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Annual Report for the period of 1 January 2019 to 31 August 2019 on the Scientific Activity of MTA SZTAKI

Budapest, 25 November, 2019

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I. Main duties of the research unit between the 1st of January and the 31st of August, 2019

Their *mission statement* defined in 2016 says: "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 goals for 2019 were defined and pursued in conformity with the above mission and also with their new slogan: "*Excellence in science and innovation*". They have won new *projects in basic research*, and published in the reporting period 181 articles, 59 of them in a periodical with an impact factor. Of these articles whose cumulated impact factor was 154,659, 44 belonged to the Q1 type and 21 to the D1 type. They won the mandate to organize a couple of outstanding international conferences.

They have strengthened further their *innovation activity*, first of all through *EPIC InnoLabs Nonprofit Ltd.*, a joint venture company established in 2018 together with the *Fraunhofer Gesellschaft* with SZTAKI's majority share which has extended its activities to overseas locations as well.

They have filed the application for three new patents, 7 of the previous ones have been renewed, some of them even in multiple countries. They play continuously a leading role in the Industry 4.0 National Technology Platform Association and are founding members of both the 5G Coalition and the Artificial Intelligence Coalition. To enable a better liaising with the Hungarian industry partners they maintain sites in Győr and Kecskemét.

The main direction of the Institute's current activity is research in *cyber-physical systems* (*CPS*). Expectations towards the cyber-physical systems are already enormous and are growing speedily, simultaneously with the appearance of the new technologies, these being such as robustness, self-organization, 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 research and other results between the 1st of January and the 31st of August, 2019

a) Outstanding research results

In the following, besides of presenting the Institute's four key directions in basic research (computer science, artificial intelligence, machine learning; systems and control theory; engineering and management intelligence; machine perception and interaction), five additional sub-sections summarise the application-oriented achievements in the areas of vehicle and transport industry; production informatics and logistics; energetics, sustainable development; medicine, biology and agriculture; networks, distributed computing and the internet of the future.

THE MAIN DIRECTIONS IN BASIC RESEARCH

Computer science, artificial intelligence, machine learning

The main focus of their research in computer science lies in exploring the mathematical foundations of artificial intelligence and practices of machine learning. A characteristic feature of their approach with respect to their basic and applied research in artificial intelligence is a strong collaboration of engineers and mathematicians: while research remains basically of experimental nature, but due to the huge size of the data, their procedures have to be based on deep knowledge of the algorithm and probability theories, as well as they have to be demonstrable rigorously in mathematical terms. Main results achieved in the reporting period:

- Tight lower bounds were obtained on how the value of graph genus (describing on what surfaces a graph can be embedded) influences the complexity of algorithmic tasks like the multiway cut problem and shortest cut graph problem. This result was the first of this type and received the Best Paper award at the prestigious International Symposium on Computational Geometry (SoCG 2019).
- A thorough study explored how excluding a fixed induced subgraph H influences the complexity of various fundamental algorithmic graph problems. Among other results, a full characterization was given for those graphs H whose exclusion allows a subexponential time algorithm for finding a maximum-sized set of vertices at a given distance from each other.
- They extended their earlier algorithmic results on simultaneous isometry of quadratic forms to real and complex matrices. This development opens up a way towards numerical applications, including problems form quantum mechanics.
- New results have been obtained in the study of the projective norm graph NG(q,4). It is known that this graph does not contain copies of the complete bipartite graph K{4,7} as a subgraph. Using their earlier results, they have proved that the variant of the graph defined over algebraic number fields (and hence infinite) may also contain K{4,6} subgraphs. In these studies, they applied methods from algebraic number theory. They also studied in this broader context the Singer type difference sets whose existence had been established earlier.
- They considered possible cryptographic applications of the so-called explicit isomorphism problem, a question they had intensely studied earlier in a series of works. They intend to find algorithmic problems in this direction, for which interesting zero-knowledge protocols can be developed, and which, at the same time, are more difficult from the perspective of algorithmic complexity, than the widely used problems. Then the former ones could partially replace the latter, and give rise to more secure methods. They have some preliminary results in this direction. A related achievement of them is a novel, more efficient algorithm to find a solution to ternary homogeneous quadratic equations in algebraic number fields.
- The logarithmic least squares optimality of the geometric mean of weight vectors, calculated from all spanning trees of the graph associated with an incomplete pairwise comparison matrix, has been proven.
- An axiomatic characterization of the Logarithmic Least Squares Method, used for deriving a reference vector from a pairwise comparison matrix, has been provided. Since it is the only reasonable weight vector invariant to a transformation of triads (3x3 submatrices), the use of any other methods requires explaining the violation of this axiom.
- A new method has been proposed for approximating an inconsistent pairwise comparison matrix by consistent matrices in the maximum norm. The method, after a logarithmic transformation, reduces the original problem into solving a sequence of special network flow problems.

These research activities in computer science were funded largely by high-prestige grants: the *ERC Consolidator Grant* and the *MTA Momentum Grant*. Their main industrial partners in the research and development activities are Ericsson Hungary, OTP Bank and Bosch.

Systems and control theory

The main areas of their activity in basic research are systems modelling, model reduction and identification, as well as the control of adaptive and robust distributed and networked systems.

