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Annual Report 2017
on the Scientific Activity
at MTA SZTAKI

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CONTENTS

I. Priorities and main tasks in 2017

According to its mission statement defined in 2016: "relying on its strong – and characteristically focused – basic research activities, MTA SZTAKI generates new results while utilising a framework of widespread domestic and international cooperation, and facilitates their applications to the benefit of the sustainable development of the economy and society, and, at the same time, avails in its fields of activity to preserve and, as far as possible, to raise the Hungarian scientific-technical culture to a higher level."

The main direction of the institute's current activity is research in *cyber-physical systems* (*CPS*) that creates the framework of, and brings the activities pursued here, into the dominant mainstream of international research. Its laboratories (such as the i4D intelligent space, the systems and control, the SmartFactory, the cloud computing and the cooperative cyber-physical research laboratories) were created in line with this end and as a result, new interactions between theory and practical engineering approach are being born here.

CPS are computational structures that are strongly linked with the surrounding physical world and the physical processes therein while making an intensive use of internet based services for data access and data processing. The cyber-physical approach may lead to smart cities, smart systems in manufacturing, transport, logistics and energetics and CPS may also contribute to creating a higher level of quality of life. According to the ever more generally accepted view among professionals, *cyber-physical production systems* (*CPPS*) can be expected to pave the way to a 4th Industrial Revolution, often referred to as Industry 4.0.

Expectations towards the cyber-physical systems are already enormous and are growing speedily, simultaneously with the appearance of the new technologies, they are such as robustness, self-organisation, adaptive situational awareness, transparency, predictability, efficiency, inter-operability, and global traceability, to mention only the most important fields. Indeed, notable advances made in areas such as cooperative control, multi-agent systems, complex adaptive systems, emergent systems, sensor networks, data mining and so on, have been reinforcing the expectations of further significant progress, thus strengthening the demand for continuous research.

II. Outstanding results in research, development and public relations

a) Research, development and innovation

In the following, besides of presenting the institute's four key directions in basic research (computer science, systems and control theory, engineering and business intelligence, machine perception and interaction), five sub-sections summarise how the results attained in basic research are aligned to the major international trends and simultaneously, also to the goal setting of the Hungarian Smart Specialisation Strategy (S3), the Széchenyi 2020 Programme and the Irinyi Plan. The application oriented achievements in the areas of vehicle and transport industry; production informatics and logistics; energy, sustainable development and precision agriculture; security, surveillance and medical applications; networks, distributed computing and the internet of the future are covered by separate sub-chapters.

<u>THE MAIN DIRECTIONS IN BASIC RESEARCH</u>

<u>Computer Science</u>

The research pursued in this area leverages the synergies of several interrelated fields, including the theory of algorithms with emphasis on new parallel hardware architectures; data mining, information retrieval; machine learning, database theory and that of large (extremal) graphs. A characteristic feature of the basic and applied research in data science is a strong

collaboration of engineers and mathematicians: while the approach is fundamentally of experimental nature and, due to the huge volumes of data, the algorithms have to be based on rigorously proven and validated foundations, as well as on a deep knowledge in the theory of algorithms and probability calculations.

Main results achieved in 2017:

- One of their main lines of research in the field of *parameterized algorithms* is the so-called "square root phenomenon" on planar graphs: it has been observed that the optimal algorithm for most combinatorial problems has exponential running time in the square root of the parameter. For example, they proved that for the colouration of unit disks in the plane (and for many other objects) there is no faster algorithm then the ones that are exponential in the number of disks.
- *Counting subgraphs* and other patterns in graphs is a classic, well-studied algorithmic problem, whose complexity and theoretical significance come from the fact that there are many cases where finding an occurrence of a given pattern is an easy task, while counting the number of all occurrences is algorithmically difficult. They achieved a significant breakthrough in understanding the parameterized complexity of counting problems: they proved a general theorem stating that every such problem can be reformulated as a task of counting homomorphisms, whose computational complexity is much better understood.
- In connection with the noted *Combinatorial Nullstellensatz* of Alon they have shown that the constructive version of the special case of the problem, which is defined over the two element fields, is a complete problem for the PPA problem class introduced by Papadimitriou. The polynomial meeting Alon's requirements is given by a special Boolean formula.
- They have achieved results in the study of an important algebraic graph construction, the *projective norm graph*. They managed to describe the automorphism group of these graphs, and established the pseudorandom nature of the projective norm graphs with respect to an interesting graph parameter (i.e. the number of 3-decomposable subgraphs in them).
- They analysed the temporal *behaviour of online connections* and recognized that the possessors of certain information (e.g. users listening to a particular artist or, sharing a given message) form a subgraph, which is denser compared to a random one. Based on their observations, they have revised the model of Leskovec et al. so that in fact, it does not relate to the densification of the communities, but rather to information spread from a dense core. They provided an appropriate information propagation model for this phenomenon.
- The goal of *recommendation systems* is to learn users' preferences, taste, and provide personalized selection of the most relevant products. Recommendation by online machine learning is able to modify its model immediately after each transaction, compared to the standard batch overnight model recompilation. They designed new online algorithms that can use the results of batch modelling to improve quality.
- They established an upper bound on the number of touching points of plane curves in the setting when any two such curves intersect in exactly one point.
- In the field of *operations research* they have shown that for pairwise comparison matrices which are consistent if we ignore at most two elements, the eigenvector method yields a Pareto optimal weight vector. They also proved that for incomplete pairwise comparison matrices the logarithmic least squares approach is equivalent to the method based on averaging the paths of length two. They have also given an axiomatic characterization of the inconsistency index used for pairwise comparison matrices.

