 2.1.1.4. [Aprobacija_LUMII_1]
A2.3	Approbation of method for ontological semantic formalization of FrameNet micro-relations developed in activity A1.4	Mentioned semantic formalization method will be approbated by implementing in a form of software within the agreement of LETA.	Approbated method	1 pc.	Approbated at LETA. Description in in the Scientific Report of stages 1-2, Appendix 2, Chapter 2.1.10.
A2.4	Approbation of I4S 2.0 tool	Structural modelling tool for the knowledge acquisition about complex heterogeneous systems will be approbated for the industrial control system analysis in the cooperation with ICD Software AS (Norway) (letter of support is provided)	Approbated prototype	1 pc.	Due to the termination of cooperation with the company ICD Software AS, approbation of the software tool I4S was not performed. Instead, the approbation of the multi-robot simulation tool developed in the Activity 1.7 was done, which is described in the document „Lavendelis, E. Prototype of adaptive multi-agent system. Technical report, Riga Technical University, 2017”
A2.5	Approbation of	During this	Approbated	2 pcs.	1) Approbated methods for

	methods developed in the activity A1.7 for the knowledge structures combination and separation and for the knowledge structure models transformation	activity, methods for the work with knowledge structures allowing the creation of learning materials and methods for the automated development of tasks and knowledge assessment will be approbated (currently, the cooperation with JSC „Datorzinibu Centrs" is planned (letter of support is provided))	methods		the work with knowledge structures allowing the creation of learning materials and methods for the automated development of tasks and knowledge assessment. [Aprobacija_DITF_1_2] 2) For approbation of the developed method for dynamic adaptation of emotion-based tutoring, an initial version of educational game has been created, which is described in scientific publication „Petrovica, S. Multi-level adaptation of an educational game to individual student's gameplay, knowledge and emotions. Proceedings of the 9th Annual International Conference on Education and New Learning Technologies, Barcelona, Spain, July 3-5, 2017, pp. 2220-2230" 3) For approbation of the developed method for modelling of social effects of emotions, a game in form of a multi-agent system has been implemented, which is described in scientific publication „Pudane, M. Affective Multi-Agent System for Simulating Mechanisms of Social Effects of Emotions. Proceedings of Seventh International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), San Antonio, United States of America, October 23-26, 2017. San Antonio, 2017, pp. 129-134."
A2.6	Approbation of the framework developed in the activity A1.9 for semantic web	During this activity, the framework and methodology developed for the integration of	Approbated framework	1 pc.	The developed methodology for development and integration of semantic web services has been approbated in improvement of the eLOGMAR portal and other

	services integration	semantic web services in traditional websites will be approbated in the logistics problem domain in the cooperation with LOGITRANS Consult Ltd. (Estonia) (letter of support is provided)			software development projects, which is described in scientific publication „Bartusevičs, A., Lesovskis, A., Ponomarenko, V. Model-Driven Approach and Library of Reusable Source Code for Automation of IT Operations. Applied Computer Systems. Vol. 21, 2017, pp. 5-12" and Section 2.2.4 of the Scientific Report (Appendix 2)
A2.7	Approbation of browsing and visualization technology of NoSQL databases	Novel browsing and visualization technology of NoSQL databases will be approbated in the activity.	Approbated prototype	1 pc.	At FC UL created and approbated prototype of monitor wall Data visualization and browsing software prototype approbated. [Aprobacija_DF_2]
A2.8	Approbation of business process run-time security models	Business process run-time security models will be approbated in the activity.	Approbated prototype	1 pc.	Runtime security model for bank transaction clearing process approbated at Bank of Latvia. Runtime security model for ticket reservation system approbated. [Aprobacija_DF_3] Runtime security model for drone monitoring process approbated in the ARTEMIS project. [Aprobacija_DF_1]
A3	**Investment in education**				
A3.1	Development of PhD thesis	PhD thesis will be developed with a partial support from the project.	Developed PhD thesis	9 pcs.	8* *PhD Thesis of S.Rikačovs will be submitted in 2018
A3.2	Incorporation of project results into the study program	The results of the project will be incorporated into the study programs of UL and RTU	Courses which incorporate the project's results	4 pcs.	The extended functionality of the I4S software tool is being used in the RTU FCSIT doctoral study course „Structural modelling" The developed methods for knowledge structure transformation have been added to the contents of the RTU FCSIT doctoral study course „Distributed Intelligent Systems" Masters degree course

					"Deep Learning" updated with a lecture on deep reinforcement learning. Masters degree course "Data Management Systems" updated.
A3.3	Development of master's thesis	Master's thesis will be developed with a partial support from the project.	Developed master's thesis	22 pcs.	38
A4	**Publicity of results and their long-term technological prediction**				
A4.1	Informing the domain experts	For disseminating project results in the community of domain experts, public seminars will be held once in half a year, in which technologies and tools developed within the project will be demonstrated.	Organized seminar	6 pcs.	Organized 5 seminars within project 2 and co-organized 3 seminars within program. Total: 8 seminars.
A4.2	Informing the international scientific community	In 2016, an international conference *DB&IS 2016* will be organized. INTEL-EDU seminars will be held during the project execution time. Scientific publications will be prepared.	Organized conference Organized seminar Prepared scientific publications	1 pc. 3 pcs. 26 pcs.	Organized conferences 2pcs: \ 12th International Baltic Conference on Databases and Information System (DB&IS 2016) Riga, Latvia | 4-6 July 2016, 6th International Conference on Advanced Technology & Sciences (ICAT'Riga), 12-15 September, 2017 Organized 3 seminars: The 2nd Workshop on Managed Complexity (ManComp2017) co-located with the 15th International Conference on Perspectives in Business Informatics Research (BIR 2016), Copenhagen, Denmark, August 28-30, 2017 The 1st Workshop on Managed Complexity (ManComp 2016) and the 4th International Workshop

					on Intelligent Educational Systems, Technology-enhanced Learning and Technology Transfer Models (INTEL-EDU 2016) co-located with 15th International Conference on Perspectives in Business Informatics Research (BIR 2016) , Prague, Czech Republic, September 14-16, 2016 Prepared **65** scientific publications.
A4.3	Informing the Latvian society	To inform wider audience about the project results, popular scientific papers will be published in the project homepage, as well as the developed technologies and tools will be exhibited in the FCSIT "Demo room".	Published popular scientific papers Developed technologies exhibited in "Demo room"	3 pcs. 4 pcs.	Popular scientific papers: Petrovica, S., Pudane, M., Anohina-Naumeca, A., Lavendelis E. Why Computer Systems Need Emotional Intelligence?. Innovation, Volume 1, 2017, pp. 20-21. [ps_pubRTU]; 2) Interview with G.Bārzdiņš in newspaper «Diena» appendix «SestDiena» 11.06.2017. [ps_pub_LUMII_1] 3)G.Bārzdiņš consulted the movie «Tas, ko viņi neredz». [ps_pub_LUMII_2] RTU FCSIT "Demo Room": In the RTU FCSIT „BONITA ShowRoom" the possibility to demonstrate the following software developed during the project has been ensured: 1)the I4S software tool, 2)the multi-robot system virtual simulator, and 3),4) two educational games developed for the affective tutoring system
A4.4	Informing the Latvian scientific community	Reports about the research results will be given in the annual UL and RTU scientific conferences.	Reports given	14 pcs.	18 reports given
A4.5	Forecast of the technological	Technological forecast methods	Forecast of knowledge	1 pc.	Forecast published in program's web page

	development of the scientific direction	will be developed and used in performing the long-term technological forecast of scientific and technological directions developed in the project.	engineering		

1. **Further development of data ontology depiction methods and approbation on real medical data.**
   A widely-used form of representing data is a relational database. However, it requires the knowledge of the SQL to query the data, and domain experts usually lack such knowledge. To offer them the possibility of querying the data themselves (without involving programmers) we have introduced a new method of depicting the data - the semistar ontology. Experiments show that semistar ontologies are easily perceptible by end-users, and that has allowed us to develop for this kind of ontologies a new query language that is based on the natural language. Since semistar ontologies are granular by nature (i.e. the data can be naturally divided into distinct slices) we have also been able to implement the language very efficiently. The proposed data depiction method together with the query language has been introduced for use in Riga Children's Clinical University Hospital. [Aprobacija_LUMII_1]

2. **Research of ontology-based linked data and further development of their application in e-Government and e-Medicine domains.**
   Linked Data is a set of principles for publishing and working with interlinked RDF data that is usually structured according to commonly agreed ontologies. As a part of this research, we studied the applications of Linked Data in two important real-life domains - e-Government and e-Medicine.
   The report consists of an overview of the state of Linked Data, a discussion of general considerations for applying Linked Data to various domains (RDF data validation and Linked Data access control) and a detailed survey of applications of Linked Data technologies in e-Government and e-Medicine. Based on detailed studies of existing research, we conclude that e-Government applications of Linked Data are focused on open data initiatives where new activities include standards for representing information in open data portals (e.g. the DCAT vocabulary) and datasets. The healthcare (e-Medicine) and life sciences domain is richer in its applications of Linked Data and ontologies - there are hundreds of large, interlinked ontologies that users need to access and use.
   In both domains there is a potential for further research and application of Linked Data and ontologies. Of special interest in e-Medicine is the recently published release 3.0 of the FHIR healthcare information interchange standard which adds support for RDF and Linked Data. Another potential area for future development is RDF and Linked Data technologies that are necessary across domains (e.g. RDF data validation).

3. **Fast query language usage testing on Children's Clinical University Hospital data.**
   Usability testing of Fast query language, which is developed in the previous project stages, has been performed on CCUH data for years 2015 and 2016. Practical application of the system has proved that domain experts (physicians) after approximately 2 hours long training were able to write independently (without assistance of programmer) queries of such complexity which were actual for the analyses of hospital processes of last two years.

Usability testing also showed that the developed system provides very high speed of performance – in average les then 0.5 seconds for traditional queries. In general, usability testing has proved that the developed system can be practically used for the analysis of hospital's processes.
Besides that, a publication [SoSyM_SNIP] is prepared and submitted for the publication in journal "Software and System Modeling (SoSyM)"

4. **Further development of web-based methods for modeling of hard-to-formalize systems**
The UL IMCS team already has a significant experience in creating a support for the building of sufficiently rich domain specific graphical modeling languages using the local tool building platform TDA developed by the team. The experience has shown that such domain specific languages are appropriate for modeling of hard-to-formalize systems. Now a web-based tool building platform version has been developed. This platform enables the online development of both a graphical modeling language and its editor using the Configurator tool, and supports on-the-fly testing the language on examples and modifying it if required. The platform runs on a server, but each user working in a web browser can participate in the development of the language and its editor, and use the already developed language for modeling. All the modifications are synchronized between the concurrent users within a team. Currently an executable platform prototype and its usage methodology containing several examples have been developed. Two scientific papers on the principles of the platform have been published.
The next step in the platform development is to migrate from the currently used metamodel instantiation to metamodel specialization. This would ease the definition of a language and its editor and make this activity accessible to experts in various problem domains for whom such domain specific modeling languages are really required. This is because the specialization approach does not require a knowledge on internal system details (as the instantiation does), only simple metamodel subclass creation based on standard class diagram features is required. At the same time all the possibilities of the existing platform are retained. Currently the basic principles of such approach have been developed and published in five prestigious papers, and its implementation principles in the platform have been chosen.