- In the fields of *signal processing and system identification*, new research achievements related to model reduction were obtained. Useful error bounds are now provided for the accuracy of the approximation both for the H2 and the H-infinity cases. These bounds depend on the hyperbolic distances between the uncertain poles. A model reduction strategy relied solely on these hyperbolic pole distances was developed. Effective algorithms for modular decomposition, as well as state-of-the-art model reduction procedures for the inherently high-dimensional dynamic models of flexible wing aircraft and similar engineering objects were developed. These make use of the modal decomposition and apply the theory of quasi-linear parameter varying (qLPV) systems.
- Research was carried out to explore the global input-output application possibilities of the *geometric system* and theoretic methods with the intention of revealing the common geometric basis of the robust control design methods. Starting from the geometric interpretation of Klein's approach, it was shown that transformations of certain hyperbolic spaces provide a common theoretical basis for robust control tasks. Furthermore, important systems theoretical properties of an action, or group of actions, invariantly describing a given property on the stabilizing set, or on the set of all stabilizing controllers associated with the given performance level were determined.
- A *coordinate-independent, geometric-based parameterization* was introduced following a group theory approach. The resulting parameterization preserves many of the advantageous properties of Youla parameterization, which is coordinate-dependent. The concept of the 'root-of-the-system' was introduced, and conditions for its existence were defined. In connection with the control problems related to nonlinear systems, and with the robust design using linear parameter varying (LPV) and qLPV models, it was shown that the Möbius transformations described by unimodular matrices preserve the internal stability of the closed-loop. An explicit formula was provided for the realization of the transformed loop.
- In the field of *fault detection and null-space based structural reconfiguration*, it was demonstrated how the switched reconfiguration control design procedures can be successfully applied in the design of fault-tolerant controls, and for guaranteeing system quality requirements. Effective invariant subspace algorithms were developed to determine the dynamic detection filters that generate the null-spaces for LPV systems.
- An important new area of research is the development of modern control methods that are based on *machine learning* and on efficient computational and optimization techniques. The aim is to complement and combine the classical control design procedures with learning structures, so that the resulting enhanced control design methodology can make the implementation of controllers for complex control tasks easier, and the computationally demanding controls run real-time.
- Temporal logic formalism was used to specify *complex performance requirements and limitations*. The resulting control design problem can be formulated as a linear, or nonlinear mixed-integer optimization. The new, efficient computational methods were successfully employed not only in the control design, but they also performed well in nonlinear systems analysis.
- A novel procedure was developed for establishing the *stability of polynomial and rational*

nonlinear systems, for the construction of the Lyapunov function, and of the stability domain. The method formulates the problem as nonlinear matrix inequalities, and uses zero-space relaxation to reduce them to a convex optimization problem. Compared to other methods known from the literature, the proposed approach proved to be effective both in regards to computational complexity, and in regards to the accuracy of the stability range estimation. The method was extended to estimate the induced L2 norm of a nonlinear system. It was successfully applied to find out the dissipativity and passivity properties of the system, as well as to construct inputs/ outputs that guarantee its passivity.

The primary users of the results obtained in systems and control theory are the energy, transport and vehicle industries. Together with industrial partners (e.g. Airbus, Bosch and Knorr-Bremse), they conducted activities in European and Hungarian research projects with the aim of exploiting the theoretical results directly in the industrial practice.

Engineering and business intelligence

In the course of the so-called Industry 4.0 process, considered to be the fourth industrial revolution one witnesses to the rise of the cyber-physical production systems, linking together very tightly, one could already say, inseparably, material, energy, information, and financial processes and, but notwithstanding, possessing simultaneously an autonomy of their own. The impact of these systems on the societal and natural environment is so immense that keeping them in operation has to reflect on both – characteristically contradictory – viewpoints of efficiency and sustainability. Thus, the research in the field demands for multidisciplinary approach and apparatus.

Main results obtained in the reporting period are as follows:

- New approximation algorithms were constructed for various special cases of the *single-machine scheduling problem* under raw material constraints and with the total weighted completion time objective.
- For parallel resources, they developed a common approximation scheme for minimizing the late work and maximizing the early work as well as for resource balancing problems. The basis of the common scheme is the observation that there are equivalences in the three problems.
- A new formulation and also a new exact method for the single-machine scheduling problem with stochastic processing times and minimum tardiness objective were developed.
- They studied a *resource loading problem*, where the duration of the activities depends on the amount of resources assigned to them over time, and varies between a lower and an upper bound, accordingly. They devised a new integer programming formulation, new cutting planes and with the help of them obtained new computational results that superseded the previous ones.
- For the *assembly planning* problem with arbitrary liaison graph, they developed a new mathematical programming based formulation, and extended the logical Bender's decomposition-based procedure for the new model. The two key factors in the success of the new method are the new geometric reasoning techniques and the way of handling the disjunctive constraints derived from them.
- In international collaboration, they have provided a world-wide survey of *human-robot collaboration* in mechanical assembly, including the key enabling technologies, the actual standards, as well as their limiting factors.
- They have developed a *data-driven, distribution-free framework* to quantify the uncertainty of regression models constructed by kernel methods, such as support vector machines or kernel ridge regression. By exploiting some mild regularity of the measurement noises, such as being symmetric or exchangeable, the method can construct

confidence regions, with strong non-asymptotic guarantees, for an "ideal" representation of the system generating the data.
- They have studied the behaviour of the solutions of parameter-dependent Poisson equations, which are one of the main tools of analyzing *stochastic approximation* methods in Markovian environments. They have isolated conditions under which a solution uniquely exists (up to a constant), and it is Lipschitz continuous with respect to the parameters of the Markov chain family.
- They have proposed three kernel-based resampling methods to construct region-estimates for the regression function of *binary classification*. They have proved that, under general conditions, these methods build estimates with exact confidence guarantees, moreover, they are also strongly consistent, i.e. asymptotically, the regions do not contain any "false" regression functions.
- A control algorithm of *autonomously guided vehicles (AGVs)* has substantially been improved by the application of domain-specific local search heuristics.
- In cooperation with RWTH Aachen University and Fraunhofer IPT, multi-agent simulation technology and reinforcement learning have been used for efficient control of an automated prototype platform designed for stem cell propagation in a novel strategic programme for the *biological transformation of manufacturing* initiated by the Fraunhofer Society (FhG). Approximately 30% efficiency increase has been achieved on the simulated model of the platform using a Kiefer-Wolfowitz type stochastic approximation method based on stochastic gradient descent.