- They gave a *consensus brain graph calculator algorithm* (based on the "Budapest Reference Connectome" webserver), which calculates consensus (or reference) cerebral brain graphs generated from hundreds of healthy young peoples' MRIs, revealing the physical connections of a healthy human brain in a never-seen-before detail.

These research activities were supported largely by high prestige grants: the *ERC Starting Grant* and the *MTA Momentum Grant*. Their main industrial partners in the research and development activities based on the basic research described above are: Ericsson Hungary, OTP Bank and Bosch.

Systems and control theory

Research in this field addresses various subjects of systems modelling and identification, theory of adaptive and robust control, signal processing and filtering, control of distributed and networked systems, as well as selected topics of process control. Linear and nonlinear systems in both continuous and discrete time, also in deterministic and stochastic settings are considered, as necessitated by particular applications.

- New results related to the theory of *nonlinear systems* were achieved on problems associated with robust control design based on Linear Parameter Varying (LPV) and quasi-Linear Parameter Varying (qLPV) models. It is often very convenient to consider maps between controller sets that are defined by Möbius transformations. It was pointed out that Mobius transformations defined by unimodal matrices preserve the internal stability of the closed loop, uniformly. They have also formulated an explicit formula for the calculation of the elements of the transformed loop in a universal approach which involves LTV and LPV systems as well.
- The properties of a common geometric background in the *robust control design* problem were explained. The geometric approach of the Klein design methodology was successfully applied to the solution of robust control problems.
- Youla parametrization of stabilizing *controllers based on information feedback* is one of the most fundamental results of modern control theory. Relying on the geometric techniques introduced in their previous work, a novel alternative geometric parametrization has been provided using a set theory approach. Unlike the method of the original Youla parametrization, this parametrization is coordinate free: it is based only on the knowledge of the plant and a single stabilizing controller.
- In the field of *fault detection and null space based structural reconfiguration* it has been shown how design methods for fault tolerant reconfiguration algorithms can be applied that guarantee stability and enable to retain performance of the system design goals. By the introduction of the novel geometric techniques characterised above, new design methods could be established for stability retaining sensor recombination algorithms.
- Further significant efforts have been made in the systematic reduction processes of *flexible engineering structures*, such as airplane wings and other large-dimensional mathematical models describing such engineering objects. New results were achieved by classifying and following the hyperbolic metrics of poles in the very large-dimensional LPV and qLPV systems based on modal decomposition and preserving the consistency of states.
- In the area of *signal processing and system identification*, new results have been achieved with respect to the model reduction. Based on results of the Kolmogorov n-width theory, useful bounds were given for the worst case error approximation – both in the cases of H_2 and H_infinity – in terms of the hyperbolic distance related to the sets of uncertain poles. A related model reduction strategy that uses only this a priori pole information was also proposed.

The results obtained and described above have been primarily used in the energy, transportation and vehicle industries. These results of basic and applied research were beneficial in various industrial projects performed in close cooperation with respected industrial partners such as e.g., Airbus, Bosch and Knorr-Bremse. Together with the industrial partners they conducted activities in European and Hungarian collaborative projects in an attempt to exploit theoretical results in the industrial practice, directly.

Engineering and business intelligence

Research in this field focused on the design, planning and control of cyber-physical production and logistic systems, as well as the adaptation of their operation to the ever changing conditions. Interdisciplinary research was conducted in a number of fields related to computational theory, operations research, manufacturing science, production engineering and artificial intelligence. Main results obtained in 2017 are as follows:

- They devised a multi-criteria approximation scheme for the *resource constrained shortest path problem* under the condition that the number of criteria is constant. There was also shown that if this condition does not hold, then no such scheme exists. This negative result was extended to the multi-criteria knapsack problem, and also to the multi-criteria matroid basis problem.
- They have developed a new poly-time approximation scheme for *machine scheduling problems with non-renewable resources* considering various objective functions and identified cases when such a scheme does not exist.
- For the *multi-depot, integrated vehicle and crew scheduling problem* they have devised a new exact, branch-and-price based method, and demonstrated its performance on benchmarks from the literature.
- A new branch-and-cut algorithm was elaborated for solving the *single machine scheduling problem with non-renewable resources* and the maximum lateness objective.
- They gave a formal proof of the NP-completeness of the *electricity tariff optimization problem in smart grids*. The proof applies to various models from the literature whose complexity status had been unknown before.
- Based on their optimization engine made for solving large-scale linear second-order cone programs, they developed a new optimization engine for solving *large-scale robust linear programs*.
- They proposed a *distribution-free estimation method* for stochastic linear (dynamical) systems for the detection of under-modelling, as an extension of the previously developed Sign-Perturbed Sums (SPS) algorithm. The new method can still deliver exact, non-asymptotically guaranteed confidence regions, in case the model is correctly specified. On the other hand, it can asymptotically detect with probability one if the system is under-modelled.
- It was proven under mild statistical assumptions that the SPS algorithm is strongly consistent, that is, its confidence regions shrink around the true parameter as the sample size increases. Furthermore, the SPS regions converge with probability one to the classical (asymptotic) confidence ellipsoids, i.e., the ones based on the asymptotic Gaussian distribution of the scaled estimation errors.
- They introduced a *new correlation method*, called SPCR (Sign-Perturbed Correlation Regions), as a combination of two existing finite-sample methods. SPCR combines the flexibility and computational advantages of LSCR (Leave-out Sign-dominant Correlation Regions) with the exactness of SPS.
- They elaborated an iterative and hierarchical approach to solving macro- and micro-level problems in *assembly planning* in an integrated way using Benders decomposition.

Generic geometric reasoning methods were developed that extract assembly feature parameters and perform collision detection on approximate mesh models of parts.