5. **FrameNet micro-relation ontology formalization in the form of AMR (Abstract Meaning Representation) and development of appropriate machine learning methods for semantic analysis of text. Research of application of these innovative methods in other areas, e.g., text generation and robotics.**
In this project phase the following AMR (Abstract Meaning Representation) research has been carried out:
   - Participation in SemEval-2017 workshop Task 9: Abstract Meaning Representation Parsing and Generation (co-located with ACL 2017). We won the Generation track by integrating AMR and GF (Grammatical Framework) approaches as described in our paper [LUMII_SemEval].
   - Participation in TAC KBP Task 2016 at MNIST. A pre-defined ontology Knowledge Base there had to be Populated with facts from English source text. Using AMR parser we achieved highest precision among participants, but due to low recall overall results were mediocre. Detailed description in our paper [LUMII_SUMMA].
   - Doctoral thesis by Peteris Paikens (adviser Guntis Barzdins) "LATVIAN SEMANTIC PARSING TOOLCHAIN" has been completed and successfully defended 5/12/2017. It describes AMR and FrameNet micro-ontology approach for semantic parsing of Latvian. phD_LUMII_Paikens

In parallel we transferred our deep learning expertise to the field of robotics:

- Master thesis by Nauris Dorbe (adviser Guntis Barzdins) "DRIVERLESS CARS TUITION USING REINFORCEMENT LEARNING ARTIFICIAL DEEP NEURAL NETWORKS WITHIN COOPERATE DRIVING SYSTEM" has been completed and achieved 1.place in the Latvian Master thesis competition ZIBIT.
- Doctoral thesis by Uldis Locans (adviser Guntis Barzdins) "Future Processor Hardware Architectures for the Benefit of Precise Particle Accelerator Modeling". Among other topics it explores GPU computing architectures relevant for training deep neural networks. [phD_LUMII_Locans]
- Prepared a paper [LUMII_ViGiL] for NIPS 2017 Workshop on Visually-Grounded Interaction and Language (ViGIL) exploring language and robotics relationship via grounded reinforcement learning.
- Masters degree course "Deep Learning" updated with a lecture on deep reinforcement learning.

6. **Long-term technological prognosis for R&D directions developed in the project (IMCS, UL)**

   Prognosis can be found in [Projekts2_Prognoze] chapter 2.1.

7. **Development of methods for transformation of knowledge structures and approbation of the prototype of intelligent structural modelling tool I4S 2.0 in the study process for working with knowledge structures (concept maps)**

   Research on linking and shared use of different knowledge structures used in distributed artificial intelligence allowed formulation of two basic principles: (1) the fundamental schema for knowledge representation is ontology, and (2) an ontology is transformable (directly or indirectly) into traditional AI knowledge representation schemas – semantic networks and their equivalent – concept maps, frame system, production rules, and knowledge structures formalized using first order logic language. The developed method which is focused on network structures includes 5 mutual transformation pairs: (1) ontology – semantic network or concept map, (2) semantic network or concept map – production rules, (3) semantic network or concept map – frame system, (4) semantic network or concept map – logical schema, and (5) production rules – logical schema. The method consists from 10 algorithms for semiautomatic mutual transformations. Detailed description of algorithms is available in the scientific report of this project (Section 2.2.2.2.).

   Research on processing of knowledge structures resulted in the development of two methods: (1) a method of concept map processing for development of study materials and automated task generation and (2) a method for automated knowledge assessment.

   The first method which is modification of earlier developed (before the current project started) method is based on analysis of expert's concept map, which results in identification of so called graph patterns (subgraphs), for instance, a class concept together with all subclass concepts. A learning object is attached to each subgraph, with different handling of the following types of linking phrases: (1) a linguistic linking phrase, (2) the linking phrase "is a / is instance of / is part of", (3) the linking phrase "has property", and (4) the linking phrase "has synonym". The learning objects are arranged into learning paths, ordering them in sequence of required prerequisite knowledge and placing them in hierarchical levels according to their importance. After students have developed their concept maps, and their mistakes are identified, a personalized learning path is constructed, which allows automatic generation of tasks for knowledge remediation. For implementation of method three algorithms are proposed. Detailed description of algorithms is available in the scientific report of this project (Section 2.2.2.3.).

   The second developed method is based on conception of relations replacement network (RRN) which contains information about possible replacement of one linking phrase with another semantically equivalent linking phrase. Analysis of 186 concept maps constructed by students of study course "Fundamentals of Artificial Intelligence" allow to find that only in around 21% of concept maps students used exactly the same linking phrase as an expert

and every student's concept map contained on average 34% propositions with different linking phrases (in other cases relationships defined between concepts were incorrect). Besides, it was found that the variety of linking phrases used is rather wide and only 4%-25% of students used linking phrases that match with an expert's one. In turn, 18%-39% of propositions were labeled with different linking phrases that had semantically close meaning. Analysis allows concluding that currently known automated knowledge assessment systems are not able adequately to assess a rather large part of students' concept maps. For development of valuable automated knowledge assessment system, the conception of RRN must be realized. The RRN must be trained to get ability to discriminate between semantically equivalent, correct propositions and incorrect ones. An algorithm is created and implemented for building RRN from a given set of evaluated concept maps. The initial structure of RRN has been built.

Both methods were approbated in the RTU study course "Fundamentals of Artificial Intelligence" (the approbation is confirmed by a certificate of RTU Vice-Rector for Academic Affairs).

Approbation of the prototype of I4S software tool was carried out using 114 concept maps constructed by the students of study programme "Computer Systems" in the RTU study course "Fundamentals of Artificial Intelligence" (the approbation is confirmed by a certificate of RTU Vice-Rector for Academic Affairs). The complexity of concept maps was evaluated on the basis of Systems Theory criteria, which are supplemented with a novel formula for quantitative assessment of structural complexity, the degree of centralization and relative weights of hierarchical levels. The importance of concept map elements was determined in accordance with ranking of graph nodes (a method used in structural modelling), which is based both on local information (in- and out-degrees of nodes) and global information about the connectivity of the corresponding underlying graph as a whole (analysis of paths and cycles).

8. Development, combination, and usage of knowledge structure models for decision making in multi-agent systems and intelligent tutoring systems

Architecture of an adaptive multi-agent system, a toolset consisting of Ontology Learning Tool and Multi-Agent System Management (MAS) Tool, as well as machine learning algorithm for learning to match capabilities with corresponding tasks were developed during the first stages of the project. During the fourth stage of the project, a MAS prototype was developed. The prototype works in a virtual environment and simulates a heterogeneous multi-robot system for cleaning tasks, thus validating the toolset and the learning algorithm. The learning algorithm significantly improved the evaluations of the cleaning method choice (the quality at which the tasks are performed), which proves that in the particular conditions the learning algorithm works well enough and is capable to find optimal task allocations even if the initial information is very limited. It is also achieving reasonable results based on comparably small example set. The developed prototype proves that the aim of the activity, namely, to develop multi-agent system whose knowledge structure and knowledge itself can be adapted, has been achieved. The ontology tool enables the change in knowledge structures while the learning algorithm implements autonomous knowledge change.

Regarding the Intelligent Tutoring Systems during the last year of the project, adaptation approach for tutoring process has been developed, which considers characteristics of an individual learner at two adaptation levels (the macro- and micro-level). Personality model is used at the macro-level providing data about a learning style and an achievement goal, as well as teacher's type and default mood are determined based on personality traits. This influences teacher's (system's) decisions and behavior or interventions (frequency, intervention type and content) at the micro-level and the achievement goal set for a learner during the assessment process. Overall, four different types of teachers (Friend, Expert, Coach, and Remediator/Evaluator) are integrated in this approach corresponding to the

particular learning style of a student and interacting based on developed reacting rules. Furthermore, emotional states are identified with an aim of recognizing potentially problematic questions and providing timely teacher's interventions in case of negatively valenced emotions or low attention level.

To fully model human emotions the method for modelling emotion flow among agents was developed. This method heavily relies on psychology and sociology research direction on emotions as a social information carrier. When modelling emotion flow, multi-agent system methods are used and agents are viewed as social beings that consider other agents' states in their reasoning (in this case – affective states). Based on psychology research, five mechanisms that allow communicate emotions, were identified, namely, primary emotional contagion, secondary emotional contagion, pattern invoking, direct communication and manipulation. Mechanisms were then detailed and formalised for further implementation which is the core of the method for modelling emotion flow. It was validated on the board game "Snakes and Ladders", which demonstrated that the method allows achieving group level patterns (namely, convergence and divergence). The results can be used to create full-fledged simulation of a human group, for example, a classroom full of virtual peers.

9. Model, process, enterprise architecture and other knowledge/artefact amalgamation in FREEDOM framework and development of the methodics for requirements engineering knowledge/artefact maintenance and distribution

In order to develop the methodics (a simplified methodology) for maintaining and distributing requirements engineering knowledge/artefacts, it was first necessary to understand how various requirements engineering artefacts are related to the continuous requirements engineering framework FREEDOM. The research on compatibility of the artefacts of selected enterprise architecture and software engineering approaches with the FREEDOM framework and continuous requirements engineering processes and artifact research on specific project management techniques and problem areas showed that (1) although some of the artefacts and processes are common in several situations, there are knowledge/artifacts that are specific for particular project management methods and particular problem areas, (2) enterprise models are an appropriate form of knowledge representation in the of FREEDOM framework for reflecting future and current situation of a company, and (3) in the context of continuous requirements engineering, the FREEDOM framework can be used in a fractal form. In addition, the concepts of the FREEDOM framework were linked to the two concepts types of time dimension: interval and moment (instant). The interdependence between the time concepts is reflected in the time concept ontology of the FREEDOM framework implemented in the Protégé tool. The method for illustrating the potential artifact flows in the FREEDOM framework also is developed. In order to capture artifacts and flow of information, an oriented graph was used, where the vertices depicted the functions of the FREEDOM bus, but the links between them – information and artifact flows. Links are encoded with colors to show the type of link, and the links that represent the artifact flow can have names. The developed method was applied to several cases to make sure that it can display the necessary information in a readily perceptible manner. In addition, groups of external information sources have been identified that are advisable to look at in order to consider knowledge of the external environment during continuous engineering, as well as research on the use of analytical methods in requirements engineering was done. An approach has been developed to help ensure that processes and regulatory documents are consistent. The requirements engineering model has been designed for the development of the methodics for maintaining and disseminating requirements engineering knowledge/artefacts, and the aspects of socialization in communicating the requirements have been investigated. The developed methodics contains two general blocks and four sequential blocks, each of which consists of corresponding activities and/or recommendations.

