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„Cyber-physical systems - Long term technological prognosis"

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Introduction

Cyber-physical systems (CPS) are also sometimes called 3C systems, because they have three key aspects: Computation, Communication, Control, which are responsible for the “cyber” part in these systems. Additionally CPS use the information from the “physical” world, usually through sensor measurements, and as a result have some impact on the external world, as a result usually providing some kind of benefit, e.g. service improvement, efficiency or security.

In one important dimension a CPS system can be envisioned as a cycle: it observes the world through sensors, calculates what needs to be changed and implements these changes, after which the cycle starts from the beginning. Another CPS dimension is the intercommunication with other systems and coordination between these systems. For example, a CPS could be responsible for keeping a comfortable temperature in the building, while at the same time communicating with similar systems and acquiring weather forecast to do this task with minimal energy expenditure both for the building and the whole smart city.

The goal of this document is to outline the technological development directions of CPS field in general, and specifically the parts developed in state research programme SOPHIS, project No. 1 KiFiS. This outline will be based on both research experience and analysis of modern technology tendencies. Even though this outline is aimed at defining the probable long term future (10+ years) of these technologies, this task is quite ambitious and the real goal of the authors is to outline the main elements of the future vision, so that it would be easier to select accents for future research directions both globally and in Latvia, to work towards this vision as efficiently as possible.

The general development direction is aimed towards not only improving the efficiency of local “single building” scale CPS, but also a positive impact on a more global scale. For this to happen, several general directions need to be developed in the future:

- Wireless communication solutions, which include thousands of low energy sensors, not only capable of very energy efficient operation, but also of cohabiting in the same communication space with many transmitters and receivers, which potentially have very different tasks and operational variables.
- Low energy embedded systems for smart signal pre-processing, data aggregation and data processing, which are capable of functioning for months or even years from a single limited energy source or even harvest the limited energy resources from the surrounding environment, e.g. solar panels, kinetic energy or movement of people.
- Control algorithms and solutions, which supports efficient functioning of systems, both by conserving resources and functioning in a more optimal manner towards their mission.
- Sensor systems and algorithms, which are capable of observing the surrounding environment with high precision and low cost, so that they can be mass produced and deployed to critical points in target environments.

This shows, that it is important to continue research in both high efficiency and smaller size sensors and embedded hardware, as well as developing new system wide algorithms and solutions for data processing, system modelling and analysis, thus providing a new insight into world processes, including health of individuals and societies, safer and more efficient traffic and processes in cities and industry.

Future CPS cannot be imagined without these specific capabilities, which should be developed both in local and international scale by gaining competence and investing resources and intellectual work:

- Internet of Things (IoT), including connecting embedded systems (both sensors and actuators) to global internet communication as well as other networks, and integration of smart systems with innovative processes in community and industry which enables these new technologies.
- Cloud Computing, which provides access to efficient high performance computing and data storage, reducing the complexity of worrying about their physical location. In other words, it is a virtual data processing tool available from anywhere.
- Artificial Intelligence is the field that allows efficient decision making based on data which is available for the first time, based purely on generalized previous experience, knowledge base and training.
- Image processing, which together with the already mentioned technologies is capable of more and more complex tasks, (e.g. object detection on the road, helping cars, to make safer and more efficient navigation decisions).

Because of synergy among these technologies, in the future most of devices and sensors will work within a unified system, which will improve quality and efficiency of life and health of both individuals and society as a whole while also bringing new challenges such as privacy and security.

MedWear group result prognosis

Within confines of project KiFiS multiple prototype sensor devices have been developed with the goal of helping in healthcare (e.g. heart rate and ECG analysis devices) as well as improving quality of life (e.g. headband for computer pointer control). The future prognosis for these kinds of devices is that they will become smaller, more convenient and more unobtrusive, without losing the quality of acquired data. It can be foreseen, that about 80% of the work of medical professionals will be replaced with technological solutions [FORT1204]. To work towards this goal, the following development directions must be noted, which are potentially worthwhile for spending research time, energy and resources.

Energy resources and batteries will be reduced in size in the future, but not too rapidly, because reduction in size increases energy density per volume unit, which has physical limitations. Thus, the focus should be on research, which reduces energy consumption, both by improved signal processing and through realization of better communication protocols.

Wearable sensor devices should be comfortable and unobtrusive. This means, that more electronics and sensor solutions will be in more unconventional shapes, such as flexible substrates, or even electronic tattoos.

To make devices unobtrusive, it can be foreseen, that they will be more and more integrated into clothing. This means, that an infrastructure is required for efficient communication bot within single piece of clothing, and between multiple pieces of clothing (e.g. shoes, pants, shirts) and how to transfer this data to some kind of base station responsible for transferring this data to internet cloud.

