Arvutisüsteemide instituut

2020. aasta teadus- ja arendustegevuse aruanne

Arvutisüsteemide instituut

Department of Computer Systems

Margus Kruus, margus.kruus@taltech.ee

<u>Instituudis tegutsevad järgmised uurimisrühmad:</u>

- Usaldusväärsete arvutisüsteemide keskus
- Biorobootika keskus
- Arukate süsteemide keskus
- Riistvara turvalisuse keskus
- Nutika riistvara uurimiskeskus
- Sardtehisintellekti labor

<u>The Department conducts research within 6 research groups:</u>

- Centre of Dependable Computing Systems
- Centre for Biorobotics
- Centre for Intelligent Systems
- Centre for Hardware Security
- Smart Hardware Research Center
- Embedded AI Research Lab

Teadus- ja arendustegevuse ülevaade uurimisrühmade lõikes

Centre for Dependable Computing Systems

Head of the centre: Jaan Raik, professor, +372 6202257, jaan.raik@taltech.ee

Academic staff: Jaan Raik, professor, Peeter Ellervee, professor, Maksim Jenihhin, professor, Gert Jervan, professor, Thomas Hollstein, adjunct professor, Masoud Daneshtalab, adjunct professor, Raimund-Johannes Ubar, professor emeritus, Aleksander Sudnitsõn, associate professor, Kalle Tammemäe, associate professor, Tara Ghasempouri, senior researcher, Behrad Niazmand, 0.1 researcher, Lembit Jürimägi, lecturer,
PhD students: Karl Janson, PhD student-junior researcher, Madis Kerner, PhD student-junior researcher, Xinhui Lai, PhD student-junior researcher, Adeboye Stephen Oyeniran, PhD student-junior researcher, Lauri Vihman, PhD student-junior researcher, Ameer Shalabi, PhD student-junior researcher, Hardi Selg, PhD student-junior researcher, Mohammad Hasan Ahmadilivani, PhD student-junior researcher

Keywords:
Nanoelectronics design, reliability, security, verification and test; multi-/many-core systems.

Expertise:
The research at the Centre for Dependable Computing Systems covers a wide range of topics in the areas of design, reliability, security, verification and testing of nanoelectronic systems (including multi-/many-core systems). The main research activities in 2020 were the following:
• Hardware security (cooperation with Airbus, Frankfurt UAS, TU Delft, Intrinsic-ID, Riscure);
• Embedded artificial intelligence architectures (Mälardalen University);
• Cross-layer resilience in sensor networks (cooperation: Testonica Lab OÜ);
• Verification (assertion mining) (cooperation: EPFL/Lausanne, TU Hamburg, DLR, University of California Irvine);
• Diagnostic test generation and microprocessor testing (cooperation: Politecnico di Torino);
• Multi-aspect verification of computing systems (cooperation: iROC Technologies);
• Study of aging and rejuvenation in nanometer technologies (cooperation: TU Delft, Politecnico di Torino and PUCRS, Brazil);
• Optimisation of fault injection campaigns (cooperation: Cadence);

Most significant projects:
- VFP17093 "RESCUE ETN - Interdependent Challenges of Reliability, Security and Quality in Nanoelectronic Systems Design", 2017-2022
- VFP20015 "Secure and Assured Hardware: Facilitating ESTonia's Digital Society", 2021-2023
- TAR16013 "Estonian Centre of Excellence in ICT Research", 2016-2023
- AR20013IA "Real-time building performance audit", 2021-2023

Most significant publications:

- Kerner, Madis; Tammemäe, Kalle; Raik, Jaan; Hollstein, Thomas (2021). Triple Fixed-Point MAC Unit for Deep Learning. *Design Automation and Test in Europe Conference (DATE)*. IEEE.

- Jürimägi, Lembit; Ubar, Raimund; Jenihhin, Maksim; Raik, Jaan (2020). Calculation of Probabilistic Testability Measures for Digital Circuits with Structurally Synthesized BDDs. *Microprocessors and Microsystems*, 77, 1−12.

- Oyeniran, Adeboye Stephen; Ubar, Raimund; Jenihhin, Maksim; Raik, Jaan (2020). High-Level Implementation-Independent Functional Software-Based Self-Test for RISC Processors. *Journal of Electronic Testing*. DOI: 10.1007/s10836-020-05856-7.

The centre has been the initiator of several pan-European actions. Currently it coordinates the Horizon2020 Marie Skłodowska Curie ITN RESCUE project and is contributing to a newly launched Horizon2020 Twinning Action SAFEST. We are also partners in the national ICT centre of research excellence EXCITE.

In 2020, the centre organized a prestigious research conference IEEE European Test Symposium. Due to the COVID pandemic the conference took place virtually. However, the 25th anniversary event was a huge success with a record number of participants and ten international companies sponsoring it.

The research group published more than 40 research papers and 2 PhD theses were defended by its members during 2020.

The research of the center is related to the following Academic Development Plan priority directions:
- Dependable IT solutions (with the head of the center, Prof. J. Raik leading the Coordination Board);
- Smart and energy-efficient environments.

The activities of the research group are related to the following research areas:
- 2. Engineering and technology, 2.2 Electrical engineering, electronic engineering, information engineering;
- 1. Natural Sciences, 1.2 Computer and information sciences.

The most significant awards for the research group members in 2020:
- Lembit Jürimägi, ITC / IEEE TTTC G.W. Gordon Student Service Award;
- Madis Kerner, HiPEAC Paper Award.

Usaldusväärsete arvutisüsteemide keskus

Keskuse juht: tenuuriprofessor Jaan Raik, jaan.raik@taltech.ee

Akadeemiline personal: Jaan Raik, tenuuriprofessor, Peeter Ellervee, tenuuriprofessor, Maksim Jenihhin, tenuuriprofessor, Gert Jervan, tenuuriprofessor, Thomas Hollstein, kaasatud professor, Masoud Daneshtalab, kaasatud professor, Raimund-Johannes Ubar, emeriitprofessor, Aleksander Sudnitsõn, dotsent, Kalle Tammemäe, dotsent, Tara Ghasempouri, vanemteadur, Behrad Niazmand, 0,1 teadur, Lembit Jürimägi, lektor

Doktorandid: Karl Janson, doktorant-nooremteadur, Madis Kerner, doktorant-nooremteadur, Xinhui Lai, doktorant-nooremteadur, Adeboye Stephen Oyeniran, doktorant-nooremteadur, Lauri Vihman doktorant-nooremteadur, Ameer Shalabi, doktorant-nooremteadur, Hardi Selg, doktorant-nooremteadur, Mohammad Hasan Ahmadilivani, doktorant-nooremteadur

Võtmesõnad:

nanoelektroonika projekteerimine, töökindlus, turvalisus, verifitseerimine ja test; mitme-/paljutuumalised süsteemid.