Most of the targeted basic research was carried out in the frameworks of national research projects (OTKA, GINOP, NKFIA). Moreover, they have paved the way for further research and development projects, initiated, in several cases, by their industrial partners. Both the *Smart Factory pilot system in Budapest* and the *Industry 4.0 pilot production and logistics laboratory* established at SZTAKI's Győr site in 2017 have been substantially extended. These facilities promote applied research, education of the researchers of the future as well as industrial innovation.

Machine perception and interaction

- *Salient object models* have been developed for multiple applications that effectively combine handcrafted saliency features and machine learning techniques.
- They have enabled the *universal fitting of robust models*, for noise-laden data. Their method operates automatically, without the need for the user to specify a noise threshold parameter, while providing much more accurate results than the semi-automatic state-of-the-art methods.
- *Estimation of the orientation (surface normal) of spatial surfaces* based on multi-view correspondences of affine image regions has been achieved, while being able to filter out erroneous views robustly.
- *Optimal refinement of image regions* constrained by the multi-view geometry was performed while correcting the shape of uncertain image features, too. The efficacy of the procedure has been demonstrated for estimating the motion of a multi-camera system.
- A new theoretical approach has been developed and applied to the *robust estimation of the relative motion* between arbitrary central camera views, based on affine correspondences.
- A new procedure has been developed to improve the speed and accuracy of the phase retrieval of rare transparent samples in *holographic microscopy*. This method applies two in-line hologram recordings, a distant one and a near one, and provides accurate and fast phase retrieval which otherwise was a slow iterative procedure.
- Using *off-axis holography*, it is easy to obtain the measured objects' phase distribution.

However, due to the generally applied spatial filtering, the achievable resolution or the measured area is considerably limited. A new algorithm has been developed that provides for rare samples the fast reconstruction of the in-line component which is always present in off-axis holograms. This way, for rare specimens, the resolution obtained from a single off-axis hologram recording can be significantly increased, while in the case of dense specimens, it can be attained using two hologram recordings.

- *Phase-shifting interferometry* has been successfully applied to measure the phase distribution of diverse samples using a new optical measurement setup. In this new setup, the required phase shifts are provided by the random phase fluctuations of a fiber-coupled laser. These parasitic fluctuations are caused by the temperature changes and miniature vibrations of the fiber. The compensation of this phenomenon is hard that can inhibit the application of fiber-coupled lasers in various measurements. Nevertheless, it can be efficiently applied here to replace the otherwise required expensive, precise, nanoscale actuator device. A new algorithm is developed, that determines the exact extent of these random phase shifts, and based on these data, provides the accurate reconstruction of the phase distribution of the measured objects.
- An on-line learning method (context calibration) was introduced for building the adaptation capability of a *deep learning convolution neural network-based collision avoidance system*. The simulation tests of the system have been completed. The feasibility of the method was also tested on resource-limited unmanned aerial vehicle hardware.
- An automatic positioning system was developed and demonstrated on *real flight tests*. The vision-based system calculates the position from ground objects identified with known positions. The completed system is a step forward to the integration of unmanned aerial vehicles into the airspace, as well as it further increases the redundancy of the onboard instrumentation to improve aviation safety. Deployment of dynamic virtual urban and rural test environments in the CARLA simulation system has begun. These simulations enable to perform Vehicle-in-the-Loop tests using the autonomous vehicle of our institute.

RESEARCH AND DEVELOPMENT ACTIVITY

Vehicle and transportation systems

Technology developments related to vehicle industry and transport were structured typically by the aerial and road transportation means and systems.

- As far as the *decision-making strategies for autonomous vehicle systems* are concerned, the research focused on the design of safe vehicle trajectories that are characterised by minimal vehicle control energy involved. Statistical, probability and model-based algorithms were proposed for motion prediction of non-autonomous vehicles. Such predictions are now incorporated in the autonomous vehicle control discipline via certain model predictive control (MPC) methods. The generated safe and energy-efficient trajectories, on the other hand, were used for training artificial neural networks employed for solving cooperative control and decision-making tasks.
- In the field of the vehicular applications that require deep control theory insight, an actuator-integrated, robust, LPV-based reconfiguration strategy – to be used in conjunction with a *variable geometry suspension system* – was developed for steering and torque-vectoring. The results gained from theoretical control design methods were evaluated on a real cyber-physical testbench. It is expected that the compact construction characterizing the variable-geometry systems may gain importance in urban traffic solutions, for instance, in improving the controllability of the light-weight electric vehicles.