Most of the targeted basic research was carried out in the frameworks of national research projects (OTKA, GINOP). The theoretical results provided ground for subsequent industry-motivated applied R&D projects (see details later). In order to support experimental research as well, the so-called Smart Factory pilot environment was extended at the Budapest site, while a new Industry 4.0 laboratory was set up at their site in Győr to deal with technologies for human-robot collaboration for assembly, and automated guided vehicles for internal logistics.

Machine perception and interaction

- For a *multilevel hierarchical analysis of high-resolution images*, a general three-layer Marked Point Process (MPP) based framework has been developed that is able to detect objects, object parts, and object groups that occur in the image.
- Theoretical and applied research in *projective geometry*: It has been shown that the full three-dimensional reconstruction process can be made by using affine transformations when converting spatial information into perspective images, and in contrast to point-based methods, surface normal vectors can be extracted directly. The quality of the results allows, among other things, that the reversed engineering algorithms recognize the reconstructed shapes.
- Procedures have been created for the automatic retrieval of 3-way normalized slices from *medical databases*. Using the slices, an automatic segmentation algorithm has been developed to locate tumour regions in brain images.
- In *digital holographic microscopy* different image descriptors, focus measures were applied so far to define the proper reconstruction distance of the objects from the recorded holograms. A new measuring technique has been developed, that applies multiple illuminating lasers and triangulation, providing high-precision, high-speed focal distance determination.
- *Multi-layer optical model of plant leafs* was developed, which enabled the estimation of the chlorophyll contents in green leafs, and other natural dye contents in colour leafs. The method requires transmissive and reflective measurements with spectroscope or hyperspectral camera.
- They have designed a *point cloud based workcell calibration* method, utilizing General-purpose Programming on Graphics Processing Units (GPGPU). The method receives a point cloud as input data, divides it into independent sub-clouds and identifies the ones corresponding to linear components. These linear components are matched with their appropriate counterparts on the reference CAD geometries. The results have been validated in a robotic workcell.
- They analysed the time series of sensor data generated during the manufacturing process for the purpose of production *quality forecasting and predictive maintenance* tasks. They considered the task of predicting the scrap rate of the production line, which is difficult, since pressure and temperature time series of the individual products had to be considered as part to a hierarchical manufacturing process of lead-frames, shifts, and cleaning cycles. They gave a novel method for processing such time series of time series.

RESEARCH AND DEVELOPMENT ACTIVITY

Vehicle and transportation systems

Technology development related to vehicle and transportation systems technology was structured by the requirements of air and road vehicles. The theory of cooperative systems, the integrated methods of the design of vehicle control systems, advanced communication technologies in vehicle networks, the theory and practice of fault tolerant board control systems' design, and furthermore, advanced drivers assistance technologies were in the focus.

- *Autonomous transportation systems:* Research and development related to the functions of autonomous vehicles and intelligent traffic infrastructure focused on the energy-optimal speed profile of road vehicles. In the optimisation procedure the road, the environment and the traffic conditions had to be taken into consideration just as road slopes, the traffic flow, security and traffic specifications, speed limits, the visual ranges and the weather conditions. The research included the integrated methods of the construction of vehicle control systems, the theory of cooperative control systems, safety and security communication solutions, navigation and information technologies, fault-tolerant vehicle architectures, as well as analyses related to communication delays. Developments complementing the above-mentioned research – besides the simulation-based analysis – concentrated on the realization of the energy-optimal speed design of real commercial vehicles. The tests were carried out in close cooperation with Knorr-Bremse and IKARUS. The truck using the realized optimal solution achieved 6-8 % fuel saving compared to the truck controlled by a professional driver. Vehicle-controlled solutions specifically for commercial vehicles open the doors to automated transport, economical and environmentally-friendly operations, and the application of electro mobility in public transportation.
- *Vehicle control and dynamics:* Analysis of actuator effectiveness related to intelligent road vehicles were carried out. Research activities were focused on the computation of controlled invariant sets in which the stability of the vehicle can be guaranteed. The analysis of the lateral dynamics and road stability was emphasized by the coordination of the steering and the driving/braking systems. Besides computation algorithms based on polynomial methods, data-based analysis methods were also developed. The motivation was the development of robust algorithms based on machine learning. In the methods, using different simulation environments, various performance measures of road vehicles were analysed.
- *Avionics and Unmanned Aerial Vehicles (UAV) applications:* A novel safety critical control architecture for avionics applications in UAVs was developed. The method enables continued operation of the autonomous aircraft in the event of a single component failure. This capability is essential for the integration of UAVs into the common airspace. A camera based sense-and-avoid (SAA) collision avoidance detection system was developed to help mitigate risks of mid-air collision in aviation. The system uses information fusion from the state of the aircraft and information on the predicted path of intruder aircrafts. It was developed with the goal of integration of UAVs into the shared airspace in mind. The fault tolerant architecture and the vision-based collision avoidance were implemented for a small-scale, redundant avionic system that is unique among comparable systems in that the GPU based image processing unit together with navigation instruments are capable of the timely detection of situations potentially leading to collision. A set of experiments have been carried out based on the implementation, which confirmed that the technology provides a viable solution to the safe spatial separation of autonomous aircrafts throughout the duration of their journey. Processing and analysis were performed on simulation and physical

measurement data with the purpose of developing solutions for path estimation and collision probability calculation, in a research supported by the US Office of Naval Research (ONR). The research of deep neural network based learning technology was conducted for object detection and collision avoidance in the air.