Kompetentsid:

Usaldusväärsete arvutisüsteemide keskuse uurimistöö põhisuunad hõlmavad laia teemade ringi digitaalsüsteemide (k.a. mitme- ja paljutuumalised süsteemid) projekteerimise, usaldusväärsuse, turvalisuse, verifitseerimise ja testimise vallast. Peamised uurimissuunad aastal 2020 hõlmasid:

- Digitaaltehnoloogia vananemisprotsesside ja noorendamisstrateegiate uurimine (koostöö Delfti TÜ, Politecnico di Torino ja PUCRS, Brasiiliaga);
- Riistvara turve (koostöö: Airbus, Frankfurt UAS, Delfti TÜ, Intrinsic-ID, Riscure);
- Sardsüsteemide tehisinntellekti arhitektuurid (koostöö: Mälardaleni Ülikool, Tartu Ülikool);
- Kihiülene usaldusväärsus sensorvõrkudes (koostöö: Testonica Lab OÜ);
- Verifitseerimine (omaduste kaevandamine) (koostöö: EPFL/Lausanne, TU Hamburg, Saksa kosmosekeskus DLR, University of California Irvine);
- Diagnostiline testigenereerimine ja mikroprotsessorite test (koostöö: Politecnico di Torino);
- Küberfüüsikaliste süsteemide riistvara/tarkvara koossimuleerimine (koostöö: Saksa kosmosekeskus DLR)
- Arvutisüsteemide erinevate aspektide koosverifitseerimine (koostöö: iROC technologies);
- Rikkesisestusmeetodite optimiseerimine (koostöö: Cadence).

Olulisemad teadusprojektid:

- VFP17093 "RESCUE ETN - Nanoelektroonika süsteemide usaldusväärsuse, turvalisuse ja vastastikuses sõltuvuses olevad väljakutsed", 2017-2021
- VFP20015 "Turvaline ja kindel riistvara: Eesti digitaalse ühiskonna hüvanguks", 2021-2023
- TAR16013 "IT Tippkeskus EXCITE", 2016-2023
- AR20013IA "Hoone suutlikkuse audit reaalajas", 2021-2023

Olulisemad publikatsioonid:

- Kerner, Madis; Tammemäe, Kalle; Raik, Jaan; Hollstein, Thomas (2021). Triple Fixed-Point MAC Unit for Deep Learning. *Design Automation and Test in Europe Conference (DATE)*. IEEE.

- Jürimägi, Lembit; Ubar, Raimund; Jenihhin, Maksim; Raik, Jaan (2020). Calculation of Probabilistic Testability Measures for Digital Circuits with Structurally Synthesized BDDs. *Microprocessors and Microsystems*, 77, 1−12.

- Oyeniran, Adeboye Stephen; Ubar, Raimund; Jenihhin, Maksim; Raik, Jaan (2020). High-Level Implementation-Independent Functional Software-Based Self-Test for RISC Processors. *Journal of Electronic Testing*. DOI: 10.1007/s10836-020-05856-7.

Keskus on mitmete üle-Euroopaliste aktsioonide eestvedaja. Hetkel koordineerides Horisont2020 Marie Skłodowska Curie ITN projekti RESCUE ning panustades Horisont2020 Twining projekti SAFEST. Samuti ollakse partneriks Arvutisüsteemide instituudi poolt koordineeritavas teaduse tippkeskuses EXCITE.

2020. aastal korraldas keskus maineka teaduskonverentsi IEEE Euroopa testisümpoosion. COVID pandeemia tõttu toimus konverents virtuaalselt. Sellele vaatamata osutus 25. juubeliüritus edukaks – osales rekordarv delegaate ja konverentsi sponsoreerisid kümme rahvusvahelist tehnoloogiaettevõtet.

Aasta jooksul avaldati rohkem kui 40 teaduspublikatsiooni ning uurimisgrupis kaitsti edukalt 2 doktoritööd.

Keskuse töö on seotud järgmiste AAK prioriteetsete suundadega:
- Usaldusväärsed IT-lahendused (kusjuures keskuse juht, prof. J. Raik on nimetatud suuna Koordinatsiooni kogu juhiks);
- Targad ja energiatõhusad keskkonnad.

Uurimisrühma tegevuse on seotud järgmiste teadusvaldkondadega:
- 2. Tehnika ja tehnoloogia   2.2   Elektrotehnika, elektroonika, infotehnika;
- 1. Loodusteadused   1.2   Arvutiteadus ja informaatika.

Uurimisrühma olulised tunnustused aastal 2020:
-   Lembit Jürimägi, ITC/IEEE TTTC G.W. Gordon'i nimeline tudengist vabatahtliku preemia;
-   Madis Kerner, HiPEAC parima artikli preemia.

Centre for Biorobotics

1. **The Centre for Biorobotics** specializes in research and development of underwater technologies with a focus on underwater robotics inspired by biological principles, underwater sensing and sensor networks, and multiscale data-driven modelling.
2. Research group's overview:
   - **2.1. Name**: Centre for Biorobotics;
   - **2.2. Head of the centre**: Maarja Kruusmaa, Professor, (+3725183074, maarja.kruusmaa@taltech.ee);
   - **2.3.** List of members of the research group holding an academic position (by name), incl. separately:
     - **2.3.1. postdoctoral fellows**: Juri Gavšin, Margit Egerer, Asko Ristolainen, Gert Toming, Jeffrey A. Tuhtan, Laura Piho
     - **2.3.2. doctoral students:** Christian Meurer, Roza Gkliva, Mohamed Walid Remmas, Cecilia Monoli, Simon Pierre Godon, Lizaveta Miasayedava, Ali Hassan Khan, Michail Panteris, Konstantin Bilozor ja Jürgen Soom
     - **2.3.3. non-academic members:** Jaan Rebane, Andres Ernits, Kilian Ochs
   - **2.4. Keywords**: underwater robotics, underwater sensing, environmental monitoring
   - **2.5. Competences:** underwater robotics, robot locomotion in multi-phase environments, underwater sensing, experimental fluid mechanics, sensor networks for environmental monitoring