10. **Improvement and approbation of the framework and methodology for integration of semantic web services in traditional web portals for usage in various problem domains**
    To evaluate the latest developments for the logistic portal eLOGMAR, various testing approaches were summarized to discover the best approaches for portals based on Semantic Web services. The resulting summary was used to develop a new method for improvement and change evaluation in Semantic Web-based portals. During the improvement and evaluation of the eLOGMAR portal, the developed configuration management approach EAF was used to properly track all changes. In parallel, the EAF approach was in other different software development projects. Based on ongoing research, further improvement points were determined for EAF, as well as various problems faced during implementation of the EAF approach in real software development projects. Some of these problems could be solved by using virtualization technologies, but some problems are dependent on the "human factor". In addition, general problems and solutions of moving innovations from scientific field to the real business world were studied. Some of these solutions could also be applied for implementation of the EAF methodology in different software development projects.

11. **Long-term technological prognosis for R&D directions developed in the project (RTU FCSIT)**
    Prognosis can be found in [Projekts2_Prognoze] chapter 2.2.

12. **Development of experimental data visualization and browsing software accordingly to the capabilities of the infrastructure of the monitor wall.**
    Research was done in two directions during forth stage:
    i. Development of information visualization infrastructure, during which display wall was improved technically and functionality was added;
    ii. Development applications for display wall, during which was made approbation of display wall for two applications – model based data visualization and visualization of large graphs.

    Positive references are got form partners who made approbation of prototypes.
    Efficiency and scalability issues was the main focus of the fourth stage. Display wall was built using medium power hardware, that provides 52 megapixel images Compared with Reality Deck solution that uses most modern technologies and provide 88 Mpix, our result is in line with project's goal of creating a relatively cheap and yet sufficiently powerful solution for large images. The authors of the work have successfully used both the standard (Google Chrome, PDF viewer) and domain-specific (video surveillance) software. This eliminates necessity to create a special display wall software - everything that runs on a standard PC will also work on the display wall.
    The display wall prototype was used to model database-based information. The main benefits are high display resolution, which allows you to display a lot of information at the same time, including simultaneously displaying different levels of database (physical, logical, conceptual), and relevant data, and also allows you to navigate through data using "traditional" navigation through data items while navigating in models. The prototype was designed as a versatile tool capable of running on various operating systems as well as browsing various types of databases. Particularly emphasizes that the method used allows browsing data from several related databases at the same time (including databases may be in different database management systems). This option is not offered even in the tools developed by world's leading companies.
    The second approbation of the display wall was to capture a large graph (over 400 vertices) that illustrates the interconnection of the testing terminology. The concepts of the testing (terms), taken from the glossary, serve as graph vertices. Graph edges represent a reference from one term to another. Since glossary contains over 400 different terms then the corresponding graph reaches a considerable size. Such graph visualization, in order for a

person to be able to understand the term relationships, to identify the most important terms referred to by many other terms, can not be realized with a traditional one or two computer screens.

The proposed solution by using a display wall gives many benefits to the graphic representation of the graph: at the same time a large part or even the entire graph of the graphs can be seen, the graph can be scaled out and its individual parts can be viewed immediately, user can arrange graph vertices in the desired configuration. Large companies offer significantly smaller, but more expensive screens to offer analogue graphical visualization capabilities.

The development of the display wall can not be considered complete because interactive collaboration capabilities with display walls needed to be improved, layout must be improved according screen edges, as well as other improvements must be made.

13. **Further development of the runtime verification methods by building the ticket reservation system's runtime verification model.**

During the fourth stage of the research, the works started in the first three stages were continued, developing runtime verification protocols prototype and analyzing three practical applications. Different tasks of the economy, in which the approbation of the runtime verification was performed, have been deliberately chosen. These various examples of use serve as proof that low-resource runtime verification can be used to solve many real problems.

Within the framework of the study, a prototype of the runtime verification solution for the interbank clearing system was created.

The second runtime verification prototype was created for controlling the drones (RUAV - Rotor Unmanned Autonym Vehicle). As you know, flight control of program-driven autonomous equipment is necessary both for analyzing event-based events and for handling unforeseen events that can trigger emergency situations. There are a lot of different events that can cause emergency crashes. It is precisely in such situations that an external, easily configurable runtime event analysis mechanism, as developed in this study, is required.

The prototype of run-time verification for drones management was created within the ARTEMIS project R5-COP (Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems), Deliverable Number D34.42 "SIL-based Verification using on-line monitoring". The development of the drone software was carried out according to the following scheme. First, a drone mission model was created in the MATLAB / Simulink environment, defining a mission using the Extended Finite State Machine (EFSM) formalization. From this base model, using Simulink's latest features, program code was generated that could be transmitted to the drone memory. Before executing programs on a real drone, it was tested in simulation mode in the MATLAB / Simulink environment, in addition to visualizing the drone flight in virtual reality on the display screen. This allowed to check the operation of the drone control programs without risk of breaking the drone software due to errors.

The runtime verification component was added to the base process as a separate autonomous component that received flight event information from the base process. The steps in the implementation of the runtime verification process were tied to the steps of the underlying process and were executed independently of each other. This implementation mechanism allows you to check the compliance of the basic process with the verification description.

The Drone Flight Analysis in simulation mode confirmed the main findings described in the previous section. In addition, simplicity and transparency of the implementation of runtime verification process was shown. At the same time, the limitations of applying the proposed solution to real-time hardware and simulation model MATLAB / Simulink environment appeared..

The detailed study content can be found in the ARTEMIS project R5-COP (Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems) 2017.year report "Deliverable Number D34.42 SIL-based Verification using on-line monitoring".

The theater ticketing system was selected as the third prototype of the run-time verification process, with a run-time control component added. The chosen ticket distribution system has been used for many years in the New Riga Theater. The operation of the system has shown that correct distribution of tickets faces serious problems in situations of unforeseen people reactions or interruptions to the Internet connection occur. A solution to these problems, when the business process is influenced by events outside the information system, was searched in runtime verification.

In order to provide the necessary verification, the verification mechanism was supplemented by databases events verification agents, thus making sure the extension of the runtime verification mechanism. This ensured the validation of existing agent interfaces, and also enabled identification of potential database event logging problems. Basically, they relate to timely identification of changes in record data.

Any significant inconsistencies in the processes not detected during ticket sales verification. Since the payment of tickets and the shipment of purchased tickets are asynchronous, there may be situations when tickets are sent to the buyer with a certain delay in case of a large system load. In order to avoid confusion, the system owner has determined that the ticket must have been prepared and shipped within a maximum of five minutes. During the verification it was found that in most cases (98%) this condition is also observed.

14. Long term technological prognosis for R&D directions developed in the project (UL FC)

Prognosis can be found in [Projekts2_Prognoze] chapter 2.3.

Stage 4:

Scientific publications:

[SoSyM_SNIP] A.Kalnins, J.Barzdins. Metamodel Specialization for Graphical Language Support. To be published in the journal of "Software and System Modeling (SoSyM)" **(Scopus SNIP>1)**.

[LUMII_ViGiL] G. Barzdins, R. Liepins, P. F. Barzdins, D. Gosko. dBaby: Grounded Language Teaching through Games and Efficient Reinforcement Learning. NIPS 2017 Workshop on Visually-Grounded Interaction and Language (ViGIL), 2017, https://nips2017vigil.github.io/papers/2017/dBaby.pdf

[LUMII_SemEval] N. Gruzitis, D. Gosko, G. Barzdins RIGOTRIO at SemEval-2017 Task 9: Combining machine learning and grammar engineering for AMR parsing and generation Proceedings of the 11th International Workshop on Semantic Evaluation (SemEval), 2017 http://www.aclweb.org/anthology/S17-2159 (SCOPUS)

[LUMII_SUMMA] P. Paikens, G. Barzdins, A. Mendes, D. Ferreira, S. Broscheit, M. S. C. Almeida, S. Miranda, D. Nogueira, P. Balage, A. F. T. Martins SUMMA at TAC Knowledge Base Population Task 2016 Proceedings of the 9th Text Analysis Conference (TAC), 2017. https://tac.nist.gov/publications/2016/participant.papers/TAC2016.summa.proceedings.pdf

[RTU_1] Bartusevics, A., Lesovskis, A., Ponomarenko, V. Model-Driven Approach and Library of Reusable Source Code for Automation of IT Operations. Applied Computer Systems. Vol.21, 2017, pp.5-12. (indexed in ISI Web of Science)

[RTU_2] Novickis, L., Ponomarenko, V., Mitasiunas, A. Information Technology Transfer Model as a Bridge between Science and Business Sector". Procedia Computer Science, Vol.104, 2017, pp.120-126. (indexed in Scopus)

[RTU_3] Bartusevics, A. Novickis, L., Lesovskis, A. "An Approach for Development of Reusable Function Library for Automation of Continuous Processes", Procedia Computer Science, Vol.104, 2017, pp. 112-119. (indexed in Scopus)

[RTU_4] Bartusevics, A. Automation of Continuous Services: What Companies of Latvia Says about it?. Procedia Computer Science, Vol.104, 2017, pp.81-88. (indexed in Scopus)
[RTU_5] Ponomarenko, V., Novickis, L. A Review of Information Technology Transfer Process, Its Topicality, and Related Models. In: Rezekne Academy of Technologies. Rezekne: Rezekne Academy of Technologies, Vol. II, 2017, pp. 128.-132. (indexed in Scopus) (Ponomarenko_Novickis_2017a.pdf)
[RTU_6] Petrovica, S. Multi-level adaptation of an educational game to individual student's gameplay, knowledge and emotions. Proceedings of the 9th Annual International Conference on Education and New Learning Technologies, 2017, pp. 2220-2230. (to be indexed in ISI Web of Science)
[RTU_7] Pudane, M. Classification of Agent-Based Models from the Perspective of Multi-Agent Systems. Proceedings of the 5th IEEE Workshop on Advances in Information, Electronic and Electrical Engineering AIEEE'2017, Latvia, Riga, November 24.-25., 2017. (to be indexed in Scopus) (Pudane_2017a.pdf)
[RTU_8] Pudane, M. Affective Multi-Agent System for Simulating Mechanisms of Social Effects of Emotions. Proceedings of Seventh International Conference on Affective Computing and Intelligent Interaction Workshops and Demos, 2017, pp. 129-134. (to be indexed in Scopus) (Pudane_2017a.pdf)
[RTU_9]Ponomarenko V., Novickis L. Sustainable development and improvement of the Semantic Web Portal. International Journal of Computers, Volume 2, 2017, pp. 74–79. (Ponomarenko_Novickis_2017b.pdf)

Popular science publications:
[ps_pubRTU] Petrovica, S., Pudane, M., Anohina-Naumeca, A., Lavendelis E. Why Computer Systems Need Emotional Intelligence?. Innovation, Volume 1, 2017, pp. 20-21.
[ps_pub_LUMII_G] G.Bārzdiņš's interview in the newspaper's «Diena» appendix «SestDiena» 11.06.2017, https://www.diena.lv/raksts/sestdiena/intervijas/neuzskata-vairs-par-kertu-14174110
[ps_pub_LUMII_G] G.Bārzdiņš consulting the movie «Tas, ko viņi neredz» http://www.tvnet.lv/izklaide/kino/622295-noskaties_tokalova_filmas_tas_ko_vini_neredz_reklamas_rulliti

Other documents:
[RTU_TechReport] Lavendelis, E. Prototype of adaptive multi-agent system. Technical report, Riga Technical University, 2017.