- Significant amount of data concerning vehicle dynamics can be collected through the *communication and sensor networks of autonomous vehicles*. By analyzing these large datasets using a Big Data approach, the controllability regions of the intelligent ego-vehicle, as well as that of the surrounding road network were computed. A methodology for incorporating the above results into vehicle control systems via model predictive control (MPC) and the linear parameter varying (LPV) frameworks was devised.
- In the field of *artificial intelligence (AI) methods for autonomous vehicles*, a design architecture was developed using the robust control framework. The proposed method involving multiple AI agents provides theoretical performance guarantees for the closed-loop system. It seems very promising in the context of autonomous vehicles.
- A *camera-based airborne sense and avoid system for unmanned aircrafts (UAVs)* has been researched to implement "sense and avoid" functions. The own aircraft visually detects the intruder aircraft with its onboard multi-camera vision system, generated by a photorealistic simulation environment, fed to the GPU image processing unit and navigation system. Within the framework of a multidisciplinary research program, the development of closed-loop control by significantly progressing the synergy between the fields of flight dynamics, machine sensing and deep learning increased the reliability of collision detection. The technology developed provides a solution for the safe spatial separation of autonomous aircraft and contributes to the safe navigation of a GPS-driven designated route. Based on the strong collaboration between the partners a follow-up H2020 project was submitted in 2019.
- Data processing, image acquisition and sensor fusion methods for *automatic landing systems* using visual information have been investigated. Image processing and sensor fusion methods have been developed which, in addition to detecting a landing site with a given geometry, can also be used to monitor the estimation confidence of GPS or ILS based landing. The results have been validated within a flight test campaign in France, using a large UAV platform. The results have attracted the interest of Dassault Aviation and Airbus.
- The avionics system, developed by SZTAKI have been validated in the FLEXOP H2020 project, during flight tests. Several models of different abstraction levels have been developed to describe the *dynamic behaviour of an entire aircraft*, based on which advanced control methods have been used to show a 20% increase in a flutter-free stable operating envelope. This provides the technology to apply novel wing structural design improvements leading either to 8% fuel efficiency improvement or a 25% payload increase at unvaried fuel consumption.
- A LIDAR based localization and environment detection system has been demonstrated in a real outdoor situation, on the Zalaegerszeg (ZalaZone) test track. Environment detection procedures have been developed that are adaptive to the real traffic circumstances, thus achieving proper classification and tracking of the road surface, the field objects, and vehicles.
- A *LIDAR camera calibration technique* has been proposed which is able to correct registration errors caused by sensor displacement during driving in a fully automatic manner. By using this method, executing wearisome and frequently applied manual calibration processes is not necessary anymore.
- A method has been developed that reliably *recognizes objects from partial information* (even over long distances) using the vehicles' 3D laser environment sensing.
- A *deep learning-based* method has been proposed which can classify the points of large-scale spatial point clouds, via locally examining a fixed-size neighborhood of them. The new approach can distinguish up to 9 classes (pedestrian, vehicle, moving phantom, etc.) in a dense urban environment.

- A method has been developed to enable the *localization of autonomous vehicles equipped with LIDAR* in urban environments where a pre-recorded point cloud map exists. The proposed method recognizes geometrically similar locations between the online 3D cloud and the *a priori* offline map, thus correcting the accumulated error of the incremental drift in the vehicle trajectory. In addition to this, another method has been developed for LIDAR based SLAM algorithms that can automatically localize changes in the environment for autonomous mobile machines. The great advantage of this method is that no additional processing is required besides the mapping and localization algorithm.

Production informatics and logistics

Research, development and innovation in *production informatics and logistics* focused on the design and modelling, operational control, optimization, monitoring and adaptation to real-life conditions of the production, service providing and logistics systems at every, i.e. plant, company and network levels. Key results achieved in the reporting period are as follows:

- In international cooperation, they made an in-depth study of *global production networks*. The main challenges and factors were identified that have a substantial impact on the footprint and performance of such networks, along with design principles for transforming historical network structures to be more competitive, and, at the same time, sustainable. The analysis was accompanied by industrial case studies.
- A simulation model has been defined for studying *robustness and diffusion of disturbance in supply networks*. Based on the model, a pilot simulation system has been implemented containing two of the numerous possible strategic decision problems (i.e. supplier selection and pricing).
- Leveraging open-source technologies, they developed a *reference architecture for solving industrial data analytics problems*. In addition to having flexible data collection, storage and processing layers, the architecture supports the real-time visualization of the data and the analytics results, and provides the opportunity to feed-back information into the enterprise decision making processes.
- A new *cloud-based, fluid computing architecture* has been developed, in which the core services of Cyber-Physical Production Systems with regards to sensing, actuation, computation, and networking are defined in a unified abstraction model. This model provided the basis for the implementation of an experimental I4.0 manufacturing and logistics pilot system.
- In collaboration with our industrial partner, a novel method was developed for the online supervision of *ceramics milling* that efficiently integrates the non-linear design of experiment method with the learning and search techniques of artificial intelligence.
- A new experimental method was introduced for *magnetic assisted ball burnishing* in consideration of surface roughness, hardness, resistance against corrosion, macro-geometrical features and burr elimination dependencies. The novel technique was tested on ball burnishing of various materials (steel, aluminum, and polymer).
- They obtained new polyhedral results for an *energy-constrained project scheduling problem*, where the total energy requirements of the tasks must be fulfilled while the energy expenditure is determined by the number of resources assigned to them over time.
- They developed the very first *virtual reality industrial standard* called OpenXR, within the Khronos Group which is the largest IT industrial standardization consortium. The industrial integration problems of virtual reality technologies have been resolved, in collaboration with IT giant companies like Google, NVidia, Microsoft, Intel, and Samsung. They created the innovative software technology called ApertusVR which is the official implementation of the OpenXR standard, therefore with ApertusVR, virtual reality technologies can be incorporated into existing industrial software systems.