Most important projects (past 3 years):
- H2020 LakHsMI (Sensors for Large Scale Hydrodynamic Imaging) http://www.lakhsmi.eu
- Estonian Centre for Excellence in IT (EXCITE) http://excite.it.ee
- H2020 FitHydro (Fish Friendly Hydropower Technologies) http://www.fithydro.eu
- FLAG-ERA RoboCom++ (Rethinking Robot Companions of the Future) http://www.robocomplusplus.eu
- H2020 RISE ECOBOTICS.SEA (Bioinspired Technologies for Sustainable Marine Ecosystem)
- H2020 ROBOMINERS (Resilient Bio-inspired Modular Robotic Miners)
- MC RISE ECOBOTICS.SEA (International research and training project using robots to assess marine species biodiversity)
- COST DAMOCLESE (Understanding and Modeling Compound Climate and Weather Events)
- MC ITN RIBES (River Flow Regulation, Fish Behaviour and Status) https://www.msca-ribes.eu/
- DBU MeMo (Measuring and Modelling System for Downstream Migration)
- BMBF RETERO (Reducing animal testing to establish risk of injury to fish caused by passage through turbines by the use of robotic surrogates, computational fluid mechanics and predictive modeling) https://retero.org/
- EEA Grant Solutions for Natural and Constructed Shorelines
- Mama Mia Multi-scAle-Multi-Method Analysis of Mechanisms causing Ice Acceleration

Most important publications (past 3 years):
- Meurer, Christian; Fuentes-Perez, Juan Francisco; Schwarzwalder, Kordula; Ludvigsen, Martin; Sorensen, Asgeir Johan; Kruusmaa, Maarja (2020). 2D Estimation of Velocity Relative to Water and Tidal Currents Based on Differential Pressure for Autonomous

Underwater Vehicles. IEEE Robotics and Automation Letters, 5 (2), 3444−3451. DOI: 10.1109/LRA.2020.2976318.

- Fuentes-Pérez, J. F.; Silva, A. T.; Tuhtan, J. A; García-Vega, A.; Carbonell-Baeza, R.; Musall, M.; Kruusmaa, M. (2018). 3D modelling of non-uniform and turbulent flow in vertical slot fishways. Environmental Modelling Software, 99, 156−169. DOI: 10.1016/j.envsoft.2017.09.011.

- Simha, Ashutosh; Gkliva, Roza; Kotta, Ülle; Kruusmaa, Maarja (2020). A flapped paddle-fin for improving underwater propulsive efficiency of oscillatory actuation. IEEE Robotics and Automation Letters, 5 (2), 3176−3181. DOI: 10.1109/LRA.2020.2975747.

- Monea, M. C.; Loehr, D. K.; Meyer, C.; Preyl, V.; Xiao, J.; Steinmetz, H.; Schoenberger, H.; Drenkova-Tuhtan, A. (2020). Comparing the leaching behavior of phosphorus, aluminum and iron from post-precipitated tertiary sludge and anaerobically digested sewage sludge aiming at phosphorus recovery. Journal of Cleaner Production, 247, #119129. DOI: 10.1016/j.jclepro.2019.119129.

- Meurer, C.; Fuentes Perez, J. F.; Palomeras, N.; Carreras, M.; Kruusmaa, M. (2019). Differential Pressure Sensor Speedometer for AUV velocity estimation. IEEE Journal of Oceanic Engineering. DOI: 10.1109/JOE.2019.2907822.

- Fuentes-Pérez, J. F.; Meurer, C.; Tuhtan, J. A.; Kruusmaa, M. (2018). Differential Pressure Sensors for Underwater Speedometry in Variable Velocity and Acceleration Conditions. IEEE Journal of Oceanic Engineering, 43 (2), 418−426. DOI: 10.1109/JOE.2017.2767786.

- Costa, M. J.; Fuentes-Pérez, J. F.; Boavida, I.; Tuhtan, J. A.; Pinheiro, A. N. (2019). Fish Under Pressure: Examining Behavioural Responses of Iberian Barbel Under Simulated Hydropeaking with instream structures. PLoS ONE, 14 (1), #e0211115. DOI: 10.1371/journal.pone.0211115.

- Fuentes-Pérez, J. F.; Tuhtan, J. A.; Eckert, M.; Româo, F.; Ferreira, M. T.; Kruusmaa, M.; Branco, P. (2019). Hydraulics of vertical slot fishways: Non-uniform profiles. Journal of Hydraulic Engineering, 145 (2). DOI: 10.1061/(ASCE)HY.1943-7900.0001565.

- Ristolainen, Asko; Kalev, Kaia; Tuhtan, Jeffrey Andrew; Kuusik, Alar; Kruusmaa, Maarja (2018). Hydromorphological Classification Using Synchronous Pressure and Inertial Sensing. IEEE Transactions on Geoscience and Remote Sensing, 56 (6), 3222−3232. DOI: 10.1109/TGRS.2018.2795641.

- Ruiz-Legazpi, J.; Sanz-Ronda, F.J.; Bravo-Córdoba, F.J.; Fuentes-Pérez, J.F.; Castro-Santos, T. (2018). Influencia de factores ambientales y biométricos en la capacidad de nado del barbo ibérico (Luciobarbus bocagei Steindachner, 1864), un ciprínido potamódromo endémico de la Península Ibérica. Limnetica, 37 (2), 251−265. DOI: 10.23818/limn.37.21.

- Tuhtan, J.A.; Fuentes-Perez, J.F.; Toming, G.; Schneider, M.; Schwarzenberger, R.; Schletterer, M.; Kruusmaa, M. (2018). Man-made flows from a fish's perspective: autonomous classification of turbulent fishway flows with field data collected using an artificial lateral line. Bioinspiration Biomimetics, 13 (4), #046006. DOI: 10.1088/1748-3190/aabc79.

- Muhammad, N.; Fuentes-Perez, J. F.; Tuhtan, J. A.; Toming, G.; Musall, M.; Kruusmaa, M. (2018). Map-based localization and loop-closure detection from a moving underwater platform using flow features. Autonomous Robots, 1−16. DOI: 10.1007/s10514-018-9797-3.