Technological prognosis:
[Projekts2_Prognoze] „SOPHIS" 2nd project „ Ontology-based knowledge engineering technologies suitable for web environment" Long□term technological prognosis for R&D directions developed in the project: http://www.edi.lv/media/uploads/UserFiles/VPP_2pr_tehnologiska_prognozeF.pdf

Doctoral Thesis:
[phd_LUMII_Rikacovs] Sergejs Rikačovs (advisor prof. Jānis Bārzdiņš) dissertation (planned to submit in 2018)

[phD_LUMII_Paikens] Pēteris Paikens, "RĪKU KOPA LATVIEŠU VALODAS SEMANTIKAS ANALĪZEI" // "Toolset for semantic analysis of Latvian language" Defended at UL Promotion Council, December 2017, Scientific supervisor: G.Bārzdiņš

[phD_LUMII_Locans] Uldis Locāns, "Future Processor Hardware Architectures for the Benet of Precise Particle Accelerator Modeling" Defended at UL Promotion Council, October 2017, Scientific supervisor: G.Bārzdiņš

Master Thesis:

[LUMII_Dorbe] Nauris Dorbe, "BEZPILOTU MAŠĪNU APMĀCĪBA IZMANTOJOT STIMULĒTĀS MĀCĪŠANĀS MĀKSLĪGOS DZIĻOS NEIRONU TĪKLUS KOOPERATĪVĀS BRAUKŠANAS SISTĒMĀ" // Driverless cars tuition using reinforcement learning deep neural networks within cooperate driving system. (Advisor: prof. Guntis Bārzdiņš. Defended at UL FC 06.2017)

[DF_Baiza] Ilga Baiža Prioritāšu mehānisma izmantošana analītisko algoritmu testēšanā. // Priorities in debugging for analytic algorithms (Advisor: prof. Jānis Bičevskis. Defended at UL FC 06.2017)

[DF_Semjonova] Agnese Semjonova Integrācijas testēšanas efektivitātes uzlabošanas vadlīniju izstrāde // Development of Guidelines for Integration Testing Efficiency Improvement. (Advisor: prof. Jānis Bičevskis. Defended at UL FC 06.2017)

[RTU-Rocque] Swathi Christina Rocque. Atbalsts MVU pārejai no tradicionālajām uz mākoņpakalpojumu URP.// Towards Supporting Switching from Traditional System to Cloud ERP for SME Model (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 01.2017)

[RTU-Stepanova] Elza Stepanova. Nepārtrauktas prasību inženierijas metode mobilo lietotņu izstrādei.// Continuous Requirements Engineering Method for Mobile Application Development Model (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 02.2017)

[RTU-Ivanova]Anna Ivanova. Prasību inženierija programmizstrādē ar spējo metodi Scrum.// Requirements Engineering in Agile Scrum Software Development Model (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 06.2017)

[RTU-Bucena] Ineta Būcena. DevOps ieviešanas iespējas mazām izstrādes grupām.// DevOps Adoption for Very Small Entities (Zinātniskā vadītāja prof. M. Kirikova. (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 06.2017)

[RTU-Moncada] Idania Lizbeth Rodriguez Moncada. Mācību analītika prasmju attīstīšanas atbalstam.// Learning analytics for skill development support (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 06.2017)

[RTU-Purmalietis] Kaspars Purmalietis. Nepārtraukta prasību inženierija iesācējuzņēmumos.// Continuous Requirements Engineering for Start-Ups (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 06.2017)

[RTU-Pavlovs] Vitālijs Pavlovs. Grafu algoritmu izmantošana informācijas plūsmu analīzē.// Information Flow Analysis Using Graph Algorithms (Advisor: prof. M. Kirikova. Defended at FCSIT RTU 01.2017)

[RTU-Naveez] Muhammad Naveez. Audzēja un imunitātes savstarpējo mijiedarbību izskaidrojoša tīkla rekonstrukcija sporādiska kolorektālā vēža audzēja invazīvajā frontē.// Reconstruction of a network accounting for the tumor immunity interaction in the invasive front of sporadic colorectal cancer tumors (Advisor: prof. J. Grundspeņķis. Defended at FCSIT RTU 06.2017)

[RTU-Stasko] Arnis Staško. Daudzaģentu sistēmas politiski nozīmīgu personu noteikšanai izstrāde.// Multi-agent System Development for Identification of Politically Exposed Persons (Advisor: prof. J. Grundspeņķis. Defended at FCSIT RTU 06.2017)

[RTU-Patel] Himanshu Prakashbhai Patel.Daudzaģentu sistēmu efektīvas projektēšanas metodoloģiju novērtēšana.// Evaluation of methodologies for efficent multi agent system projects (Advisor: prof. J. Grundspeņķis. Defended at FCSIT RTU 06.2017)

[RTU-Gao] Siyuan Gao. Izkliedēta mākslīgā intelekta realizācijas metožu analīze un novērtēšana.// Analysis and evaluation of methods for implementation of distributed artificial intelligence (Advisor: prof. J. Grundspeņķis. Defended at FCSIT RTU 06.2017)

[RTU-Vasilevska] Alīna Vasiļevska. Skaitļošanas intelekta paradigmu lietojums intelektuālo aģentu vadības mehānisma izstrādei.// Application of Computational Intelligence Paradigms in the Development of Intelligent Agent Control Mechanism (Advisor: prof. J. Grundspeņķis. Defended at FCSIT RTU 06.2017)

2.2.4. Further research and practical exploitation of the results

(Describe further research activities that are planned, describe possibilities to practically exploit results)

One approach to cover deep querying with nontrivial calculations is studded in the given project – Self-service ad-hoc querying using controlled natural language. This is an important step towards solving of the above mentioned problem. But the problems remains – how to make this query language more convenient for domain experts. One way how to do this, is to replace a "controlled natural language" with a simply "natural language" (i.e. without "controlled"). Until recent time it was not clear how to do this, although in the field of natural language processing there appear some useful techniques for processing unstructured natural language texts (e.g. sentence segmentation, tokenization, part of speech tagging, noun phrase chunking etc.) that could be exploited in the process of developing the query language for specialized domains. But it was insufficient for a general solution of this problem. The problem is that queries in a natural language were not formally understandable (in the sense of semantics). But methods of deep machine learning provide such techniques. It is necessary to have a big enough corpus of queries in natural language. Since there is a hope that by means of deep machine learning it will be possible to "learn" the semantic of a natural language, there is also a hope that it will be possible to understand precisely the queries in a natural language which contain subordinate clauses with relevant conditions of a query.

In this project we studied ontology-based and deep-learning methods for natural language semantics extraction. This has led to further insights resulting in visually grounded language learning concept as the most promising further research direction, described our paper: G.Barzdins et.al. dBaby: Grounded Language Teaching through Games and Efficient Reinforcement Learning. In: Visually-Grounded Interaction and Language (ViGIL), NIPS 2017 Workshop. https://nips2017vigil.github.io

Currently EAF approach provides reusable library of automation functions, which could be used to apply different automation workflows. Machine learning could help to automate development and selection process of such functions. Currently, the user should have strong knowledge about problem domain to select needed functions from the library and this is the case where automation should be applied. Combination together with machine learning could automate function selection process and could produce ready to use workflow without mentioned knowledge as well it could be done much faster. Another trend could be an improvement of visual representation and touch screen technology.

Large display surfaces need advanced means of interaction to use their advantages fully. Touch-based devices like tablets, notebooks with touchscreens and even desktops with touchscreens are used to present and share information and interact with bigger presentation surfaces – projectors, monitor walls, etc., Technological limits in bandwidths, resolutions and other areas have reduced during the last years Nevertheless, the issues with large display surfaces remains. The most important problems are: 1) truly seamless tiled displays; 2) stereoscopic large high-resolution displays; 3) easily reconfigurable large high-resolution displays;4) high-performance cluster rendering; 5) scalability; 6) design and evaluate large high-resolution display groupware; 7) effective interaction techniques; 8) perceptually valid ways of presenting information on the large displays; 9) empirical evidence for the benefits of large high-resolution displays; 10) integrating large high-resolution displays into a seamless computing environment.

2.2.5. Dissemination and outreach activities

(Describe activities that were performed during reporting period to disseminate project results)

Researchers of the RTU FCSIT participated in the organization of the 2nd Workshop on Managed Complexity (ManComp2017) co-located with the 15th International Conference on Perspectives in Business Informatics Research (BIR 2016), Copenhagen, Denmark, August 28-30, 2017. Researchers of the IMCS UL took the first place in the Generation track of the SemEval-2017 workshop Task 9: Abstract Meaning Representation Parsing and Generation.