- Automatic landing systems research by means of the application of advanced machine vision technology was performed in the collaborative framework of the VISION H2020 project. Image construction and reconstruction, image sensor fusion processes were developed for the high accuracy detection of landing space geometry and estimation of the landing threshold with confidence. *Advanced fault-tolerant control methods* were developed to maintain the high safety standards of automatic landing systems and guaranteeing safe operation in case of ILS and GPS sensor drop out.
- *Flexible aircraft wing fluttering research* was conducted in the FLEXOP H2020 European framework project. A number of models of different abstraction levels were developed for the representation of both the resonance issues (i.e. fluttering) occurring in flexible wings and the dynamic behavioural patterns of the entire aircraft structures during high speed courses. The wing instrumentation of the experimental demonstrator A/C unit, developed by the project, was made by the institute.
- *Novel applications of drones:* A new technology of applications of multipurpose drone hybrids (UAV-UUV) was researched enabling transformation of operational modes of automated flying units between air and water use. A new polymer body material which is soluble in high ion (salt) concentrated sea water was designed. The material enables the use of 3D printing technology in drone production and makes the utilization of DNS coding possible. The novel material construction together with the adaptive reconfigurable control and sensor reconfiguration algorithms are capable of the metamorphosis of the vehicle from air to water regime.

Production informatics and logistics

Research, development and innovation in *production informatics and logistics* focused on the configuration, modelling and operation of service provider and logistics systems. In this field, the institute aims at closely following current trends in cyber-physical production systems, from the level of equipment on the shop floor up to production networks. Key results achieved in 2017 are as follows:

- Based on the *crowdsourcing* concept, a new distributed manufacturing method was developed where companies can share their manufacturing resources depending on their demand and capacity. The resource owners participating in the cooperation decide autonomously whether to share or request parallel capacities for a higher level of customer service and/or resource utilization. Local forecasting and decision-making is supported by discrete-event simulation, too. The results were validated on real industrial data in cooperation with *Hitachi Manufacturing Technology Research Center Yokohama* and *Fraunhofer IPA Stuttgart*. The parallelized testing environment was installed in the Cloud infrastructure of the Hungarian Academy of Sciences.
- The fundamental concepts of *Industry 4.0 oriented architectures* (IIRA and RAMI 4.0) have been explored and analysed in terms of the industry specific modelling, interaction and standardization of Cyber-Physical Production Systems. In this context, their functional compatibility has been demonstrated and a realization framework has been defined for implementations in cloud computing environments.
- The *openness* and *transparency* of networked production processes still has significant cyber security issues. Within the conceptualization framework of Industry 4.0, a series of implementations have been realized and validated in relation to the identity, relationship and management of users, sensors, intervening bodies, gateways, and

cloud-based services, which enable and support confidentiality and trust in the inter-company business processes, while providing protection against unauthorized access to systems, services, and data.

- They developed a method that is capable of processing large volume production data, collected from multiple sources in order to *predict the manufacturing lead t*ime of products, and evaluate the impact of production environmental factors on the lead times.
- They developed a new, machine learning based method that enables the *identification of functional failures* of the products already in the early stage of the manufacturing process. The prediction model utilizes streamed technological data to provide near real-time estimation of the product quality, thus reducing the wastes and extra costs of handling failed products.
- A methodology was defined for *quality control charts* of mass production to automatically define, identify, recognize and give prognosis of production trends. The application of this novel technique enables the early correction of the production process when a production trend with possible negative consequences just starts to appear but the values are still inside the prescribed tolerance range.
- A new method was developed that enables the *long-term capacity planning* of robotized, reconfigurable manufacturing cells, utilizing the short-term operation costs predicted by the combination of mathematical optimization and simulation.
- In collaboration with Hitachi, they developed a method which combines *long-term, strategic production and capacity planning* with the technological planning of the products' manufacturing and assembly process. The method enables significant cost savings in the long run.
- They designed and implemented a communication system for supporting *bi-directional multimodal interaction in human-robot collaboration* in production environments.
- *Technological parameters* were optimized for the AQ Anton manufacturing company which resulted in significant productivity increase. A solution was implemented for path optimization with the aim of realizing cost effective machining.

<u>Energy, sustainability and precision agriculture</u>

- *Supervision and control of energy systems*: In the field of management and supervision of energy production systems, one of the earliest industrial activities in the institute is based on the strategic cooperation with MVM Paksi Atomerőmű Plc. In connection with the nuclear power plant lifetime extension project, the renewal of the existing control systems and the preparation of related projects continue to be a priority, and similarly to previous years, in 2017 the institute provided support and expertise to these activities. Moreover, it contributed to the technical specification and design process of instrumentation and control (I&C) systems based on relevant standards and specifications. They have helped to develop the testing concept of modernized I&C systems and to establish the precision requirements of the measurement devices. They supported the design of the I&C architecture of the modernized turbine control. Regarding the reconstruction of the Rod Control System (RCS) and the Reactor Power Control System (RPC), they performed an independent review of the development environments. The institute continued to cooperate in maintaining the capacity of the power plant, as well as in the preparation of the construction of new blocks.
- *Detecting and monitoring of small wetland areas by fusion of multimodal airborne and satellite images*: A new fusion Markov Random Field (fMRF) based model has been published. It is able to fuse different modalities, like 2D satellite images and airborne 3D LIDAR point-clouds, allowing the precise segmentation of remote sensing areas. This technology resulted in an automatic method for the mapping and monitoring of

wetlands areas. In an extension of the method, images of different resolutions given by different satellites (Sentinel-2A, SPOT 6/7) together with further high resolution imagery from UAV drones can be batch processed in a more efficient mapping segmentation procedure.