- Pauwels, Ine S.; Baeyens, Raf; Toming, Gert; Schneider, Matthias; Buysse, David; Coeck, Johan; Tuhtan, Jeffrey A. (2020). Multi-Species Assessment of Injury, Mortality, and Physical Conditions during Downstream Passage through a Large Archimedes

- Hydrodynamic Screw (Albert Canal, Belgium). Sustainability, 12 (20), 8722. DOI: 10.3390/su12208722.
- Drenkova-Tuhtan, A. (2019). Phosphorus elimination and recovery from wastewater and process water with reusable nanocomposite magnetic particles. Vom Wasser, 117 (2, 33-32), 37−40.
- Monea, M. C.; Meyer, C.; Steinmetz, H.; Schönberger, H.; Drenkova–Tuhtan, A. (2020). Phosphorus recovery from sewage sludge – phosphorus leaching behavior from aluminum containing tertiary and anaerobically digested sludge. Water Science Technology, 82 (8), 1509−1522. DOI: 10.2166/wst.2020.414.
- Rott, E.; Nouri, M.; Meyer, C.; Minke, R.; Schneider, M.; Mandel, K.; Drenkova-Tuhtan, A. (2018). Removal of phosphonates from synthetic and industrial wastewater with reusable magnetic adsorbent particles. Water Research, 145, 608−617. DOI: 10.1016/j.watres.2018.08.067.
- Kruusmaa, M.; Gkliva, R.; Tuhtan, J. A.; Tuvikene, A.; Alfredsen, J. A. (2020). Salmon behavioural response to robots in an aquaculture sea cage. Royal Society Open Science, 7 (3), 1−14. DOI: 10.1098/rsos.191220.
- Alexander, Andreas; Kruusmaa, Maarja; Tuhtan, Jeffrey A.; Hodson, Andrew J.; Schuler, Thomas V.; Kääb, Andreas (2020). Pressure and inertia sensing drifters for glacial hydrology flow path measurements. The Cryosphere, 14 (3), 1009−1023. DOI: 10.5194/tc-14-1009-2020.
- Fuentes-Pérez, J. F.; Eckert, M.; Tuhtan, J. A.; Ferreira, M. T.; Kruusmaa, M.; Branco, P.; (2018). Spatial preferences of Iberian barbel in a vertical slot fishway under variable hydrodynamic scenarios. Ecological Engineering, 125, 131−142. DOI: 10.1016/j.ecoleng.2018.10.014.
- Tuhtan, Jeffrey A.; Nag, Saptarshi; Kruusmaa, Maarja (2020). Underwater bioinspired sensing: New opportunities to improve environmental monitoring. IEEE Instrumentation Measurement Magazine, 30−36. DOI: 10.1109/MIM.2020.9062685.
- Ristolainen, Asko; Tuhtan, Jeffrey A.; Kruusmaa, Maarja (2019). Continuous, near-bed current velocity estimation using pressure and inertial sensing. IEEE Sensors Journal, 1−1. DOI: 10.1109/JSEN.2019.2937954.

2.6. Outstanding (internationally recognized) research results of the research group for the past year.

- Kruusmaa, M.; Gkliva, R.; Tuhtan, J. A.; Tuvikene, A.; Alfredsen, J. A. (2020). Salmon behavioural response to robots in an aquaculture sea cage. Royal Society Open Science, 7 (3), 1−14. DOI: 10.1098/rsos.191220.
- Alexander, Andreas; Kruusmaa, Maarja; Tuhtan, Jeffrey A.; Hodson, Andrew J.; Schuler, Thomas V.; Kääb, Andreas (2020). Pressure and inertia sensing drifters for glacial hydrology flow path measurements. The Cryosphere, 14 (3), 1009−1023. DOI: 10.5194/tc-14-1009-2020.

3. Additional information:
   3.1. Affiliation of the research team to the TalTech Academic Development Plan priority areas (up to two major directions):
   - Valorization of natural resources

- Dependable IT solutions

3.2. Field of research activity of the research group
- 1.5 Earth and related Environmental sciences
- 2.2 Electrical engineering, Electronic engineering, Information engineering

3.3. Honours/awards of the research group members at national/international level for the past year.
- 2020, Asya Ivanova Drenkova-Tuhtan, Best Oral Presentation Award at IWA NRR2020 Nutrient Removal and Recovery Conference, organized by Aalto University, Finland, Helsinki Region Environmental Services (HSY) and the International Water Association (IWA).

3.4. Participation of the research group members in the activities of international R&D organizations, membership of foreign academies in 2020.
- Jeffrey Tuhtan: "Measurements and Observations in the XXIst Century" working group of the International Association of Hydrological Sciences. Special Session Organizer, RiverFlow 2020, Delft, Netherlands. International Scientific Committee Member, 13th International Symposium on Ecohydraulics. Topics Board Member of MDPI Sensors Journal (Q1 in "Instruments and Instrumentation)

3.5. Information on applied research and development activities of the research group:

3.5.1. applications in business, economics, society (references to projects, contracts, news, etc.);
- Featured on ERR news and Estonian Televsion frequently for popularization of our research projects. See for example: https://etv.err.ee/982096/uudishimu-tippkeskus

3.5.2. of ongoing projects/contracts (developed technology, innovative solutions and competencies) can be applied.
- Hydrocam underwater camera licensed throughout EU, Switzerland and Norway and installed in 8 countries.
- Barotrauma sensors for hydropower turbine passage have been deployed more than 2,000 times at more than 10 sites in Europe, 4 commerical projects scheduled for 2021

Biorobootika keskus

1. **Biorobootika keskus** on spetsialiseerunud veealuste tehnoloogiate arendusele ja teadustegevusele, täpsema fookusena bioloogiast inspireeritud printsiipide rakendamisele veealuses robootikas, veealustele anduritele ning andurvõrkudel ja multiskaala andmetega põhinevale modelleerimisele.
2. Uurimisrühma tutvustus:
   2.1. **Uurimisrühm**: Biorobootika keskus
   2.2. **Uurimisrühma** juht; Maarja Kruusmaa, Professor, (+3725183074, maarja.kruusmaa@taltech.ee);
   2.3. akadeemilisel ametikohal töötavate uurimisrühma liikmete loetelu (nimeliselt), sh eraldi:
      2.3.1. **järeldoktorid:** Juri Gavšin, Margit Egerer, Asko Ristolainen, Gert Toming, Jeffrey A. Tuhtan, Laura Piho
      2.3.2. **doktorandid:** Christian Meurer, Roza Gkliva, Mohamed Walid Remmas, Cecilia Monoli, Simon Pierre Godon, Lizaveta Miasayedava, Ali Hassan Khan, Michail Panteris, Konstantin Bilozor, and Jürgen Soom
      2.3.3. **mitteakadeemilisel liikmed:** Jaan Rebane, Andres Ernits, Kilian Ochs
   2.4. **Võtmesõnad:** allveerobootika, allveeandurid, keskkonna monitoorimine
   2.5. **Kompetentsid:** allveerobootika, robotite liikumine mitme-faasilistes keskkondades, allvee andurid, eksperimentaalne vedeliku dünaamika, andurvõrgud keskkonna monitoorimiseks

Olulisemad projektid (viimased 3 aastat)