2.6.6 The spent financing by Project #2 (*euro)*

		Planned 2014.– 2017. g.	1st period	2nd period	3rd period	4th period	Sum
1000 – 9000	All expenses	806251	155792	190 536	149873	297165	806251
1000	**Salaries**	644470	114013	160284	124883	255742	654922
2000	**Goods and services** (2100+2200+2300)	161781	29655	25935	21221	38969	115780
2100	Travels	46363	8066	6484	7553	8126	30229
2200	Services	103436	21589	19436	13668	30843	85536
5000	**Assets**	0	12124	4317	3769	2454	22664

2.2.7. The resulting indicators of Project #2

Resulting indicator	Results						
	planned	Achieved					
	2014.– 2017.	Period					
		All	1st	2nd	3rd	4th	
Scientific results							
1. Number of scientific papers:	26	65	8	16	28	13	
1.1. Number of original papers (*SCOPUS*) (SNIP > 1)	4	2**	0	0	1	1	
1.2. Number of original papers included in databases IEEExplore, ACM DL, SCOPUS, Web of science	22	48	6	12	21	9	
1.3. number of peer-reviewed monographs	-	-	-	-	-	-	
1.4 number of other original research papers	-	15	2	4	6	3	
2. Number of defended theses:							
2.1. PhD theses	9	8***	1	3	2	2	
2.2. Master theses	22	38	6	1	16	15	
2.3. Bachelor theses	-	-	-	-	-	-	
3. Number of improved study courses	5	5	0	0	1	4	
4. Research							
4.1 Software prototypes	3	15	0	2	6	7	
4.2 Descriptions of methodologies	8	16	2	2	4	8	
4.3 Prototypes, technologies	-	1	-	-	1	-	
4.4 involvement in international projects	-	2	-	1	-	1	

Results of the programme outreach							
1. Interactive events of programme implementation and outreach of the results where target groups include also students, number:							
International conferences	14	20	0	3	9	8	
International seminars	0	4	-	1	1	2	
Organized seminars	9	9	1	3	2	3	
Popular science publications	3	3	0	0	0	3	
Exhibitions	-	-	-	-	-	-	
2 Long-term technology prognosis for the research and technology direction developed in frame of the programme: Biophotonics	1	1	0	0	0	1	
National economy-related indicators							
1. Private funding attracted to the scientific institution, including:							
1.1. Private co-funding for implementation of the programme projects							
1.2. Income from commercialization of IPR created in frame of the programme (expropriation of industrial property rights, licencing, awarding of exclusive or usage rights for reward)							
1.3. Income from contract research, based on programme-created results and know-how (EUR)	320000	1402545	197 500	1160000*	45 045		
1.4 Co-funding of research institutions from own resources for implementation of the programme (EUR):	10000	10000			9451	549	
2. Number of submitted, registered and active patents or breeds:							
In territory of Latvia							
Outside Latvia							
3. Number of new technologies, methods, prototypes or services created in frame of the programme and approbated in industry	6	**7**	0	2	0	5	
4. Number of implemented new technologies, methods, prototypes (contracts on IPR transfer)							
5. New spin-off created							
6. Earnings by scientific institutions from other research projects in synergy (EUR)	-	941417			891417	50000	

* The Horizon-2020 project "SUMMA" submission within H2020-ICT-16 BigData-research call is accepted and is being implemented from February 1st 2016 till January 31st 2019 by SIA ”LETA” with the participation of SOPHIS researchers.

** Missing papers (*SCOPUS*) (SNIP > 1) are compensated with 26 scientific papers indexed by IEEExplore, ACM DL, SCOPUS and Web of science databases..
*** PhD thesis of Sergejs Rikačovs (supervised by. prof. Jānis Bārzdiņš) will be submitted in 2018.

Leader of the project No.2. J.Bārzdiņš 01.2018
(signature and transcript) *(date)*

2.3.1. Project # 3

title	BIOPHOTONICS: imaging, diagnostics and monitoring	
PI:		
Name, surname	Jānis Spīgulis	
Scientific degree	Dr.habil.phys.	
Scientific institution	Institute of Atomic Physics and Spectroscopy, University of Latvia (IAPS UL)	
position	Professor, Head of Biophotonics Laboratory, IAPS	
contacts	*Phone*	29485347; 67228249
	E-mail	janis.spigulis@lu.lv

2. 3.2. Goals of the project and its main results.

1. To develop innovative technologies for capturing and processing of bio-object images. 6 imaging technologies have been developed or improved in the project.

2. To develop and approbate new, image-based methodologies of clinical diagnostics and monitoring. 6 clinical methodologies have been developed and clinically approbated in the project.

3. In collaboration with industrial partners, to approbate and implement the new developments in healthcare and related fields, to create basis for development of competitive products and services. The developed in project methods and technologies have been approbated and successfully implemented in clinical praxis of the Hospital of Traumatology and Orthopheadics and Latvian Oncology Centre of Riga Eastern University Hospital. Clinical studies have been performed also in the Laser Plastics Clinic and Dermatology Clinic of Prof. Janis Kisis.

2.3.3. Tasks of the 3rd project

The following tasks have been set at the project proposal:

1. To elaborate and approbate experimentally new imaging technologies:

1.1. Technology for obtaining several monochromatic spectral images from data of a single RGB image.

1.2. Video-imaging technology for non-contact monitoring of cardiovascular parameters at the near infrared spectral range.

1.3. Infrared imaging technology for quantitative estimation of tissue condition.

2. To develop methods, algorithms and programmes for operative and efficient processing of the obtained images, including calculations of the parametric maps.

3. To improve software of a prototype device for multimodal skin imaging, to approbate it clinically and to carry out technology transfer.

4. To develop new concepts, methods and technologies for non-contact, non-invasive and minimally invasive diagnostic imaging.

5. To approbate the developed methodologies, software and prototype devices pre-clinically in small groups of patients (20-50 persons).

To reach the goals, the following activities have been performed – see the table below where the achieved results are presented, too:

No.	Activity	Description	Result	The planned number	Achieved*
A1.	Research	A1.1. Studies aimed at development of new imaging technologies	New technologies for imaging of bio-objects	3	6
		A1.2. Processing of the bio-object images and diagnostic imaging	Software packages for implementation of the new technologies	3	4
		A1.3. Development of prototype devices for optical diagnostics and monitoring	New prototypes	3	4
			Improved prototype	1	1
A2.	Approbation and transfer of technologies	A2.1. Clinical approbation of prototypes and software	Clinically approbated prototypes with novel software	3	4
		A2.2. Technology transfer	Patent applications	4	4
A3.	Education	A3.1. Exploitation of the project results in study courses	Study courses with implemented project results	2	2
		A3.2. PhD Theses and Master projects	PhD Theses on project subject	2	2
			Master Theses on project subject	6	6
A4.	Publicity and technology forecast	A4.1. Conference reports	Reports at international conferences	7	26
		A4.2. Scientific publications	Internationally cited published papers	11	16
		A4.3. Science outreach	Science outreach events	4	4
		A4.4. Technology prognosis of the field	Prognosis for development of biophotonics	1	1

*) see the details below and in the Annex – scientific report and published papers

2.3.4. The achieved results of Project #3

The research activities and their results are described in details at the Annex documents of this report – see the attachment. Here we provide a shortened report on the main results only.

1.1. Altogether 6 innovative imaging technologies have been developed or improved:
New principle of spectral imaging – monochromatic imaging within a narrow (<1nm) spectral band at illumination only by discrete spectral lines – Annex, chapter 1
Obtaining of 3 monochromatic images by a single snapshot, under illumination by 3 laser spectral lines - Annex, chapter 1
The "double-snapshot" technology for obtaining 4-6 monochromatic images from data of two RGB images - Annex, chapter 1
PPGI – photoplethysmographic video-imaging at near-infrared and combined (NIR + green) illumination - Annex, chapter 2
Combined PPGI and thermal imaging (including the merge of both images in projection - Annex, chapter 2
Imaging technology for detection of counterfeit banknotes - Annex, chapter 1
1.2. Four new software programme packages have been developed:
For mapping of skin chromophore distribution using monochromatic spectral images captured under illumination by 3, 4 and 5 laser lines (algorithms in Annex, chapter 1)
For obtaining of photoplethysmographic images of improved quality (algorithms in Annex, chapter 2)
For monitoring of local anaesthesia efficiency during wrist surgery (algorithms in Annex, chapter 2)
For determination of skin optical parameters in the near infrared spectral range (algorithms in Annex, chapter 3, and reports of the 2nd and 3rd periods of the project)
1.3. One prototype device was improved (*SkImager,* the improvements described at reports of the 1st and 2nd periods of the project)
1.4. 8 prototype devices with newly developed software were clinically approbated:
1) Smartphone with add-on illuminator by 3 laser lines for mapping of skin oxy-haemoglobin (HbO), deoxy-haemoglobin (Hb) and melanin (Mel) – Annex, chapter 1.
2) Illuminator by 4 laser lines with smartphone camera for mapping of skin HbO, Hb, Mel and bilirubin (Blr) – Annex, chapter 1.
3) Illuminator by 5 laser lines with CMOS camera for mapping of skin HbO, Hb, Mel and lipids – Annex, chapter 1.
4) Smartphone with 405 nm LED illuminator for imaging of skin tumour fluorescence – reference [4].
5) Compact (4x4x4 cm) PPGI device with NIR-LED illumination for skin perfusion mapping – Annex, chapter 2.
6) Specialized PPGI device with NIR and green LED illumination for anaesthesia control during wrist surgery – Annex, chapter 2.
7) PPGI camera fixed at the operation lamp – Annex, chapter 2.
8) NIR imaging/spectroscopy device for estimation of skin hydration – Annex, chapter 3 and reports of the 1st and 2nd periods.

1.5. Four patent applications were prepared and submitted:
LV 15106 B, 2016. – Method and device for mapping of skin chromophores under illumination by several spectral lines.
LV P-17-17, 2017. – Device for obtaining speckle-free images under illumination by scattered

laser light.
PCT/EP2017/063565, 2017. - Device for speckle-free imaging under laser illumination.
LV P-17-78, 2017. – Method for detection of coloured counterfeits.

1.6. The project results were exploited in two study courses at Faculty of Physics and Mathematics, University of Latvia:
Biophotonics, Master course, Fizi5094
Laser physics, Bachelor course, Fizi3034

1.7. Two PhD Theses on project topics have been defended - I.Saknīte (2015) and V.Lukinsone (2017).

1.8. Six Master projects 0n project topics have been defended – O.Ļašuka and J.Bauers (2015), R.Janovskis (2016), and I.Ošiņa, A.Dzērve and G.Tunēns (2017).

1.9. Results of the project were presented at 26 international conference reports (see the list by the end of Annex).

1.10. Results of the project were published in 16 papers at SCOPUS-cited editions, including 4 papers at journals with SNIP>1 (list by the end of Annex).

1.11. Four science outreach events – Researcher's Nights in September of years 2014, 2015, 2016 and 2017 – were organized at Institute of Atomic Physics and Spectroscopy with presentations of the project results.
1.12. Based on results of expert discussions at the project conference "Biophotonics Riga – 2017", technology prognosis on further development of biophotonics has been prepared.

To summarize, the planned goals and tasks of the project have been achieved and in some positions also surpassed. The original imaging technologies are approbated in laboratory and clinical environment; their applicability for non-contact mapping of skin pathology and microcirculation parameters has been confirmed. Results are significant for clinical diagnostics and monitoring, as objective quantitative information about the health state can be obtained in a patient-friendly manner. The scientific significance of results is determined by novelty of the developed technologies, confirmed by 4 patent applications, 16 international level publications and 26 conference reports presented at 10 countries worldwide. Results of the project are practically implemented at the Riga Hospital of Traumatology and Orthopaedics (remote control of anaesthesia efficiency during surgeries) and at Latvian Oncology Centre, RAKUS (non-contact diagnostics of skin tumours).