- *Precision agriculture*: the setting-up of a research infrastructure for supporting precision agriculture that is unique and exceptionally large in the region was finished. This Big Data and cloud based infrastructure established collects by the project's termination at the end of 2017 agriculture related data from nearly 1000 sensor columns placed over 110 areas covering 8000 hectares of more than 50 farmers in order to create an efficient agricultural decision making system.
- A *micro air vehicle (MAV)* equipped with RGB and multispectral camera system was developed in order to study the evolution over a biological cycle of crops and fruit plantation areas, and more importantly, to detect and estimate damages due to extreme climate, insect proliferation, etc. The periodically collected data was overlaid and analysed together with the freely available ESA Sentinel satellite imagery. Consequently, their extensive research included a wide range of data sources and workflows with different characteristics applied in the field of smart and ecological farming.
- They were the first to demonstrate the probable presence of giant viruses in hot and cold desert soil samples. In co-operation with Hungarian microbiologists, the metagenomic sequences from the Hungarian alkaline lakes were analysed. Using their new methods and optimizing computing capacity, insight was gained into the taxonomic and functional composition of the bacterial communities of Hungarian saline lakes.

<u>Security, surveillance medical applications</u>

- Their *3D biometric gait analysis and recognition method* developed in previous years has been adapted to measurements of new compact laser and infrared sensors to meet real-world requirements. The result of their development has been shown during a two-week real-time demonstration at the Frankfurt Motor Show (iaa.de) in September 2017.
- Using state-of-the-art sensors that collect spatial data for a comprehensive analysis of dynamic environments, methods have been developed for *real-time detection and recognition of objects*, such as vehicles and pedestrians, based on measurements of Lidar laser scanners on moving car mounts even in case of partially detected shapes. Locating shapes perceived in the space enables to position and display events in detailed three-dimensional city maps, and thus to compare current measurements with stored, detailed urban models as well as to detect various environmental changes.
- *Visual navigation algorithms* were developed for further increasing flight safety in air traffic. The algorithms can identify the position of the aircraft and the accuracy of the position using the standard runway markers.
- *Vision based high-precision object detecting and tracking algorithms* were developed and implemented for monitoring small manoeuvring objects, by applying quasi stationary cameras. The algorithm uses the tracking results to predict the positions for enhancing the detection accuracy. The accuracy of the tracking was significantly increased by correlation based methods.
- They operate continually for the Hungarian internet providers the HunCERT, the team of surveillance, responding to the *cyber security incidents*. In 2017 more than 6500 incidents were reported and handled; they issued 10 extraordinary warnings. A nation-wide security monitoring system was set up, in close cooperation with the National Institute for Cyber Security (GovCERT) and the Hungarian Directorate General for Protection against Disasters (LRLIBEK).

- The institute was mandated in 2017 by the Governmental Information-Technology Development Agency within the framework of its NIIF programme to operate the EduID federative *identification infrastructure* servicing more than 100 institutions of the Hungarian research and higher education community and covering thousands of internet based services.
- Monitoring the *cloud based IT platforms* is in practice a complex task: it requires understanding the way of operation of the distributed data processing systems, how errors may be eliminated in them and what may possibly cause their performance deterioration. Their experts recommended establishing a framework system for optimising and tracing distributed systems.
- *Non-contact, visual body monitoring algorithms* were developed to measure physiological data, like the pulse, the blood oxygen level, and the breath rate, using video image flows collected in the visual and infrared region. The pulse and the blood oxygenation measurement is based on photo plethysmography, while the breath calculation is based on motion. The algorithms were tested both on premature infants and adults.
- New, fully automated decision support system has been developed as part of the *medical procedure protocol*. The deep convolution neural network based medical diagnostic expert software system will assist the physician to evaluate the histopathological nature of the colon polyp after performing an endoscopy examination.

Networks, network systems and services, the future of the Internet

- *Network coding* is a quite strong, linear algebra based approach for sending messages through a network, which allows reliable communication even in the presence of failed elements in the network. They developed a novel method called GDC (Generalized Diversity Coding). The GDC imposes weaker requirements on the network than the demand for three disjoint s-t data flows, as prescribed in the traditional DC approach. The new method is based on graph theory arguments. XOR-combination of data streams is needed only in the starting and ending points of the communication. They proposed an efficient algorithm for the related network decomposition task.
- The H2020 COLA project has implemented a framework for *automated scaling of container-based infrastructures* under the name of MiCADO, which provides capacities for container infrastructures using cloud resources with dynamic load, cost and performance optimization. The developed solution is a significant step forward in the context of a cloud-agnostic, auto-scaling container infrastructure orchestration.
- The Occopus orchestration tool developed by them provides *coordinated configuration and deployment services* for distributed applications and infrastructures on hybrid cloud resources. With the addition of new features and functionalities to the plugins handling different clouds like CloudSigma and CloudBroker, Occopus have become able to uniquely manage these cloud resources together with other widespread clouds in a coordinated way.
- Several new methods have been developed and implemented which make the creation of new virtual disks, the composition of the desired software much simpler, faster, and more reliable. The optimization of the size of a disc image, with a particular functionality, results in a reduction in size of over 60%, which, on the one hand, accelerates the launch of virtual machines and, on the other hand, reduces the cost of cloud systems due to smaller storage space requirements. The elaborated *disk image decomposition technique* also supports incremental storage and composition of disc images during the initialization, which significantly reduces storage space requirements (up to 80%).

- A *container (docker) based*, distributed, so-called *micro-service platform* was created. Compared to traditional cloud computing services, the platform developed is more efficient, the required e-Infrastructure and the application runs are more manageable and scalable, significantly reducing the expertise required both by the user and the infrastructure manager.
- ApertusVR, a novel, open-source programing library for virtual and extended reality was developed that assist software developers to adapt the virtual and extended reality technologies quickly and effectively to the requirements of industry and research.

b) Science and society

The communication policy and PR activity of the institute are determined by the usage of advanced channels, transparency, corporate social responsibility and the dynamic mixing of the researchers' attitude with the marketing approaches. In 2017 the institute outperformed the previous years by issuing 70 press releases and having nearly 300 media appearances.