- H2020 LakHsMI (Sensors for Large Scale Hydrodynamic Imaging) http://www.lakhsmi.eu
- Estonian Centre for Excellence in IT (EXCITE) http://excite.it.ee
- H2020 FitHydro (Fish Friendly Hydropower Technologies) http://www.fithydro.eu
- FLAG-ERA RoboCom++ (Rethinking Robot Companions of the Future) http://www.robocomplusplus.eu
- H2020 RISE ECOBOTICS.SEA (Bioinspired Technologies for Sustainable Marine Ecosystem)
- H2020 ROBOMINERS (Resilient Bio-inspired Modular Robotic Miners)
- MC RISE ECOBOTICS.SEA (International research and training project using robots to assess marine species biodiversity)
- COST DAMOCLESE (Understanding and Modeling Compound Climate and Weather Events)
- MC ITN RIBES (River Flow Regulation, Fish Behaviour and Status) https://www.msca-ribes.eu/
- DBU MeMo (Measuring and Modelling System for Downstream Migration)
- BMBF RETERO (Reducing animal testing to establish risk of injury to fish caused by passage through turbines by the use of robotic surrogates, computational fluid mechanics and predictive modeling) https://retero.org/
- EEA Grant Solutions for Natural and Constructed Shorelines
- Mama Mia Multi-scAle-Multi-Method Analysis of Mechanisms causing Ice Acceleration

Olulisemad artiklid (viimased 3 aastat)

- Meurer, Christian; Fuentes-Perez, Juan Francisco; Schwarzwalder, Kordula; Ludvigsen, Martin; Sorensen, Asgeir Johan; Kruusmaa, Maarja (2020). 2D Estimation of Velocity Relative to Water and Tidal Currents Based on Differential Pressure for Autonomous

Underwater Vehicles. IEEE Robotics and Automation Letters, 5 (2), 3444−3451. DOI: 10.1109/LRA.2020.2976318.

- Fuentes-Pérez, J. F.; Silva, A. T.; Tuhtan, J. A; García-Vega, A.; Carbonell-Baeza, R.; Musall, M.; Kruusmaa, M. (2018). 3D modelling of non-uniform and turbulent flow in vertical slot fishways. Environmental Modelling Software, 99, 156−169. DOI: 10.1016/j.envsoft.2017.09.011.

- Simha, Ashutosh; Gkliva, Roza; Kotta, Ülle; Kruusmaa, Maarja (2020). A flapped paddle-fin for improving underwater propulsive efficiency of oscillatory actuation. IEEE Robotics and Automation Letters, 5 (2), 3176−3181. DOI: 10.1109/LRA.2020.2975747.

- Monea, M. C.; Loehr, D. K.; Meyer, C.; Preyl, V.; Xiao, J.; Steinmetz, H.; Schoenberger, H.; Drenkova-Tuhtan, A. (2020). Comparing the leaching behavior of phosphorus, aluminum and iron from post-precipitated tertiary sludge and anaerobically digested sewage sludge aiming at phosphorus recovery. Journal of Cleaner Production, 247, #119129. DOI: 10.1016/j.jclepro.2019.119129.

- Meurer, C.; Fuentes Perez, J. F.; Palomeras, N.; Carreras, M.; Kruusmaa, M. (2019). Differential Pressure Sensor Speedometer for AUV velocity estimation. IEEE Journal of Oceanic Engineering. DOI: 10.1109/JOE.2019.2907822.

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2.6. Uurimisrühma lõppenud aasta rahvusvahelisel tasemel väljapaistvad teadustulemused.

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- Alexander, Andreas; Kruusmaa, Maarja; Tuhtan, Jeffrey A.; Hodson, Andrew J.; Schuler, Thomas V.; Kääb, Andreas (2020). Pressure and inertia sensing drifters for glacial hydrology flow path measurements. The Cryosphere, 14 (3), 1009−1023. DOI: 10.5194/tc-14-1009-2020.

3. Täiendav info:
   3.1. uurimisrühma seotus AAK prioriteetse suunaga (kuni kaks olulisemat suunda)
   - Keskkonnaressursside vääristamine
   - Usaldusväärsed IT lahendused

   3.2. uurimisrühma tegevusega seotud teadusvaldkond

- 1.5 Maateadused ja nendega seotud keskkonnateadused
- 2.2 Elektrotehnika, elektroonika, infotehnika

3.3. uurimisrühma liikmete rahvusvahelisel ja riiklikul tasemel olulised tunnustused lõppenud aastal;

- 2020, Asya Ivanova Drenkova-Tuhtan, Best Oral Presentation Award at IWA NRR2020 Nutrient Removal and Recovery Conference, organized by Aalto University, Finland, Helsinki Region Environmental Services (HSY) and the International Water Association (IWA).

3.4. uurimisrühma liikmete osalus välisriikide akadeemiate ja/või muude oluliste TA&I-ga seotud välisorganisatsioonide töös lõppenud aastal

- Jeffrey Tuhtan: "Measurements and Observations in the XXIst Century" working group of the International Association of Hydrological Sciences. Special Session Organizer, RiverFlow 2020, Delft, Netherlands. International Scientific Committee Member, 13th International Symposium on Ecohydraulics. Topics Board Member of MDPI Sensors Journal (Q1 in "Instruments and Instrumentation)

3.5. Info uurimisrühma rakendusliku väljundiga teadus- ja arendustegevuse kohta:

    3.5.1. uurimisrühma senised rakendused ettevõtluses, majanduses, ühiskonnas (kirjeldus ning viited projektidele, lepingutele, uudistele vms);

- Lugu ERR uudistes ning ERR muudes kanalites teadustöö esitlemine. Näide: https://etv.err.ee/982096/uudishimu-tippkeskus

    3.5.2. kus käimasolevate projektide/lepingute tulemusi (väljatöötatud tehnoloogiat, uudseid lahendusi ja kompetentse) saab rakendada.

- Hydrocam veealune kaamerasüsteem: litsentseeritud läbi EL, Šveitsi ja Norra, paigaldatud kaheksas riigis.
- Barotrauma andurid hüdroelektrijaamade turbiinide hindamiseks: kasutatud enam kui 2000 korral enam kui 10 asukohas Euroopas. 4 kommertsprojekti plaanitud 2021 aastaks.

Centre for Intelligent Systems

Head of the centre: professor Eduard Petlenkov, eduard.petlenkov@taltech.ee
Members: Kristina Vassiljeva, Aleksei Tepljakov, Kadri Umbleja, Ahmet Köse, Vitali Vansovitš
Doctoral students: Andrei Maalberg, Maksimilian Tarasevich, Saleh Ragheb Saleh Alsaleh, Abiodun Emmanuel Onile, Olutosin Ajibola Ademola, Hossein Alimohammadi, Vjatšeslav Škiparev

The Centre consists of two laboratories: Control Systems Research Laboratory and Virtual and Augmented Reality Laboratory.