The spent financing by Project #3 (*euro)*

		Planned 2014.–2017. g.	1st period	2nd period	3rd period	4th period	Sum
1000 – 9000	All expenses	372870	66325	84419	82158	121 798	354700*
1000	**Salaries**	310739	39 206	71355	73858	49733	194946
2000	**Goods and services** (2100+2200+2300)	62131	12 178	13063	8300	34285	55648
2100	Travels	8500	5310	0	584	12940	18834
2200	Services	39091	6655	8442	7216	21345	43658
2300	Materials			4621	500	2727	7848
5000	**Assets**	0	0	0	0	35 051	35051

*The part of the Project no. 3 Biometric assignments were carried out and implemented within the framework of Project No.1. Task financing was transferred to Project No.1.

2.3.6. The resulting indicators of Project #3

Resulting indicator	Results						
	planned	achieved					
	2014.–2017.	period					
		All	1st	2nd	3rd	4th	
1. Number of scientific papers:	11	18	1	3	3	11	
1.1. Number of original papers (*SCOPUS*) (SNIP > 1)	4	4	0	1	0	2 + 1*	
1.2. Number of original papers included in databases IEEExplore, ACM DL, SCOPUS, Web of science	7	12	1	1	3	7	
1.3. number of peer-reviewed monographs	0	1	0	0	0	1	
1.4 number of other original research papers	0	1	0	1	0	0	
2. Number of defended theses:							
2.1. PhD theses	2	2	0	1	0	1	
2.2. Master theses	6	6	2	0	1	3	
2.3. Bachelor theses		4	2	0	0	2	
3. Number of improved study courses	2	2	0	0	1	1	
4. Research							
4.1 prototypes of programmes	3	4	0	0	1	3	
4.2 Descriptions of methodologies	3	3	3	0	0	0	
4.3 Prototypes, technologies	3	6	0	3	1	2	
4.4 involvement in international projects	0	1	0	0	1	0	

Results of the programme outreach							
1. Interactive events of programme implementation and outreach of the results where target groups include also students, number:							
conferences	7	26	5	5	6	10	
seminars	4	5	1	2	1	1	
Organized seminars	5	5	1	1	1	2	
Popular papers	4	4	0	0	2	2	
Exhibitions	2	2	0	1	1	0	
2 Long-term technology prognosis for the research and technology direction developed in frame of the programme: Biophotonics	1	1	0	0	0	1	
National economy-related indicators							
1. Private funding attracted to the scientific institution, including:							
1.1. Private co-funding for implementation of the programme projects	10 000	70 820	0	0	70 820	0	
1.2. Income from commercialization of IPR created in frame of the programme (expropriation of industrial property rights, licencing, awarding of exclusive or usage rights for reward)							
1.3. Income from contract research, based on programme-created results and know-how (EUR)	10 000	11 255	0	0	1755	9500	
1.4 Co-funding of research institutions from own resources for implementation of the programme (EUR):	12000	42593	0	16874	25719	0	
2. Number of submitted, registered and active patents or breeds:							
In territory of Latvia	2	3	0	1	0	2	
Outside Latvia	2	1**	0	0	0	1	
3. Number of new technologies, methods, prototypes or services created in frame of the programme and approbated in industry	3	4	1	0	3	0	
4. Number of implemented new technologies, methods, prototypes (contracts on IPR transfer)	2	2	0	0	0	2***	
5. New spin-off created	1****	0	0	0	0	0	
6. Earnings by the scientific	0	29376				29376	

institutions from other research projects in synergy (EUR)							

*) submitted in 2017

**) one more PCT application was planned, based on LV patent-2016, but due to misunderstandings the submission deadline was passed. Instead, one more LV patent application was submitted.

***) contracts on implementation of project results in HTO and LOC are prepared and agreed with partners, currently transferred to legal departments for final formulations.

****) Spin-off was planned to implement the 4 patented solutions, but 3 of them are still in the evaluation phase.

Leader of the project No.3. Jānis Spīgulis .01.2018.

(signature and transcript) *(date)*

2.4.1. Project No. 4

Title	Development of technologies for secure and reliable smart-city		
Project leader's name, surname	Ints Mednieks		
Degree	Dr.sc.comp.		
Institution	Institute of Electronics and Computer Science		
Position	Senior researcher		
Contacts	*Phone number*		+371 67558112
	E-mail		mednieks@edi.lv

2.4.2. Project goal and objectives
(Describe the project goals and objectives so that the achievements reported below could be placed in context and evaluated)

1. Provide centralized urban monitoring for security needs, based on the collection of data from video and other sensors located throughout the urban area, fast data transmission and efficient processing using high performance computing technology for the identification of specific security threats and generate warnings about them.

Project focused on processing video data collected in multiple points in the city and transmitted to the data centre for processing. A new WDM-PON transmission technology with all optical channel add-drop function was developed and approbated. Deep artificial neural networks were chosen as the basis for data processing methods. Two deep neural network-based methods were developed and implemented in software for video and other sensor data processing on HPC platform to target urban security problems. One of them was approbated in real-life conditions.

2. Advance the use of satellite or airborne remote sensing (RS) data for the control of emergency situations and dynamic monitoring of environment by transforming the information provided by remote sensors to the form of maps illustrating parameters characterizing an emergency or environment and their changes.

Three novel methods and algorithms were developed for processing of multispectral and hyperspectral RS data for land use monitoring. Software for simulation of flooding was developed and approbated.

3. Develop a mobile ultra-wideband (UWB) antenna array radar-based imaging technology for mapping urban underground infrastructure as well as for creation of advanced security systems working in conditions where the direct visibility is obstructed or impossible, including examining the possibility of wireless data transmission of radar images in the 60GHz range;

Security monitoring technology using UWB sensors was developed and approbated in real-life conditions.

4. Solving the bacteriological safety problems of city's water supply by creating a specialized control system.

Online control system for detection of bacteriological contamination in water supply system was developed and approbated.

2.3.3. Tasks of the 4th project

The following tasks have been set at the project proposal:

1. Development of the centralized monitoring approach for the city based on using the multi-sensor data acquisition points.
2. Development of highly efficient optical fiber transmission technology for transmission of high volume sensor data to processing centres.
3. Development signal processing techniques and algorithms for recognition of predefined scenarios of actions or events related with the security in the city; implementation of algorithms by solving inverse problems and adapting for use of high-performance computing (HPC).
4. Development of methods and algorithms for urban security monitoring based on RS data acquisition and processing; implementation of algorithms in HPC-oriented software.
5. Development of urban infrastructure security monitoring technologies using UWB sensors and solving inverse problems for localization of objects.
6. Development of the bacteriological quality control system for the city water supply network.
7. Transfer of the developed technologies and solutions to end users to facilitate their uptake by the national economy.

To reach the goals, the following activities have been performed – see the table below where the achieved results are presented, too:

No.	Activity	Description	Result	The planned number	Achieved (see the details in Annex – scientific report and published papers)
A1	Research and development	A1.1. Specification development of multi - sensor data acquisition points	Multi-sensor point specification (scientific report)	1	1
		A1.2. Development of new optical data transmission technology	A new optical communications technology	1	1
		A1.3. Development of video and other acquired data analysis methods and algorithms	New processing methods	2	2
			Software packages for implementation of methods	1	1
		A1.4. Development of remote sensing data processing methods for urban safety monitoring	New processing methods	2	3
			Software packages for implementation of methods	1	1
		A1.5. Development of the ultra-wideband technology and	A new ultra-wideband radar technology	1	1
			New mock-up devices	1	2

		UWB-based systems for security monitoring			
		A1.6. Development of the bacteriological quality control system for the city water supply network	New water supply control system	1	1
A2	Approval and transfer of technology	A2.1. Approval of prototype systems and software	Technology validated in companies	3	3
		A2.2. Technology transfer	Software package validated in companies	2	2
A3	Education	A3.1. Exploitation of results in study courses	Courses involving the use of project results	3	3
		A3.2. Doctoral and Master's thesis development	Doctoral theses on the project topics	5	4 (+ 3pre-defended)
			Master's thesis on the topics of the project	17	16
A4	Dissemination of results and long-term technological forecasting	A4.1. Conference reports	Reports in international conferences	12	28
		A4.2. Scientific publications	Publications in internationally quoted journals	21	36
		A4.3. Popularization of science in society	Science promotion events	7	7
		A4.3. Technological forecasting of smart cities' development	Technological forecasts	1	1

2.4.4. The achieved results of Project #4

Five research groups were formed for the execution of the project with the following research topics:

- EDI BIGDATA group developed methods and software for video and other sensor data processing to target urban security problems;
- EDI REMSENS group developed remote sensing data processing techniques for monitoring of the urban environment;
- EDI RADAR group developed ultra-wideband radar technology-based solutions for urban security systems' needs;
- RTU TI group of researchers developed optical networking solutions for smart cities data transmission;
- RTU BF team of researchers developed solutions for controlling the urban water supply systems.

The research activities and their results are described in details at the Appendix documents of this report (Appendix 4 and Appendixes 4.1…4.15)– see the attachment. Here we provide a shortened report on the main results.

EDI BIGDATA group:

1. Understanding deep learning and setting up High Performance Computing environment. Deep learning is recognized as the most suited method for video signal and other signal content analysis. The considered smart city data analysis is based on deep learning and further experimentation is mainly focused on investigation of artificial neural networks. High Performance Computing environment and deep learning frameworks are configured. It consists of configuration of the 12 EDI HPC servers with NVIDIA Tesla K40 graphic cards. Now servers run Ubuntu operating system and Caffe, Torch and Tensorflow deep learning frameworks.
2. Face identification in images. For exploration of unique object descriptors, the human facial images are processed, and deep learning neural networks trained. The trained deep neural network descriptor converts any image with face into feature vector which can be compared to another vector to find the class members. The descriptor is based on AlexNet artificial neural network ANN architecture and trained on COLOR-FERET image data set. Experiments shows that trained ANN finally achieves 94% accuracy on COLOR- FERET frontal image subset containing more than 100 classes in testing set. More detailed it is described in the paper: K. Sudars, "Face Recognition Face2vec Based on Deep Learning: Small Database Case". Automatic Control and Computer Science.
3. Object counting in videos. During the project, R.Kadikis has prepared draft of his PhD work "Efficient methods for detection and characterization of moving objects in video", pre-defended it, and is ready to receive PhD degree in the near future. Also, the work on video analysis is made and represented in a publication: R.Kadikis, "Recurrent neural network based virtual detection line" (the 10th International Conference on Machine Vision ICMV 2017, Vienna, Austria). The developed recurrent neural network counts objects crossing the line. To acquire labeled data for the moving object detector, two approaches were investigated. One of the approaches resulted in a method and an application for semi-automatic labeling. In this approach an algorithm performs fast but erroneous labeling. Then a human is presented with a GUI that allows convenient error correction. The second approach was based on the generation of synthetic data using game engine. Using this engine, a simplified environment with moving spheres was developed. This simulation will allow to generate a large amount of labeled data which in turn will allow to estimate if this approach of data generation is promising for more complex environments. The system is approbated under real-time conditions. It processes real-time surveillance videos for car counting. The developed system gathers statistics about car parking at the Turiba University. The system is successfully tested, and the technology is ready for usage in industry.
4. Efficient sensor data gathering. One of main results in the project in the field of efficient data acquisition is K. Ozols dissertation: K.Ozols, "Asynchronous Data Acquisition of Electroencephalogram Signals". K. Ozols has received a PhD degree from Riga Technical University. Other results are shown in 3 scientific papers.