Besides the online media, its relationships with the television, radio and the printed media were further reinforced. The work pursued at the institute was presented in 2017 by a series of articles in *Forbes, Autopro, Computerworld, GyártásTrend, Techstory, Techmonitor, Piac és Profit, Magyar Idők, Magyar Nemzet and IT Business.* Numerous scientific results were published in the biggest professional online and printed media and the partners' newsfeeds. The institute's experts gave interviews at several occasions in the most important commercial media like *Kossuth Rádió, RTL Klub, hirado.hu, M5, Figyelő, InfoRádió, index.hu, origo.hu, hvg.hu, 24.hu,* etc. The contents presented in the social media – *Facebook, LinkedIn, Wikipedia, YouTube and Videotorium* – was updated on a daily basis and had always a high number of views.

The institute presented its development projects to about 400 interested visitors at the event "Researchers' Night", for the first time at our premises both in Budapest and Győr. They held several presentations at the '*Feast of the Hungarian Science'* event, too. The institute participated successfully at the most prestigious professional exhibitions like the *Automotive Hungary,* '*The Days of Industry 2017*', the *II. Opel Scientific Conference,* the *Web Summit,* the *Exhibition of Automotive Supplier Firms, the Frankfurt Motor Show* as well as at the event *INDIGO,* where the institute acted as main organiser.

They developed a number of mobile phone applications which are downloadable free of charge, among them the first Hungarian application on film-tourism *GUIDE@HAND Film Destination Budapest* and the healthcare service *D+ Sport.* They supported several national cultural and social programs by developing special smart phone applications, e.g. for the *Fall Festival of the Hungarian Museums*, the *Museums' Night*, the *National Nature Reserve of the Fossils at Ipolytarnóc* or for the *Week of Communities* and the fans of the *Dunaferr Football Club.*

The Hungarian 5G Coalition was established with the institute's active participation.

In cooperation with the Wigner Data Center they maintain and continuously enhance the *MTA Cloud* research cloud infrastructure servicing the needs for high performance computing of the various MTA research institutes.

The institute carries out the project of developing the new digital archiving software system of the scientific publication registration service *MTMT (The Repository of Hungarian Scientific Publications).* This year the work on the final software version of the system has been finished which is followed now by the test and integration phase aiming at the planned launch of the service next year.

III. Domestic and international relations in 2017

Organization of international and important national events

Entitled as „*INDIGO Ipari Digitalizációs Szakmai Nap*", an *Industrial Digitisation Workshop* has been organized on the most relevant topics, the emerging international trends as well as the key technologies enabling the digital transformation of the industry. The over two hundred participants of the forum represented all characteristic segments of the national ecosystem: representatives of large companies, small and medium-sized companies, IT and technology providers, trade associations and government, universities and research entities were all present.

Members of the institute play an active role in the leadership of the most significant international societies relevant to their research domain (including *CIRP, IEEE, IFAC, IMEKO*), as well as in the working committees thereof and, also in preparing their conferences and workshops. The international workshop „*15th IMEKO TC10 Workshop on Technical Diagnostics: Technical Diagnostics in Cyber-Physical Era*" was organised in Budapest on 5-7th of June. They made considerable contribution to the „*Central European Cooperation for Industry 4.0 Workshop*" held in Budapest on 20th September at the initiative of the EU.

International relations

The institute's successful participation in the *EU research programmes* continued in 2017: within the 7th Framework Program they participated in 45 grant winning projects, in 8 cases they had even the role of the consortium leader. In the Horizon 2020 program, up to now 14 winning projects may be reported with the consortium leadership in 3 of them.

The institute has a strong project background in research and technological development for *commercial aviation and vehicle industry*. With respect to the research in avionics, the relationships with the Department of Aerospace Engineering and Mechanics at the University of Minnesota, the US Office of Naval Research (ONR), the Laboratoire de l'Intégration du Matériau au Système at the University of Bordeaux, as well as the German Aerospace Centre (DLR) and the European Space Agency (ESA) should be mentioned.

As a 2nd place winner of the high-prestige *Teaming* research excellence programme of the EU *Horizon 2020 Widening* programme, the project *EPIC – "Centre of Excellence in Production Informatics and Control"* was launched in 2017 thus creating the institutionalised foundation to establish a Centre of Excellence in the long-term European cooperation of SZTAKI, the Fraunhofer Gesellschaft Germany and the Faculty of Mechanical Engineering and that of Transportation and Vehicle Engineering of the Budapest University of Technology and Economics that is able to produce internationally acknowledged results in the field of the cyber-physical production and logistic systems.

The institute runs the *Hungarian Office of World Wide Web Consortium (W3C*), which participates in the activities of the W3C Working Groups, directly contributing to the development of the Web by having early access to information about new technical features and tendencies. The W3C Hungarian Office promotes the adoption of W3C recommendations in Hungary, provides information on W3C technologies and brings people interested in web technologies and international experts together.

Research and development cooperation with the industry

Besides of having collaboration with certain small and medium-sized (SME) companies in the field of *industrial digitization,* R&D cooperation has been pursued with important large companies, like Audi Motor Hungaria (deployment of a production planning tool), Opel

(visual recognition, business intelligence), Volvo (human-robot symbiosis in assembly), AQ Anton (scheduling, process optimization), Aventics Hungary (scheduling, paperless production). The cooperative research work with *Hitachi Ltd., Manufacturing Technology Research Center* dating back to more than ten years has been continued.