Our core competences are:
- Modelling, control, and analysis of complex nonlinear dynamic systems;
- Computational Intelligence based algorithms: Artificial Neural Networks, Genetic Algorithms, Fuzzy Logic, etc.;
- Self-learning and adaptation methods in control systems;
- Fractional-order modelling and control;
- Distributed control systems;
- Data analysis;
- Development of research software;
- Virtual and Augmented Reality applications;
- Digital twins.

The research group focuses on development and implementation of novel efficient control techniques for Industry 4.0 applications based on the combination of classical industrial controllers with computational intelligence methods and knowledge based reasoning.

Key words: control, modelling of dynamic systems, computational intelligence, machine learning, adaptive and self-learning systems, extended reality, digital twins.

In 2020 the research group has published 20 research papers (8 articles 1.1 and 12 papers 3.1 according to ETIS classificator), participated in the following R&D projects:
- Intelligent Control Systems for Industry 4.0
- University Business Cooperation for Promoting Virtual, Augmented and Mixed Reality Applications within Small and Medium-sized Manufacturing Companies
- Energy flexilibilty service pilot project
- Automated machine learning and rule-based methods for fault detection of air handling units to increase their efficiency.
- Applied Research on Connecting Power Market Demand Response Service Platforms to Advanced Electric Power Consumables and Intelligent System Planning and Management.
- Fractional-order systems; analysis, synthesis and their importance for future design.
- Monte-Carlo analysis of the spreading rate of a virus as a function of human mobility and social distancing
- Applied research for creating a cost-effective interchangeable 3D spatial data infrastructure with survey-grade accuracy

Homepage: https://is-centre.eu/

Arukate süsteemide keskus

Keskuse juht: professor Eduard Petlenkov, eduard.petlenkov@taltech.ee
Liikmed: Kristina Vassiljeva, Aleksei Tepljakov, Kadri Umbleja, Ahmet Köse, Vitali Vansovitš
Doktorandid: Andrei Maalberg, Maksimilian Tarasevich, Saleh Ragheb Saleh Alsaleh, Abiodun Emmanuel Onile, Olutosin Ajibola Ademola, Hossein Alimohammadi, Vjatšeslav Škiparev

Keskus koosneb kahest teaduslaborist: Automaatjuhtimise teaduslaboratoorium ja Virtuaalse ja täiendatud reaalsuse laboratoorium.

Arukate süsteemide keskuse **põhikompetentsideks on:**
- Keeruliste dünaamiliste süsteemide modelleerimine ja juhtimine;
- Murrulistel tuletistel põhinevad mudelid ja juhtimisalgoritmid;
- Teadustarkvara arendus;
- Iseõppimise ja adapteerimise meetodid juhtimissüsteemides;
- Tehisintellekti meetodid - tehisnärvivõrgud, hägus loogika, geneetilised algoritmid;
- Hajusjuhtimissüsteemid;
- Andmeanalüüs;
- Virtuaal- ja liitreaalsuse rakendused;
- Digitaalsed kaksikud.

Uurimisgruppi põhifookuseks on uute efektiivsete juhtimismeetodite väljatöötamine ja realiseerimine uue põlvkonna tööstuse (Tööstus 4.0) rakendustes, uurimistöö baseerub klassikaliste tööstuskontrollerite integreerimisel teadmispõhiste meetoditega.

Võtmesõnad: juhtimissüsteemid, dünaamiliste süsteemide modelleerimine, tehisintellekti meetodid, masinõpe, adaptiivsed ja iseõppivad süsteemid, liitreaalsus, digitaalsed kaksikud.

Uurimisgrupp avaldas **2020.aastal** 20 teaduspublikatsiooni (8 ajakirjaartiklit - ja 12 artiklit konverentside kogumikes - 3.1 ETIS-e klassifikaatori järgi) ja osales järgmistes teadusprojektides:
- Arukad juhtimismeetodid Tööstus 4.0 jaoks
- Ülikoolide ja ettevõttete koostöövõrgustik virtuaalse-, täiendatud- ja liitreaalsuse edendamiseks väikestes ja keskmistes tootmisettevõtetes
- Energiatarbimise juhtimise paindlikkustoote pilootprojekt
- Murrulised süsteemid: analüüs, süntees ja nende tähtsus tuleviku disaini jaoks.
- Rakendusuuring elektrituru nõudlusele reageerimise teenusplatvormi intelligentse planeerimis- ja juhtimissüsteemi arendamiseks ning keerukate koduste elektriseadmetega ühendamiseks
- Masinõppel ja reeglipõhisel veatuvastusel põhinevad automaatsed meetodid ventilatsiooniseadmete efektiivsuse suurendamiseks
- Viiruse levimiskiiruse Monte-Carlo analüüs sõltuvuses inimeste mobiilsusest ja sotsiaalsest distantseerumisest
- Kuluefektiivse ühildatava geodeetilise täpsusega 3D ruumiandmete taristu loomise rakendusuuring

Veebileht: : https://is-centre.eu/

Centre for Hardware Security

Head of the centre: Professor Samuel Pagliarini, samuel.pagliarini@taltech.ee
Doctoral students: Antonio Felipe Costa de Almeida, Malik Imran, Tiago Diadami Perez, Zain Ul Abideen, Mohammad Eslami
Postdoctoral fellows: Mahdieh Grailoo, Levent Aksoy

The Centre for Hardware Security conducts research in all applied aspects of Hardware Security: our aim is to validate security techniques in real silicon. The Centre's research on integrated circuit (IC) design, electronic design automation (EDA), and cryptographic hardware enables trustworthy IC-based systems to be built. Threats such as Hardware Trojans, reverse engineering, circuit (de)obfuscation, IP piracy, IC overbuilding, side-channel attacks, etc., are addressed through an array of technical countermeasures.