It has always been an important question - what to do with the gathered sensor data, so that they would provide significant added value and actual impact. Because of this interdisciplinary cooperation should be developed between doctors, physiotherapists, sports scientists etc., which would provide more impactful contribution through analyzing human physiological data, both in short term (e.g. in diagnostics) and long term (e.g. by determining the tendency of impact of physical activities on the overall level of health both for sufferers of different illnesses, such as diabetes, and healthy individuals).

Rise of application value can also be foreseen through improvement of quality of life, including for people with special needs. But for this, unfortunately the working data is not precise enough, with significant signal noise, fragmented and different from person to person.

For this reason work should be invested in research developing systems, which are capable to dynamically adapt both based on machine learning and methods of artificial intelligence, by learning from data, which is gathered in long term or from a wider group of people, and afterwards matching them to the specific peculiarities of the specific user.

Testbed grroup result prognosis

A classic situation both in IoT research and industry is that the solution works while being tested in laboratory, but when transferred to the target environment or multiplied and set up for several clients, new problems pop up. To catch and solve these problems earlier, EDI is developing the wireless sensor network TestBed environment. In the future sensors will be placed in even more new environments, which means, that not only new problems because of these environments will be discovered, but also, that more networks will have to solve problems of coexisting with each other, because multiple independent systems can be in conflict with each other. Because of this it is critical to continue improving and developing the TestBed environment, especially by testing it on as much different applications as possible. Some important factors:

The TestBed has important value as a stationary solution built into infrastructure of a building - an environment where other wireless signal sources reside, such as WiFi and other industrial devices, people moving freely around the environment and interfering with wireless communications of low energy signals. In such an environment systems can be tested, which should be able to work in other buildings, for example, hospitals or public buildings.

In addition, it is important to provide opportunity for dynamic tests, such as in the middle of a forest, garden or on the roads in an urban environment. For this purpose the TestBed should also include mobile test nodes, which are capable of working autonomously from a mobile power source, which can be placed in freely selected places of a new target environment. This TestBed functionality is no less important than the stationary one, because in the future even more target environments will become interesting for testing new solutions.

One additional functionality, which is less developed for the existing TestBed, is the opportunity to monitor the communication environment, to be able to predict what new wireless communication challenges exist in the new environment. For example, are there any spectrum ranges, which are more filled or noisy than others, and how this situation changes in time. This important in the process of developing specification and practical communication solutions for new systems, for example, to see in which frequencies and channels to transmit to reduce SNR, which error correction or reliability solutions to choose.

Security is an important part of CPS, especially, because these systems impact the actual physical environment we inhabit. Because of this, the TestBed environment should be developed also with security solution tests in mind, such as developed jamming and penetration testing environments as part or extensions of the TestBed.

The TestBed should be able to provide an opportunity to connect stand-alone devices, because in the future new platforms will be developed. Because of this a flexible interface should be developed, which provides the activities and monitoring of these new external devices. This includes not only the target environment devices, but also measurement tools, such as spectrum analyzers, which can be connected through a digital interface.

SmartCar group result prognosis

There are two important systems developed in EDI for intelligent transport system (ITS) solutions in the context of CPS: Full scale self-driving car platform, as well as the environment for model ITS systems, where new solutions can be developed and tested in a miniature tract, as demonstrated by recent publication and master’s thesis of real time video analysis for car control using neural networks, which can then be transferred to the full size car. Both directions are have promise in both near future and longer term. The model test track allows the development of new algorithms without fear of causing traffic accidents in real environments, while the life-size self-driving car platform allows for autonomous or semi-autonomous driving research in fields, which are only apparent in full scale environment, such as real life road conditions, lighting and car physical properties. This also serves as a platform for new developed sensor devices and data analysis algorithms. Because of this, it is important to continue develop both of these directions.

These main directions must be mentioned in the case of future vision for the self-driving cars and intelligent transport systems:

Focus on the video processing vs LIDAR or other more expensive technologies. Video cameras as sensors have become more miniature and reasonably low cost, so they are attractive platforms for basing car management system on them. This is even more important because of the fact that people make most of their driving decisions on vision thus the overall driving infrastructure and culture is based on visual cues (e.g. road marking, traffic lights, car break lights etc.). Because of this, both general image acquisition and processing should be developed for overall view of the road and surroundings of the car, as well as deep learning and artificial intelligence solutions, to be able to make secure and high quality decisions for driving of the car in real environment.

Sensor data fusion algorithms, because each of the separate sensors have their limitations and the road environment is high risk environments, so redundancy is important. Thus the road can be seen from multiple perspectives, such as cameras, LIDAR, audio signals, car built in sensors, including the speed and how slippery the road is.

Additional attention is needed in the future for analysis of the car driver while sitting at the wheel. Even now the car making companies are trying to predict what kind of maneuver the driver is going to execute even before it has happened, or to evaluate if the tiredness level of the driver is not so high as to be a risk to traffic safety.

And finally it is important to tell, that the development of the autonomous model track is a great instrument and investment for attracting future young and brilliant minds both in autonomous driving, and for the science in Latvia in general.

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