Energetics and sustainable development

- In the field of control and supervision of power generation systems, industrial activities – related to the strategic cooperation – has continued. In the frame of this cooperation, expert support activities were carried out in conjunction with the instrumentation and control systems *reconstruction projects of the MVM Paks Nuclear Power Plant*. The experts played a significant role in developing the concept of top-level engineering support systems of the modernized control architecture, and in compiling the qualification requirements for the control circuits to be upgraded. The review of engineering and safety requirements of the I&C upgrade of the turbine control system was realized and a suitable maintenance strategy for the reactor protection system (RVR) was established.
- They proposed a bi-level programming model and a novel solution approach to *tariff optimization in smart grids* for demand response management. The approach converts the bi-level program into an equivalent single-level quadratic program by exploiting the inherent duality of the lower level problem, and then solves it using search techniques based on successive linear programming.
- The practical application of the above Stackelberg approach is often hindered by the assumption that the leader has perfect information about the followers' decision model and its parameters. They demonstrated by computational experiments that, given a model that characterizes follower behaviour with suitable accuracy, the parameters can be reconstructed from the historic behaviour.
- An optimization model for investigating the role of *renewable energy sources* in the domestic energy portfolio was defined. The mathematical definition has boiled down to a nonlinear distribution problem.
- They participated in an international consortium whose mission is to develop the concept of a new *digital platform for supporting the Circular Economy* between various sectors. The platform will overcome current information asymmetry among value-chain stakeholders, thus unlocks new business models which are based on data-enhanced recovery and re-use of functions and materials from high value-added post-use products. This concept is the basis of a successful H2020 application.
- An *optical sorting system* has been developed to reduce the *plastic pollution* of our environment. This separates different types of plastics (PET, PE, PVC). The efficiency of the waste sorting separator in Búslakpuszta has been raised to 88% in the selection of PET bottles from household waste. This makes it possible to recycle large numbers of PET bottles for promoting a green future in Hungary.

Medical, biological and agricultural applications

- A deep learning-based system has been developed for *visual monitoring of vital life signs*. The system has been tested in clinical applications for premature babies. The system is able to measure infants' heart and respiration rates by monitoring moving abdominal and exposed skin areas without the need to insert measurement units or wires into the incubator.
- In the zMed GINOP project, automatic approaches have been proposed for the *segmentation of different organs and tumors* by using machine learning, and deep learning-based techniques, especially convolutional neural networks. A new method for brain tumor detection and segmentation has been introduced, via combining salience-based and machine learning-based features from medical images.
- A prototype of a smartphone application has been prepared that can help medical students in their studies by visualizing a 3D anatomical model in the user's real environment. The application shows the precise location and the joint of the parts of the body, as well as detailed lexical information about them. The application also contains a quiz that helps to

test the learnings.

- *Agricultural data* were analyzed using artificial intelligence methods. The aim of the research was to improve the accuracy of *yield forecasting*. The investigated dataset produced by the Széchenyi University included, among other things, the soil characteristics, meteorological conditions, farming parameters and yields of the 15.3 ha research area, divided into 63 treatment units. The results showed that XGBoost was very efficient in medium to high corn yield estimates.
- In the field of *robotic crop monitoring and precision agriculture*, automatic object detection image processing methods for crop (tomato) recognition have been investigated. A new algorithm for processing stereo panoramic image pairs has been developed to recognize, separate and count the crop, and to estimate the stages of its ripening.

Networks, distributed computing and Internet of the future

- They have analyzed further the *Generalized Diversity Coding (GDC)* approach they had developed earlier in the context of coding in communication networks. In GDC the input data stream of the sender is divided into two streams and the XOR of them forms a third data stream. For the purposes of reliable communication, it is sufficient if two of these three streams arrive free of errors to the receiver, where then the original message can easily be recovered. They studied several algorithmic questions related to GDC, for example, a polynomial-time algorithm was given for determining the minimum cost of sending a message with GDC.
- They gave a new neural embedding method for analyzing *social networks* that is capable of processing a dynamic graph in the form of an edge stream.
- They extended the popular Node2Vec method to analyze the properties of the nodes in an edge stream. Graph embedding methods represent the nodes of the graph in a low dimensional vector space that preserves the properties of the original graph. They developed two types of models, one based on walks and another based on the graph neighborhood, and both of them outperformed the static models for the similarity search of Twitter users and the link prediction of dynamic social network graphs.
- With regard to infrastructures to support artificial intelligence solutions, they carried out research on the application of Apache Spark, which has the advantage of distributed computing capability, exploiting several computers at the same time. They performed experiments on a cluster of multiple computers deployed on MTA Cloud and on the cluster of "Lendület" research group, respectively.
- They developed a lightweight, on-the-fly, dynamic re-partitioning module for distributed data processing systems, including Apache Spark and Apache Flink, which improves the overall performance at a negligible overhead. Their method re-partitions data adaptively during execution without any extra sampling task or aggregation phase prior to making the partitioning decision. During their experiments on real and generated exponent-distributed data they achieved 1.5-10 fold speedup on various Spark and Flink applications.
- They constructed *MTA Cloud* and provided support for the users in cooperation with MTA Wigner Data Center. They continued the development of reference architectures (started last year) for supporting research on artificial intelligence and worked out two additional architectures: one contains Keras, Tensorflow, Jupyter notebook while the other combines Keras, Tensorflow, Jupyter notebook with GPU support. They developed teaching materials for the users of MTA Cloud as two one-day courses in relation to the reference architectures.
- In the framework of the H2020 COLA EU project, the main research goal was to elaborate