They strive to *patent* those results internationally which have a potential of industrial take-up. Hence, in 2017 patent applications were submitted on the micro-machining of ceramic materials, as well as – jointly with Hitachi – on a novel method supporting production, capacity and assembly planning. Earlier joint patents with Hitachi were renewed, among others that one whose background research result won in 2017 the *Technical Award* of the *Japan Society for Precision Engineering* (JSPE).

Technology transfer in the field of production informatics and logistics is gaining more and more momentum as the core activity of the *Centre of Excellence in Production Informatics and Control* (EPIC).

In the framework of a strategic collaboration, the institute serves as an outstanding local competence centre in discrete-event driven simulation as well as in production planning and scheduling for the *Siemens* PLM software lines *Tecnomatix* and *Preactor APS*.

In the course of 2017 the *Ipar 4.0 National Technological Platform* (I4.0 NTP) led by the institute has been turned into legal entity (association). The platform brings together several dozens of Hungarian companies, research institutes, universities and organizations interested in the digital transformation of the industry. They made an in-depth nation-wide survey of the Industry 4.0 readiness and expectations of industrial firms, organized a number of events and as leaders of the Strategic Planning working group coordinated the elaboration of a detailed I4.0 based industry development strategy for the government.

In the framework of the *Centre of Excellence in Research of Vehicle Technologies (J3K)*, operated by the institute on behalf of the Hungarian Academy of Sciences, the institute contributed to the scientific activity and is becoming a strategic research partner in the vehicle industry in the Győr industrial region. The operation of the Centre is supported by Audi Hungaria, the Széchenyi University and the city council of Győr.

Their scientists took part in the planning and specification works of the new *automotive proving ground to be built in Zalaegerszeg, Hungary*. The proving ground supports the mandatory functional and performance testing of self-driving vehicle technologies in the pre-production phase. The experts of the institute contributed to the legislative and regulatory actions initiated by the Hungarian government in an attempt to support authorities with an applicable legal framework for the control and regulation of licencing self-driving vehicles on public roads.

Concerning the safe lifetime extension of nuclear reactors, the continued collaboration with the Paks Nuclear Power Plant, Hungary is mentioned. The capacity reservation efforts were made in close cooperation with MVM Paks II Power Plant Development Company, together with MVM ERBE ENERGETIKA Mérnökiroda Zrt.

The institute operates an affiliate site also in the city of Kecskemét.

National relations, participation in higher education

The institute continues to view teaching activities in graduate and post-graduate education as an important ingredient of its research work and also as an indispensable part of building the future. Hence, many researchers at the institute also fulfil teaching mandates at various Hungarian institutions of higher-level education, including BME, ELTE, Corvinus, Pannon University, PTE, ME, PPKE, CEU and Kecskemét University. On average, around 20 PhD

students conduct research work at the institute under the tutorship of senior researchers. Around 25 researchers at the institute act as external and 5 as internal founding members in various doctorate schools.

IV. Summary of the most relevant national and international grants won in 2017

CloudiFacturing — Cloudification of Production Engineering for Predictive Digital Manufacturing
(Kacsuk Péter, EU H2020-FOF, 441 000 €, 2017-2021)

The aim of the project is to digitise the production processes of SMEs by switching to cloud services.

EOSC-hu — Integrating and managing services for the European Open Science Cloud
(Kacsuk Péter, EU H2020-EINFRA, 97 500 €, 2018-2020)

The project will create a common access point for researchers to use the European Open Research Cloud Infrastructure to provide data-driven advanced research, pooling the services of local, regional and national e-infrastructures.

HopsWorks — EIT DIGITAL HopsWorks
(András Benczúr, EU H2020 EIT DIGITAL, 88 750 €, 2017-2017)

The project aims to expand the functions of HOPS (Hadoop Open Platform as a Service). Hops is a new generation European Hadoop distribution that is leader in providing multi-user, elastic scalable Big Data solution with dynamic load balancing.

Reading in EU today — Reading and Writing Literary Texts in the Age of Digital Humanities
(Kornai András, EU ERASMUS+, 32 381 €, 2017-2020)

The aim of the project is to explore new reading strategies and formulate new innovative methods to re-popularise reading.

zMed — Development of an Augmented Reality based fusion of 3D medical imag
(Tamás Szirányi, GINOP 2.2.1, 249 739 648 Ft, 2017-2020)

The project is developing new, innovative 3D imaging and visualization technologies for 3D fusion of medical data and visualization of reality.

PETFORM — Plastic extruding, bottle blow molding and labeling technology development for a new environment friendly container
(Zarándy Ákos, GINOP 2.2.1, 101 000 000 Ft, 2017-2019)

The target of the project is the development of a unique plastic extruding and bottle blow molding and labeling technology which leads to a new innovative plastic container technology.

Open incubator — New intelligent digital resuscitation table (open incubator) development for neonatal and premature infants to reduce their mortality rate and increase their chances of a healthy life
(Ákos Zarándy, VEKOP 2.2.1, 90 011 250 Ft, 2018-2019)

A multi-spectral visual system is going to be developed in the framework of the project for monitoring the blood perfusion, the limb and eye motion patterns, the body temperature distribution, and the breath activity periods of the infant.

OTKA — High speed, high resolution phase reconstruction of the off-axis holograms of sparse samples
(László Orzó, NKFIH_K, 21 026 000 Ft, 2017-2019)

The application of a special Digital Holographic Microscope for the examination of sparse samples, as it is can inspect hundred times larger volume than the conventional microscopes.

OTKA Markov Decision Processes: Estimation and Approximation Methods
(Csanád Csáji Balázs, NKFIH_KH, 15 048 000 Ft, 2017-2019)

The aim of the project is to investigate methods that can construct confidence regions (with finite sample guarantees) for semi-parametric models of controlled Markov chains and to study the use of randomization both on sequential decision problems and on the targeted confidence region constructions.