Keywords: hardware security, trustworthy integrated circuits, ASICs, cryptohardware, circuit obfuscation

Core competences:
- Design of Application Specific Integrated Circuits
- Circuit obfuscation by design partitioning and locking
- Trustworthy electronic design automation tooling (from RTL to layout)
- Countermeasures to reverse engineering, side-channel attacks, and piracy
- Crypto hardware

Key achievements in 2020:
- H2020 Twinning project SAFEST funded for 0.9M, professor Pagliarini is the coordinator
- Reached second round (interview) of the ERC STG call. Interviews were not conducted due to the pandemic. Secured 150K from ETAg's ERC support scheme.
- Fabrication of two integrated circuits designed by students of the Centre
- Achieved "first silicon success" for our first ever fabricated integrated circuit
- High-level publications appearing in IEEE D&T, Trans. on Neural Networks and Learning Systems, Transactions on VLSI
- Best paper nomination at HOST 2020
- Closing keynote talk at ICR2020
- Organization of a special session on Hardware Security at the 25th IEEE European Test Symposium (ETS 2020)
- Submission of a US/EU patent on circuit obfuscation, pending review

Riistvara turvalisuse keskus

Keskuse juht: Samuel Nascimento Pagliarini, samuel.pagliarini@taltech.ee
Doktorandid: Antonio Felipe Costa de Almeida, Malik Imran, Tiago Diadami Perez, Zain Ul Abideen, Mohammad Eslami
Järeldoktorid: Mahdieh Grailoo, Levent Aksoy

Riistvara turvalisuse keskus viib läbi uuringuid kõigis riistvara turvalisuse rakenduslikes aspektides: meie eesmärk on turvalisuse valideerimise tehnikad reaalsetes ränikiipides. Keskuse uurimistöö integraalskeemide projekteerimise, elektroonilise projekteerimise automatiseerimise (EDA) ja krüptograafilise riistvara vallas võimaldab luua usaldusväärseid riistvarapõhiseid süsteeme. Ohud nagu riistvara troojalased, pöördprojekteerimine, integraalskeemi paigutuse hägustamine, IP-piraatlus, integraalskeemide ületootmine, külgkanali rünnakud jne lahendatakse mitmesuguste tehniliste vastumeetmete abil.

Võtmesõnad: riistvara turvalisus, usaldatavad kiibid, rakendusspetsiifilised integraallülitused, riistvara krüptomoodulid, integraallülituste hägustamise (obfuskeerimise) meetodid

Põhikompetentsid:
- Rakendusspetsiifiliste integraallülituste projekteerimine
- Integraalskeemi paigutuse hägustamine projekti tükeldamise teel (Split-Chip ja Split-Fab)
- Usaldusväärse elektroonilise projekteerimise automatiseerimise töövoog (alates RTL-ist kuni paigutuseni)
- Vastumeetmed pöördprojekteerimisele, külgkanali rünnakutele ja piraatlusele
- Krüpto-riistvara

Võtmetulemused 2020 aastal:

- SAFEST, H2020 Twinning projekt, mida rahastatakse 0,9 miljoni euro eest, koordinaator on professor Pagliarini;
- Jõuti ERC STG kõne teise vooru (intervjuu). Intervjuusid pandeemia tõttu ei korraldatud. Tagatud 150 000 ETAgi ERC tugiskeemist.
- Kahe integraalskeemi valmimine, mille on välja töötanud keskuse üliõpilased;
- Edukalt on valminud esimesed integraalskeemi ränikiibid;
- Kõrgetasemelised publikatsioonid ilmusid ajakirjas IEEE D&T, Trans. on Neural Networks and Learning Systems, Transactions on VLSI;
- Parim publikatsiooni kandidaat HOST 2020-l;
- ICR2020 lõpukõne lõpetamine;
- Riistvara turvalisuse eriseansi korraldamine 25th IEEE European Test Symposiumil (ETS 2020);
- USA/EL-i patendi esitamine integraalskeemi paigutuse hägustamise kohta, hetkel ülevaatuse ootel.

Smart Hardware Research Centre (SHARC)

Head of the centre: Artur Jutman, artur.jutman@taltech.ee
Members: Sergei Devadze, Anton Tšertov, Igor Aleksejev, Dmitri Mihhailov, Sergei Odintsov, Konstantin Shibin
Magistrant: Natalia Cherezova

Keywords: System Health Awareness, Self-Healing and Adaptation to Damage, Predictive Maintenance, Embedded Systems, Embedded Software, Test and Diagnostics, DFT, FDIR.

Research focus: cutting-edge industrial-grade approaches for self-health awareness, fault tolerance and quality assurance through the entire product life cycle of microelectronic systems.

Development focus: professional design of embedded systems from hardware to software.

Core competences:
- Designing with FPGA SoCs (Zynq, CycloneV SoC and others)
- Designing with soft-processors from Xilinx (Microblaze) and Intel (NIOS II)
- VHDL and Verilog hardware design languages
- Xilinx Vivado, Altera/Intel Quartus, Lattice Diamond, ModelSim, QuestaSim
- High-speed design with Multi-gigabit transceivers
- Implementation of high-speed serial interfaces such as PCIe, SATA, USB3.0
- Memory controllers: DDR2, DDR3, DDR4; Buses: AXI, Avalon, AXI-Lite
- Bare-metal applications, bootloaders, Linux drivers and Userspace applications
- Petalinux, Yocto, FreeRTOS and embedded SDKs, ELDK
- Instrumentation for test and troubleshooting
  - ChipScope, SignalTAP II, Reveal Analyzer, Quick Instruments
  - JTAG/Boundary Scan IEEE Std. 1149.1, IEEE Std. 1149.6, IEEE Std. 1687

Key achievements in R&D:
- TRL-4 demonstrator of fitness and fault management technology for microprocessors making them self health-aware, hence helping space electronics to maintain its fitness under pressure of cosmic radiation and to withstand a higher dose.
- TRL-6 embedded instrumentation technology for marginal defect detection and their impact measurement in high-speed electronics.
- Full stack design (hardware, drivers, software), test and delivery of processing, communication, and test equipment for large accelerators: CERN and ESS/ERIC

In 2020 the research group participated in the following R&D projects:
- PRG780 - CMS experiment for high luminosity operations through trigger improvements
  - Development of parallel processing algorithms for particle detection at CERN
- VFP17095 – TETRAMAX: Technology Transfer via Multinational Application Experiments
  - Integrity validation of the IC power delivery network – methodology and demonstrator
- AR20005 - Development contracts for the European Spallation Source - ESS
  - Implementation of an EtherCAT slave board and its software support
  - Implementation of FPGA IOC FMC Carrier Card and respective software

Nutika riistvara uurimiskeskus

Keskuse juht: Dr Artur Jutman, artur.jutman@taltech.ee
Members: Sergei Devadze, Anton Tšertov, Igor Aleksejev, Dmitri Mihhailov, Sergei Odintsov, Konstantin Shibin
Magistrant: Natalia Cherezova

Võtmesõnad: sardsüsteemid, eneseteadlikud elektroonikasüsteemid, isetervenev mikroelektroonika, ennustav hooldus, test ja diagnostika, testimise projekteerimine, FDIR.