an *automatic scaling system* of the MiCADO framework and to provide optimal decision making with the utilization of artificial intelligence techniques. The solution has been integrated with the Policy Keeper component of MiCADO and its efficiency has been investigated with real applications both on MTA Cloud and Amazon Web Services.
- In the H2020 CloudiFacturing project, together with members of the consortium, they developed further a *platform for Industry 4.0* to provide seamless and uniform data transfer among different storage systems like HPC, cloud and local solutions. Furthermore, it supports workflow and HPC based execution of manufacturing process related large-scale simulations and complex analytics.
- They finished the development and implementation of the new software version of the national scientific publication registry system called *Hungarian Scientific Bibliography (MTMT2)*. The new system, that has been in normal operation since November 1, 2018, has been further developed in many aspects in 2019. The expanded functionality was resulted from exporting citation data in 1,200 different international standard formats, from data and queries regarding Hungarian researchers living outside Hungary.

a) Science and society

The communication and PR activity of the Institute is determined by the usage of advanced channels, interactivity, transparency, corporate social responsibility and the dynamic mixing of the researchers' attitude with the marketing approaches. In the reporting period, the Institute had nearly *100 media appearances*, issued 3 news-breaking press releases, and reported *50 institutional news* and events to the public.

The Institute's experts regularly gave interviews to the online and printed media, the radio and television channels, the newspapers, and magazines.

Their activities were presented by a series of articles and reports in the tv channel M5, and numerous other online media like *Origo*, *Index*, *444*, *Kisalföld.hu*, *Weborvos.hu*, *MedicaOnline*, *Webradio.hu*, *PecsiUjsag.hu*, *Sg.hu*, *HelloWorldOnline.hu*, *Jozsefvaros.hu*, *Beol.hu*, *Turizmus.com*, *Szeretunkutazni.hu*, a *Hellovidek.hu*, *Vg.hu*, az *OrientPress.hu, as well as* the newspapers *Magyar Nemzet*, *Mandiner*. Their interviews were broadcasted by *Kossuth Rádió* and, *Győr Plusz Radio.* They also appeared several times in the professional papers like *GyártásTrend*, *Érintő* ND and *AutoPro.*

Besides these, they are present in the social media, too: their *Facebook* page has over *1000 followers*, is updated more than once a day on average, this meaning more than *400 entries* annually. On monthly basis, *20 thousand accesses* are measured on average. The most important news and events of theirs are commented in English, too. This is even more so at their LinkedIn site that is followed by over *1200 people*, with an average monthly views of *5000* and over *100 published entries*. They are also present on Youtube with more than *40 video contents*.

They are represented by 4 individual pages on *Wikipedia* that are continuously updated. Their contents are planned to be extended soon.

They have expanded their GUIDE@HAND smartphone application family by developing the mobile walk app titled 'In the footsteps of the Paul Street boys' that was created with the joint financial support of the District Municipalities of Budapest Ferencváros and Józsefváros. The interactive walk for smartphones helps to get acquainted with the locations of Ferenc Molnár's world-famous novel, as well as to relive its episodes and the readers' memories. The user is guided to 13 sights, by presenting not only references to the story but also telling about the architecture of the sites, which are accompanied by short quotes from the novel, along with excerpts of the music of the period. The experience is further improved with archive photos and

a few scenes of the 1969 movie by the well-known director Zoltán Fábri.

The Institute has developed and is maintaining the new digital archiving software system of *MTMT2 (Hungarian Scientific Bibliography)* which is a bibliographic national register that centrally stores/manages scientometric metadata related to the national research activities and aims to be the core, centralized and institutional means of servicing the whole research sphere and research funding agencies in Hungary. Due to its central function, the system should meet special requirements of use and security. MTMT2 system serves around 40.000 users (of the Hungarian academia and higher education) and about 500 MTMT-2 administrators who fulfil the duties of professional data curation.

They organized together with their innovation-oriented subsidiary for the third time, the event "*INDIGO Industrial Digitization Professional Day*" where beside local experts, lecturers from Germany and the US were in the program for an audience of 150-200 attendees representing all relevant segments of the Hungarian I4.0 ecosystem: large companies, SMEs, ICT service and technology providers, professional organizations and governmental decision-makers.

They appeared also on the "*Days of Industry*" spring fair organized by Hungexpo and other regional events, too, presenting their most recent achievements.

They continued the *Rudolf E. Kalman Distinguished Lecturer Programme* and the series of "*SZTAKI meetups*". Students of elementary and grammar school classes could visit their temporary exhibition displaying old IT devices, classical computers and other valuable relics.

MTA SZTAKI, in cooperation with the Wigner Data Center, continuously supports and develops the *MTA Cloud* research cloud infrastructure that is servicing the high computation needs of the MTA research institutes.

In the frame of a European project, they successfully supported several research communities in arts and social sciences that, via a scientific port developed and operated by them, these researchers could have access to the digital services adapted to the *European Open Science Cloud*.

III. Domestic and international R&D relations in the period of 1 January 2019 to 31 August 2019

International relations

Members of the Institute actively participate in the leadership of the most significant international organizations relevant to their research domain (including *IEEE, CIRP, IFAC, IMEKO, IAPR*), as well as in the working committees and preparation of the workshops thereof.

The Institute's successful participation in the *EU research programmes* continued in 2018: within the *Horizon 2020* programme, up to now, 20 winning projects may be reported with SZTAKI having the consortium leadership in 5 of them.