EDI REMSENS group:

1. Theoretical studies in remote sensing data processing have provided the following new methods applicable to land use/ land cover classification in smart cities:
   1.1. The method for classification of data from different sources with different spatial resolution. It allows to perform fusion of sensor data within the Bayesian classifier and to combine several distributions in the design of the classifier. Obtained results have shown that it is possible to improve classification accuracy if the data fusion was used in the proposed way. In addition, classification accuracy was slightly improved when several distributions were combined in the design of the classifier.
   1.2. Two methods for selection of informative spectral bands for classification of hyperspectral images. Informativeness of spectral bands were considered on the basis of entropy of the band's image but correlation between images of spectral bands was used to avoid redundancy in the set of selected ones. Informativeness of the whole set of selected

bands was characterized by classification results of hyperspectral images using only data from bands included in the set. It was shown that one of the proposed methods provides for higher classification accuracy than methods known in scientific literature. During the project, J.Siņica-Siņavskis has prepared and pre-defended the draft PhD thesis on this topic. The paper on this topic: A.Lorencs, I.Mednieks, J.Sinica-Sinavskis. "*Selection of Informative Hyperspectral Band Subsets Based on Entropy and Correlation*" is prepared for publication in International Journal of Remote Sensing (minor revisions requested).

1.3. The approach based on fuzzy logic was proposed for classification of mixed pixels in satellite images. It was shown that this approach is promising as it allows to clean the training sets of supervised classifiers.

2. Problems faced when the vegetation mapping for smart cities from satellite images is to be implemented were assessed and practical tools for solving this task were developed.
3. Elevation models with high spatial resolution and precision were developed from LiDAR data and software allowing to simulate flooding situations on the basis of such models developed. This software was approbated in Adazi municipality and found useful for planning of new dams and providing informational services to inhabitants of the areas.

EDI RADAR group:

1. Short range ultra-wideband (UWB) radar technology advanced. Two new prototypes of sensors were developed:
   1.1. Miniature UWB radar sensor with shielded Bow-Tie type antennas.
   1.2. Universal UWB radar prototype for broad spectrum of applications. This prototype was approbated in real-life conditions at SIA "VPWash".
2. The following application tasks solved on the basis of UWB radar-based technology:
   2.1. Ice thickness measurement. Accuracy better than 98% obtained;
   2.2. Building material structure inspection;
   2.3. Remote life-sign detection (breathing, heartbeat, movement). The prototype device presented at the exhibition MINOX 2016. It can be used for:
   - medical purposes, e.g., in hospitals to remotely monitor the patient's or infant's respiratory rate during sleep,
   - security purposes, e.g., for detecting living persons or beings in the room or behind the wall,
   - rescue operations, e.g., searching for people in the rubble that are showing signs of life,
   - research work, e.g., for animal activity monitoring.

   2.4. Object detection, counting and tracking. Theoretical background of object detection and tracking in rooms was developed and experimental results obtained.

RTU TI group:

Activities of the team were related to the tasks related to studies on the different topologies of optical access networks and the choice of the most suitable topology for data transmission solutions in smart cities, as well as research on certain basic elements of the optical transmission systems and their characterizing parameters. From the analysis of network topologies, it was concluded that passive optical network transmission technology (PON), supplemented by wavelength division multiplexing (WDM), is the most suitable for metro and access network level, that corresponds to the scale of the urban network and provides a high degree of branching.

Consequently, the WDM-PON network was selected as the most appropriate technological solution for smart city data transmission, and further research was related to the analysis of various individual system components. Component research was addressed to the following tasks:

- development a nonlinearity coefficient measurement method to compare and find the most suitable optical fibers for the WDM-PON transmission system;

- creation of a multi-wavelength light source based on a parametric amplifier;
- study on the minimal channel spacing for the WDM-PON transmission system, taking into account the data rate per channel, the laser parameters and the system's spectral and energy efficiency;
- development of tunable add-drop multiplexer for connecting new end-users as well as expanding applications of optical access networks.

Main scientific results:

1. An improved fixed DWDM grid for separation of central frequencies of transmission channels has been developed, which allows to increase the spectral efficiency of the bandwidth used for transmission in WDM-PON solutions.
2. A multichannel light source that doubles the originally available wavelength range and is applicable in WDM-PON networks has been developed. It is based on a fiber optical parametric amplifier and its main elements are high-nonlinear fiber and two high-power pumping lasers. The light source model created as a result of the research makes it possible to double the initial number of 16 low-power laser spectral components to up to 32, by using the idle components created by four-wave-mixing nonlinear optical effect. Consequently, the efficiency of each laser increases twice. This is explained in more detail in the following article: *S.Olonkins "FOPA Pump Phase Modulation and Polarization Impact on Generation of Idler Components," accepted for publication in the journal Elektronika ir Electrotechnika, Vol.77, No.4, 2016, pp. 77-81, ISSN 1392-1215*, included in the SCOPUS database.
3. The measurement method of nonlinearity coefficient, based on the four-wave-mixing nonlinear optical effect, was experimentally tested. Such a measurement method can be used to evaluate the most important parameters of the optical fiber. Fiber attenuation and dispersion measurements are required to calculate the nonlinearity coefficient by using optical input and output power of optical fiber. Such an analysis of optical fiber parameters is needed to find the most suitable fiber for data transmission in WDM-PON optical transmission systems. This is explained in more detail in the publication: *I.Lavrinoviča "Evaluation of Effective Area and Nonlinearity Coefficient of Erbium-Ytterbium Doped Optical Fibers," published in full text conference proceedings: Progress in Electromagnetics Research Symposium (PIERS 2016): Proceedings, China, Shanghai, 8-11 August, 2016. Shanghai: The Electromagnetics Academy, 2016, pp.1-5. ISBN 78-1-934142-30-1* and presented in conference: *S.Spolitis "Different Optical Fiber Nonlinear Coefficient Experimental Measurements." Proceedings of 6th International Workshop on Fiber Optics in Access Networks (FOAN 2016), 4 p., Lisbon, Portugal, 2016.*
4. Developed WDM-PON access communication system with a completely optical channel add-drop module in optical line section, which provides solution for a transmission system expansion and/or branching and adding of new subscribers or services with passive (does not require power supply) optical elements without conversion from optical to electrical signal. Application of such a multiplexer is to add new subscribers to existing optical cable infrastructure as well as to expand the applicability of optical access networks, for example, by transmitting various sensor data. For this invention the Republic of Latvia patent application *No. P-17-20 "WDM-PON Transmission System with All Optical Channel Add-Drop Function"* has been filed.

Summary

From the results of the project the following should be highlighted:

1. Developed multi-channel light source has a high potential for use in WDM-PON access systems. In such systems each of end users need a light source with a certain wavelength. Accordingly, as the number of end-users increases, it is necessary to increase the number of light emitting sources. Respectively, transmission system maintenance becomes more complex because wavelength control of each light source must be carried out. In addition,

laser diodes and lasers has a certain lifetime after which their parameters did not match the initial technical specification provided by the manufacturer and must be replaced. Therefore, in the optical access networks which are characterized by the tree type branching topology very promising are light sources which allows to generate multiple wavelengths at the same time and each of them is further used for data transmission. RTU TI proposed solution allows amplifying the power of initial lasers light at the same time doubling the number of transmission channels. Therefore each light source efficiency is at least twice higher than in the traditional solution where each light source is used for transmitting one data signal;

2. The add/drop multiplexer is necessary to connect the sensors to the optical fiber infrastructure. This application is very topical in the context of smart cities because remote sensors and automated monitoring systems is one of the upcoming development directions that goes under Internet of Things (IoT) and Tactile Internet (TI) concepts. It will have a marked impact on business and society, introducing numerous new opportunities for emerging technology markets and the delivery of essential public services. That would make possible to provide such a services like remote control video surveillance systems, security systems, environment pollution monitoring systems, etc. in various locations where fiber infrastructure is available.

During the project: 14 master thesis defended (in the 4th period - 6), 10 scientific publications prepared, and the results reported at 3 conferences.

Future work directions

As a result of the research performed by RTU TI scientists a prototype of add/drop multiplexer has been created and tested in the laboratory environment. The future work would be to create optimized (size, performance, costs, etc.) component that could be tested and eventually applied in real working conditions.

RTU WRL group:

The main goal of the project was to develop monitoring and modeling tools, which could detect and recognize biological contamination in drinking water distribution system (DWDS). In other words, the technology, which was developed and adapted, was an early warning system (EWS), which consisted of various physical, chemical and biological sensors and methods, and detection algorithm, based on Mahalanobis distance method. Various tasks were set for four stages of the project to achieve this goal and were successfully fulfilled.

Work on the project started with an extensive literature review about the latest achievements in the field of on-line drinking water monitoring methods, tools and data analysis. The focus was on biological contamination detection specifically. The information obtained from various literature sources was analyzed, summarized and presented as a state-of-the-art at IWA 7th Eastern European Young Water Professionals Conference and published in conference proceedings as ”*Review on Existing and Emerging Biological Contamination Detection Tools for Drinking Water Distribution Systems.*” Microbial and general contamination event detection methods were discussed regarding possible applications in DWDS water quality monitoring.

Fluorescent staining and flow cytometric measurements (FCM) and adenosine-triphosphate (ATP) measurements were chosen as microbiological methods for system verification. Microbiological parameters were measured manually. However, it was particularly interesting to test these methods for different contamination scenarios that was never tested before. Novel ATP and FCM methods are advantageous over conventional biological methods for drinking water monitoring, since these are much faster and more accurate than cultivation-based methods. Testing and optimization of these methods were partially developed during this project and the results were published in the scientific journals. A scientific publication “*Behavior and stability of adenosine triphosphate (ATP) during chlorine disinfection*” about features of ATP measurements in the presence of chlorine was published in the top-ranked scientific journal in water field Water Research (SNIP=2.397). “*A pipeline for developing and testing staining protocols for flow*

cytometry, demonstrated with SYBR Green I and propidium iodide viability staining", describing various factors, which could influence method's outcome, was published in Journal of Microbiological Methods.