OTKA Change detection and event recognition with fusion of images and Lidar measurement
(Csaba Benedek, NKFIH_KH, 19 628 000 Ft, 2017-2019)

Various key aspect of machine-based environment interpretation are the automatic detection and recognition of objects, obstacle avoidance in navigation, and object tracking in certain applications.

OTKA Multimodal feature fusion for establishing novel 3D saliency models
(Andrea Manno-Kovács, NKFIH_KH, 19 252 000 Ft, 2017-2019)

The aim of the project is to extend the modelling of relevant visual content (saliency) for 3D multimodal data, besides of highlighting the published 2D-based image feature

OTKA Robot localization using visual information
(László Majdik András, NKFIH_KH, 19 099 000 Ft, 2017-2019)

The main objective of the project is to research and develop new, more accurate (less than 10 cm), more reliable and semantically meaningful, visual similarity based robot orientation algorithms.

V. List of the most significant scientific publications in 2017

1. Babarczi P, Tapolcai J, Pasic A, Ronyai L, Berczi-Kovacs ER, Medard M: Diversity Coding in Two-Connected Networks. IEEE-ACM TRANSACTIONS ON NETWORKING, 25:(4) 2308-2319. (2017) http://real.mtak.hu/39104/
2. Benedek Cs: An Embedded Marked Point Process Framework for Three-Level Object Population Analysis. IEEE TRANSACTIONS ON IMAGE PROCESSING, 26:(9) 4430-4445. (2017) http://eprints.sztaki.hu/9145/
3. Bozóki S: Two short proofs regarding the logarithmic least squares optimality in Chen, K., Kou, G., Tarn, J. M., Song, Y. (2015): Bridging the gap between missing and inconsistent values in eliciting preference from pairwise comparison matrices. ANNALS OF OPERATIONS RESEARCH, 253:(1) 707-708. (2017) http://eprints.sztaki.hu/9337/
4. Börcs A, Nagy B, Benedek Cs: Instant Object Detection in Lidar Point Clouds. IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, 14:(7) 992-996. (2017) http://eprints.sztaki.hu/9081/
5. Chitnis R, Egri L, Marx D: List H-Coloring a Graph by Removing Few Vertices. ALGORITHMICA, 78:(1) 110-146. (2017) http://eprints.sztaki.hu/9231/
6. Csáji B Cs, Kemény Zs, Pedone G, Kuti A, Váncza J: Wireless Multi-Sensor Networks for Smart Cities: A Prototype System with Statistical Data Analysis. IEEE SENSORS JOURNAL, 17:(23) 7667-7676. (2017) http://eprints.sztaki.hu/9274/
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8. Eichhardt I, Chetverikov D, Jankó Zs: Image-guided ToF depth upsampling: a survey. MACHINE VISION AND APPLICATIONS, 28:(3) 267-282. (2017) http://eprints.sztaki.hu/9116/
9. Gáspár P, Szabó Z, Bokor J, Németh B: Robust Control Design for Active Driver Assistance Systems. Cham (Svájc): Springer, 2017. 293 p. (Advanced in Industrial

Control) (ISBN:978-3-319-46124-3) https://link.springer.com/book/10.1007%2F978-3-319-46126-7
10. Gerencsér L, Hjalmarsson H, Huang L: Adaptive Input Design for LTI Systems. IEEE TRANSACTIONS ON AUTOMATIC CONTROL, 62:(5) 2390-2405. (2017) http://eprints.sztaki.hu/9111/ Open Access
11. Györgyi P, Kis T: Approximation schemes for parallel machine scheduling with non-renewable resources. EUROPEAN JOURNAL OF OPERATIONAL RESEARCH, 258:(1) 113-123. (2017) http://eprints.sztaki.hu/9279/
12. Gyulai D, Pfeiffer A, Monostori L: Robust production planning and control for multi-stage systems with flexible final assembly lines. INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH, 55:(13) 3657-3673. (2017) http://eprints.sztaki.hu/9119/ Open Access
13. Horváth G, Erdős G: Point cloud based robot cell calibration. CIRP ANNALS-MANUFACTURING TECHNOLOGY, 66:(1) 145-148. (2017) http://eprints.sztaki.hu/9283/
14. Kardos Cs, Kovács A, Váncza J: Decomposition approach to optimal feature-based assembly planning. CIRP ANNALS-MANUFACTURING TECHNOLOGY, 66:(1) 417-420. (2017) http://eprints.sztaki.hu/9267/
15. Kerepesi Cs, Grolmusz V: The "Giant Virus Finder" discovers an abundance of giant viruses in the Antarctic dry valleys. ARCHIVES OF VIROLOGY, 162:(6) 1671-1676. (2017) http://eprints.sztaki.hu/9110/
16. Majdik AL, Till C, Scaramuzza D: The Zurich urban micro aerial vehicle dataset. INTERNATIONAL JOURNAL OF ROBOTICS RESEARCH, 36:(3) 269-273. (2017) http://eprints.sztaki.hu/9305/
17. Németh B, Gáspár P: The relationship between the traffic flow and the look-ahead cruise control. IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, 18:(5) 1154-1164. (2017) http://eprints.sztaki.hu/9127/
18. Németh B, Gáspár P: Nonlinear analysis and control of a variable-geometry suspension system. CONTROL ENGINEERING PRACTICE, 61: 279-291. (2017) http://eprints.sztaki.hu/9121/
19. Pálovics R, Szalai P, Pap J, Frigó E, Kocsis L, Benczúr AA: Location-aware online learning for top-k recommendation. PERVASIVE AND MOBILE COMPUTING, 38:(2) 490-504. (2017) http://eprints.sztaki.hu/9323/
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