Teadussuund: Elektroonikasüsteemide jaoks uusi veakindluse, eneseteadlikkuse ja kvaliteedi-kontrolli meetodite väljatöötamine ning tööstuslikul tasemel katseprototorüüpide loomine.

Arendussuund: sardsüsteemide professionaalne projekteerimine riistvarast kuni tarkvarani.

Põhikompetentsid:
- Projekteerimne FPGA SoCs (Zynq, CycloneV SoC jne.) jaoks
- Projekteerimne Xilinx (Microblaze) ja Intel (NIOS II) pehmete protsessortuumade abil
- VHDL ja Verilog riistvara kirjelduskeeled
- Xilinx Vivado, Altera/Intel Quartus, Lattice Diamond, ModelSim, QuestaSim
- Multi-gigabit kiirusega andmetöötlussüsteemide projekteerimine FPGA transiiveritel
- Kiirte jadaliideste realiseerimine, näiteks: PCIe, SATA, USB3.0
- Mälukontrollerid: DDR2, DDR3, DDR4; siinind: AXI, Avalon, AXI-Lite
- Paljasmetalli rakendused, buudilaadurid, Linux draiverid ja Userspace rakendused
- Petalinux, Yocto, FreeRTOS ja embedded SDK, ELDK
- Testi ja tõrkeotsingu instrumendid
    - ChipScope, SignalTAP II, Reveal Analyzer, Quick Instruments
    - JTAG/Boundary Scan IEEE Std. 1149.1, IEEE Std. 1149.6, IEEE Std. 1687

T&A võtmetulemused:
- TRL-4 tasemel enesetervise ja rikete haldamise tehnoloogia demonstraator mikroprotsessorite jaoks nende eneseteadlikkuse põhikomponendina, mis annab võimaluse nt. kosmoseelektroonikal säilitada töövõimekust kosmosekiirguse all.
- TRL-6 tasemel sardinstrumentide tehnoloogia marginaalsete defektide tuvastamiseks ja nende mõju mõõtmiseks kõrgekiiruselisele digielektroonikale.
- Suurte kiirendite jaoks (CERN ja ESS/ERIC) juht-, andmetöötlus-, testimis- ja kommunikatsiooni lahenduste projekteerimine (riistvara, draiverid, tarkvara) ja tarne.

Aastal 2020 osales teadusrühm järgmistes teadus- ja arendusprojektides:
- PRG780 - CMS eksperimendi ettevalmistamine kõrge heledusega tööperioodil läbi triggeri uuenduste (CERN)
    - Paralleeltöötlus algoritmide arendamine elemetaarosakeste tuvastamiseks
- VFP17095 - Tehnoloogiasiire läbi rahvusvaheliste eksperimentide
    - IC toiteahelate kvaliteedi määramise metodoloogia ja vastav demolahendus
- AR20005 - ESSource „Euroopa NeutronkiirguseAllikas"– arendusprojektid ESS kiirendi jaoks
    - EtherCAT slave kaardi ning tarkvaralise lahenduse projekteerimine
    - FPGA IOC FMC Carrier Card riistvara ja tarkvara projekteerimine

Embedded AI Research Lab

Head of the lab: Mairo Leier, mairo.leier@taltech.ee
Members: Uljana Reinsalu, Karl Janson, Jürgen Soom, Olutosin Ajibola Ademola, Priit Ruberg

The Embedded AI Research Lab focuses on developing and optimizing machine learning solutions for the embedded systems. The laboratory collaborates internationally with research teams and companies from the maritime, smart city, autonomous vehicles, and industrial automation sectors. Focus is on maritime and mobility solutions.

Core competencies:

- embedded hardware design and prototyping,
- machine learning model optimization for embedded hardware,
- hardware accelerators for edge computing,
- image and video processing on edge devices

Keywords: embedded machine learning, edge computing, embedded systems design, signal processing

We have been involved the following **projects during year 2020**
- COVSG40 - "Development of hospital carrier robot for the North Estonia Medical Centre"
- LITEE20122 – "ISC2PT – Intelligent Smart City and Critical Infrastructure Protection Technologies"

We have coordinated following research- and development projects in 2020:
- LEP19006 – „Tark autotekk"
- LIAEE20135 – "Prototype development of sensory of automatic malfunction detection for industry doors"
- VA20069 - "ROROGREEN – Green RoRo Shipping Trough Digital Innovation"

In 2020 the research group has published 3 research papers according to ETIS classificator:
        1 article – 1.1,
        1 paper – 1.2,
        1 paper - 3.1

Homepage: https://iot.ttu.ee

Sardtehisintellekti labor

Labori juht: Mairo Leier, mairo.leier@taltech.ee
Liikmed: Uljana Reinsalu, Karl Janson, Jürgen Soom, Olutosin Ajibola Ademola, Priit Ruberg

Sardtehisintellekti labor keskendub masinõppe lahenduste arendamisele sardsüsteemides. Labor teeb rahvusvaheliselt koostööd nii merenduse, meditsiini, targa linna, autonoomsete sõidukite ja tööstusautomaatika teadusgruppide ja ettevõtetega. Põhifookus on merenduse ja mobiilsusega seotud valdkonnad.

Põhikompetentsid:
- sardriistvara disain ja prototüüpimine,
- masinõppemudelite optimeerimine sardriistvarale,
- mobiilsete sensorite arvutustehnoloogiad,
- pildi- ja videotöötlus sardriistvaral

Võtmesõnad: sardsüsteemide disain, sardtarkvara masinõpe, signaalitöötlus

Uurimisgrupp osales 2020. aastal järgmistes teadus- ja arendusprojektides:
- COVSG40 - "Haigla transpordiroboti väljatöötamine"
- LITEE20122 – "Intelligentsed Targa Linna ja Kriitilise Infrastruktuuri Toimepidevuse Tehnoloogiad II"

Uurimisgrupp juhtis 2020. aastal järgmiseid teadus- ja arendusprojekte:
- LEP19006 – „Tark autotekk"
- LIAEE20135 – "Tööstusustele automaatse rikke tuvastamise sensoorika väljatöötamine"
- VA20069 - "ROROGREEN – RORO laevanduse keskkonnasäästlikkus läbi digitaalse innovatsiooni"

Uurimisgrupp avaldas **2020. aastal** 3 publikatsiooni ETISe klassifikaatori järgi:
　　　1 article – 1.1,
　　　1 paper – 1.2,
　　　1 paper - 3.1

Keskuse veebilehe info: https://iot.ttu.ee