To develop and test the on-line monitoring system and contamination detection algorithms the pilot-scale DWDS was designed and built within the framework of this project. Hydraulic, biochemical and physical conditions in the pilot-scale system were similar to real DWDS and ensured the possibility to implement various contamination experiments. The system had two sampling points, where online physically-chemical sensors for temperature, pH, electrical conductivity, chloride ions, oxidation-reduction potential, total organic carbon, turbidity measurements were installed to monitor drinking water quality in real-time. Additionally, the system was equipped with electromagnetic flow meter and manometers to measure hydraulic parameters of the system. The data from the sensors was collected, processed and transferred to decision making – contamination detection algorithm which analyzes the data and indicates the quality of water. Contamination detection algorithm was based on cluster analysis principle and used the Mahalanobis distance model. The selection of the most reliable algorithm for contamination detection is described in the scientific publication "*On-line Drinking Water Contamination Event Detection Methods*" presented at the conference "11th International Scientific and Practical Conference Environment. Technology."

The pilot-scale DWDS equipped with on-line drinking water quality system was used for long-term drinking water quality monitoring and to simulate contamination events. Long-term drinking water quality monitoring was implemented to create the database with clear drinking water quality parameters changes, e.g., daily or seasonal changes. It was used afterward for contamination detection to distinguish contamination events from the baseline. To determine and set the baseline of clear drinking water, the data was collected during 7 months. Systematic and non-systematic drinking water quality parameters variations were detected with this approach, where temperature and electrical conductivity sensors demonstrated the most sensitive and reliable data. This approach could be defined as a high-resolution (1 minute resolution) on-line drinking water quality monitoring at the point of consumption, which has never been applied before nor in Latvia, neither in neighbor countries. While normally regular drinking water quality sampling in the distribution network is performed at the specified time, our data provides a real dynamic situation of drinking water quality. Up to now, more than 2 000 000 readings were recorded at the single point. Part of the results were presented at two international scientific conferences: RTU 57th International Scientific conference subsection "Heat, gas and water technologies" (Riga, Latvia)" and "IWA 8th Eastern European Young Water Professionals Conference (Gdansk, Poland)" and published as conference proceedings "*Long-Term Drinking Water Quality Monitoring in Drinking Water Supply Systems by On-Line Sensors*". Our results highlight a need for continuous online monitoring and reveal limitations of the existing monitoring system.

Actual long-term changes of microbial concentrations were measured with novel microorganisms determination methods, namely flow cytometric methods. The methods were used for total and viable bacteria enumeration at two locations in the Riga distribution system, and bacteria were measured weekly during one year. Seasonal changes were observed, and they were different in two locations in the network. Additional experiments were done to understand the reasons of bacterial regrowth in the network. The results of this study are particularly important as they demonstrate high potential of the method to be used for routine drinking water monitoring, and emphasize disadvantages of conventional methods used for biological analysis at water utilities worldwide. The scientific publication, based on long-term monitoring results, "*Identifying the underlying causes of biological instability in a full-scale drinking water supply system*" was submitted to Water Research journal. The results were also presented at IWA Specialist Conference Microbial Ecology and Water Engineering 2016, Copenhagen, Denmark 4-7 September 2016.

Another task for the current project was to develop and validate the contamination detection algorithm. To do that, monitoring of drinking water parameters' changes during various contamination events was done. Wastewater, surface water (river water), groundwater and E.coli

intrusion was simulated in the pilot-scale system in order to achieve this goal. Changes of physically-chemical parameters were monitored with the above-mentioned sensors, while biological quality was evaluated with flow cytometry and ATP measurements. Data analysis was performed with Mahalanobis distance algorithm. Specific "fingerprints" were obtained for each type of contamination. The "fingerprints" were different for all types of contamination and allowed to evaluate the effectiveness of different detection parameters and methods combinations. We found that the most specific "fingerprints" were obtained with both physically-chemical and biological methods. Two independent sets of experiments were accomplished – one to develop the system and other to validate it. In short, the simulation experiments were analyzed by comparing event detection probability and false alarm possibility, when measured with physically chemical sensors, and those combined with FCM/ATP/FCM+ATP. FCM and ATP were also evaluated separately. During the development period, the level of detection probability was 56-89% with false alarm rate of 5-6%. The results of experiments were summarized in scientific publication "*Detection of Drinking Water Contamination Event with Mahalanobis Distance Method, Using On-line Monitoring Sensors and Manual Measurements Data*" and submitted to journal Water Science and Technology: Water Supply. The results achieved during the verification period was more promising and reliable. Contamination detection probability with physically-chemical sensors and their combinations with FCM and/or ATP were 96% - 100% for groundwater, surface water or wastewater intrusion. However, relatively high false alarm rate was observed for wastewater: it was 30 – 54%. Interestingly, ATP used separately was the only method, which showed a high probability of E.coli detection, which was 93%. Therefore the combination of the methods proved to be an effective tool for rapid detection of unintentional contamination, but only ATP could be useful in case of the terrorist biological attack. However, detection algorithm still has a potential to improve in order to recognize the type of contamination automatically.

As the last activity, the approbation of the system in the real-scale DWDS was done. The on-line sensor system was installed in Liepaja city DWDS. This DWDS was interesting, because the network is supplied with water from different water sources. An additional goal during the approbation period was to test whether the DW monitoring system could recognize the water source the water was coming from at the certain monitoring point. The data from the system indicated two water source influence at that point, which corroborated the predictions of engineers from "Liepajas udens" ltd. The opinion of "Liepajas udens" on possible application of system/technology is summarized in Letter of comments. The evaluation of possible contamination event influence by using existing drinking water quality monitoring approach and the proposed technology was done by simulations with EPANET 2.0 software. The results showed that threat can be reduced to 2-50% of total number of consumers can by implementation of new technology.

The outcome of the project is the EWS technology, which was approved for long-term monitoring in the real DWDS and contamination detection. The main conclusions of the study are that physically-chemical sensors are effective enough for situations, when bacterial contamination risk exists due to a potential intrusion of the water with different parameters, which can happen due to system failure or pipe leakage, but the risk of intentional bacterial contamination is minimal. However, if the risk of bioterrorist attack is significant, novel biological methods should be applied.

The study course Watersupply (BŪK323) was improved with new lectures about drinking water safety and drinking water quality monitoring.

The set goals of the project were achieved and tasks were fulfilled with minor corrections. Significant results for the scientific community were obtained, described in 31 scientific paper and reported in 23 presentations. Developed technologies and software were approbated in real world conditions in external organizations, 6 technical solutions were patented.

2.4.6. The resulting indicators of Project #4

Resulting indicator	Results						
	planned	achieved					
	2014.–2017.	period					
		All	1st	2nd	3rd	4th	
1. Number of scientific papers:	22	39	2	4	16	18	
1.1. Number of original papers (*SCOPUS*) (SNIP > 1)	6	4[#]	0	0	1	1 + 2*	
1.2. Number of original papers included in databases IEEExplore, ACM DL, SCOPUS, Web of science	15	31	2	3	13	13	
1.3. number of peer-reviewed monographs	1	1	0	0	0	1	
1.4 number of other original research papers	0	3	0	1	2		
2. Number of defended theses:							
2.1. PhD theses	5	7	0	1	0	3 + 3**	
2.2. Master theses	17	17	0	7	4	5+1***	
3. Number of improved study courses	3	3	0	0	0	3	
4. Research							
4.1 prototypes of programmes	2	2	0	0	0	2	
4.2 Descriptions of methodologies	4	4	0	0	0	4	
4.3 Prototypes, technologies	4	5	0	0	0	5	
4.4 involvement in international projects		1	0	0	1	0	
Results of the programme outreach							
1. Interactive events of programme implementation and outreach of the results where target groups include also students, number:							
conferences	12	23	2	4	13	4	
seminars							
Organized seminars	7	7	1.25	2.25	1.25	2.25	
Popular papers	4	7	0	0	0	7	
Exhibitions		1	0	0	1	0	
2 Long-term technology prognosis for the research and technology direction developed in frame of the programme: Biophotonics	1	1	0	0	0	1	
National economy-related indicators							
1. Private funding attracted to the scientific institution, including:							
1.1. Private co-funding for implementation of the programme projects							

1.2. Income from commercialization of IPR created in frame of the programme (expropriation of industrial property rights, licencing, awarding of exclusive or usage rights for reward)							
1.3. Income from contract research, based on programme-created results and know-how (EUR)	10 000	30438	27438	3000	0	0	
1.4 Co-funding of research institutions from own resources for implementation of the programme (EUR):	174300	178668	16763	34730	108187	70481	
2. Number of submitted, registered and active patents or breeds:							
In territory of Latvia	6	6	0	2	0	4	
Outside Latvia	0	0	0	0	0	0	
3. Number of new technologies, methods, prototypes or services created in frame of the programme and approbated in industry	3	3	0	0	0	3	
4. Number of implemented new technologies, methods, prototypes (contracts on IPR transfer)	0	0	0	0	0	0	
5. New spin-off created	0	0	0	0	0	0	
6. Earnings by scientific institutions from other research projects in synergy (EUR)	0	977 042				977 042	

#) Missing papers (*SCOPUS*) (SNIP > 1) are compensated with 16 scientific papers indexed by IEEExplore, ACM DL, SCOPUS and Web of science databases

*) submitted in 2017

**) 3 doctoral theses pre-defended (recommended for submission by organization)

***) 1 master thesis be defended in 2018.

The spent financing by Project #4 (*euro)*

		Planned 2014.–2017. g.	1st period	2nd period	3rd period	4th period	Sum
1000 – 9000	**TOTAL COSTS**	624253	122698	147527	140498	213530	624253
1000	**Salaries**	510769	102010	129185	118850	178317	513362
2000	**Goods and services** (2100+2200)	113484	21239	18342	15999	27626	83206
12100	Travels	26150	4349	1734	3331	2809	12223
2200	Services	56754	16890	16608	11604	22853	67955

5000	**Assets**	0	0	6398	0	**0**	6398

Leader of the project No.4. I. Mednieks 31.01.2018
(signature and transcript) *(date)*

PART 3: INFORMATION ABOUT PROGRAM FINANCE

The short information about the use of program finance

The total planned funding for the whole programme 2 250 000 EUR.

Use of the funding:

		1. period	2. period	3. period	4. period
1000–9000*	**TOTAL COSTS**	429704	533160	480473	806663
1000	**Personal costs**	277274	448148	382711	630511
2000	**Consumables and services, Travel costs (**2100+2200)	73081	62172	60460	128332
2100	Travel costs	31719	17333	15468	32816
2200	Consumables and services	53326	53891	43428	93552
5000	**Fixed assets**	13574	10715	3769	37505

Leader of the programme M.Greitāns 31.01.2018.
(signature and transcript) *(date)*