In the progress of the high-prestige *Teaming* research excellence programme of the EU *Horizon 2020 Widening* programme, the project "*Centre of Excellence in Production Informatics and Control"* (EPIC) was launched in 2017 under the Institute's leadership. By this, the institutionalized foundation of the long-term European cooperation between the Institute, the Fraunhofer Gesellschaft Germany and two faculties of the BME, i.e. the Mechanical Engineering and the Transportation and Vehicle Engineering Faculties, has been created to establish the internationally recognized Centre of Excellence of the cyber-physical systems.

The Institute has a strong practical project background in research and technological development for the *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 *Laboratory for Systems Theory of the Bordeaux University*, as well as the *German Aerospace Centre (DLR)* and the *European Space Agency (ESA)* should be mentioned.

The Institute runs the *Hungarian Office of World Wide Web Consortium (W3C*) that participates in the activities of the Working Groups, thus directly contributing to the development of the Web and having early access to information about the new development directions. 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

It is considered as a task of utmost priority that the results of the economic and social research related to *industrial digitization* as well as the *Industry 4.0 ecosystem* oriented concept be broadly publicized and utilized.

In December 2017, the *Industry 4.0 National Technology Platform (Ipar 4.0 NTP)* established in May 2016 under their leadership and comprising the parties interested in the digital transformation of industry, like local research institutes, educational institutions and industrial companies with premises in Hungary, was transformed into a *legal entity of an association*. They played a key role in the operation of the Platform and acted as its representative both in Hungary and abroad. They also catalyzed a nationwide survey on the Industry 4.0 readiness of industrial companies, performed the evaluation of the responses and published a report on it.

The cooperation with the SMEs has more and more become the responsibility of *InnoLabs Ltd.* that has grown also – in the framework of a strategic collaboration – to an outstanding local competence centre for *Siemens'* PLM software lines *Tecnomatix* and *Preactor APS* in various fields (e.g. discrete-event driven simulation or production planning and scheduling). A couple of companies from the automotive sector addressed InnoLabs with their problems in robotics. The professional background to meet these demands is furthermore provided by the Institute. They pursue joint research and development activity with several Hungarian companies. Due to the relations to Western Digital, their geographic scope has been extended to overseas countries (China and Malaysia), too.

They have filed the application for three new patents, 7 of the previous ones have been renewed, some of them even in multiple countries. The joint research work dating back to 12 years with *Hitachi Ltd., Manufacturing Technology Research Center* has been pursued. This year, one new joint patent was published and six of the previous ones were renewed.

The Institute is contributing by the results in its discovery research in the vehicle industry to the eminent scientific activity being pursued in Győr, thus supporting there the regional scientific and technological R&D&I activities. The basis of this cooperation is the *Centre of Excellence in Research of Vehicle Technologies (J3K),* founded by the Hungarian Academy of Sciences on the premises of the Széchenyi István University. The operation of the Centre is supported by MTA, Audi Hungaria, the Széchenyi University and the city council of Győr.

Their scientists took part in the planning and specification works of the automotive proving ground partially completed *in Zalaegerszeg, Hungary (ZalaZone)*. The proving ground enables the mandatory functional and performance testing of the prototypes of self-driving vehicles. The results of their research and development work with regard to the self-driving vehicles were successfully demonstrated on the site.

In the area of energetics, the work concerning the safe lifetime extension of the existing blocks, in the continued collaboration with the MVM Paks Nuclear Power Plant is to be 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 affiliate sites in the cities of Győr and Kecskemét.

National relations, participation in higher education

The *Industry 4.0 National Platform Associa*tion has been established under the leadership of the Institute which is also a founding member of both the *Hungarian 5G* and the *AI Coalition*.

They applied with success at the tender aiming to create the Hungarian Research Data Alliance (HRDA), i.e. the national node of the European RDA (Research Data Alliance). Many research institutes, universities, governmental and other organizations have joined HRDA so far.

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, SZE, PTE, ME, PPKE and Kecskemét University. On average, around 20 PhD students conduct research work at the Institute under the tutorship of researchers. 25 researchers of the Institute act as external and 5 as internal founding members in various doctorate schools.

IV. Summary of the major domestic and international grants won in the period of 1 January 2019 to 31 August 2019

AI development for Lung Cancer Diagnosis based on CT images
(Benczúr András, GINOP-2.2.1-18-2018-00004, 352 015 600 Ft, 2019-2022)

The goal of the project is to develop artificial intelligence technologies that reach the accuracy of an average radiologist, so that the software can serve as second reader for lung cancer early screening.

FLIPASED — Flight Phase Adaptive Aero-Servo-Elastic Aircraft Design Methods
(Vanek Bálint, EU H2020 815058, 1 066 875 €, 2019-2022)

The goal of the FLIPASED project is to address the joint design of aircraft flexible response, flight controls, onboard avionics and certification by tackling aeroelasticity, response to atmospheric turbulence in a multidisciplinary approach, leading to research results in novel aircraft design methods.

NEANIAS — Novel EOSC services for Emerging Atmosphere, Underwater and Space Challenges
(Lovas Róbert, EU H2020 863448, 341 375 €, 2019-2022)

The main goal of the project is to elaborate new EOSC (European Open Science Cloud) services for the emerging atmosphere, underwater and space research communities.

Ready2BIM — Planning of the renovation of residential buildings and adaption into the BIM workflow
(Benedek Csaba, 2018-2.1.3-EUREKA-2018-00032, 77 600 €, 2019-2021)

The goal of the project is to develop innovative geospatial services for supporting optimal urban energy consumption and city reconstruction tasks.

Integration of velocity and suspension control to enhance automated driving comfort in road vehicles

(Gáspár Péter, 2018-2.1.13-TÉT-FR-2018-00003, 1 981 000 Ft, 2019-2020)

The aim of the project is to pursue a cooperation with the Institut Polytechnique de Grenoble and GIPSA-LAB on the topic of integrating the velocity and suspension control in order to improve driving comfort.

Optimization in Sustainable supply chains
(Kis Tamás, SNN 129178, 35 754 000 Ft, 2019-2022)

In the project, new models and algorithms will be developed for optimizing supply chains, while taking into consideration the unexpected events, the environmental impacts, and the energy consumption.

Detection of the road environment of smart vehicles and traffic events in the vicinity of the vehicles
(Fazekas Zoltán, 2018-2.1.10-TÉT-MC-2018-00009, 1 999 600 Ft, 2019-2020)

The subject of the TÉT project being done in Hungarian- Moroccon cooperation is to explore which factor is more relevant in resolving some key questions arising in driving or concerning the road traffic: the connectedness of road vehicles, the possibility of interactions with other vehicles or the intelligent sensors in the vehicles themselves.

DigiPrime — Digital Platform for Circular Economy in Cross-sectional Sustainable Value Networks
(Pedone Gianfranco, EU H2020 873111, 460 066 €, 2019-2023)

DigiPrime has the mission to develop a new concept of Circular Economy digital platform overcoming current information asymmetry among value-chain stakeholders, in order to unlock new circular business models based on the data-enhanced recovery and re-use of functions and materials from high value-added post-use products with a cross-sectorial approach.

Axiomatic ranking
(Csató László, PPD2019-9/2019, 32 707 000 Ft, 2019-2022)

This research focuses on the analysis of different ranking problems, especially those based on paired comparisons, from a theoretical perspective.

HRDA — Hungarian Research Data Alliance
(Kacsuk Péter, RDA Call for New Nodes- Wave II, 32 400 €, 2019-2020)

The HRDA aims to promote best practices of research data management in Hungary under the umbrella of RDA (Research Data Alliance).

V. List of the most significant scientific publications in the period of 1 January 2019 to 31 August 2019

1. Baráth, D.; Eichhardt, I.; Hajder, L.: Optimal Multi-View Surface Normal Estimation using Affine Correspondences. IEEE TRANSACTIONS ON IMAGE PROCESSING, 28: 7, pp. 3301-3310. (2019) SZTAKI
2. Bauer, P.; Hiba, A.; Bokor, J.; Zarándy, Á.: Three dimensional intruder closest point of approach estimation based-on monocular image parameters in aircraft sense and avoid. JOURNAL OF INTELLIGENT & ROBOTIC SYSTEMS, 93: 1-2, pp. 261-276. (2019) SZTAKI
3. Csáji, B.Cs.; Kis, K.B.: Distribution-Free Uncertainty Quantification for Kernel Methods by Gradient Perturbations, MACHINE LEARNING, 108: 8-9, pp. 1677-1699. (2019) SZTAKI
4. Csató, L.: A characterization of the Logarithmic Least Squares Method, EUROPEAN JOURNAL OF OPERATIONAL RESEARCH, 276: 1, pp. 212-216. (2019) SZTAKI

5. Gödri, I.; Kardos, Cs.; Pfeiffer, A.; Váncza, J.: Data analytics-based decision support workflow for high-mix low-volume production systems, CIRP ANNALS-MANUFACTURING TECHNOLOGY, 68: 1, pp. 471-474. (2019) SZTAKI
6. Györgyi, P.; Kis, T.: A probabilistic approach to pickup and delivery problems with time window uncertainty, EUROPEAN JOURNAL OF OPERATIONAL RESEARCH, 274: 3, pp. 909-923. (2019) SZTAKI
7. Ivanyos, G.; Kutas, P.; Rónyai, L.: Explicit equivalence of quadratic forms over Fq (t), FINITE FIELDS AND THEIR APPLICATIONS, 55, pp. 33-63. (2019) SZTAKI
8. Kelen, D.; Daróczy, B.; Ayala-Gómez, F.; Ország, A.; Benczúr, A.: Session Recommendation via Recurrent Neural Networks over Fisher Embedding Vectors, SENSORS, 19: 16, Paper No.: 3498, 23 p. (2019) SZTAKI
9. Kiss, T.; Kacsuk, P.; Kovacs, J.; Rakoczi, B.; Hajnal, A.; Farkas, A.; Gesmier, G, Terstyanszky, G.: MiCADO-Microservice-based Cloud Application-level Dynamic Orchestrator, FUTURE GENERATION COMPUTER SYSTEMS, 94, pp. 937-946. (2019) SZTAKI
10. Lanza, G.; Ferdows, K.; Kara, S.; Mourtzis, D.; Schuh, G.; Váncza, J.; Wang, L.; Wiendahl, H-P. : Global production networks: Design and operation, CIRP ANNALS-MANUFACTURING TECHNOLOGY, 68: 2, pp. 823-841. (2019) SZTAKI
11. Lipták, Gy.; Pituk, M.; Hangos, K.M.: Modelling and stability analysis of complex balanced kinetic systems with distributed time delays, JOURNAL OF PROCESS CONTROL, 84, pp. 13-23. (2019) SZTAKI
12. Manno-Kovacs, A.: Direction Selective Contour Detection for Salient Objects, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, 29: 2, pp. 375-389. (2019) SZTAKI
13. Manno-Kovacs, A.; Giusti, E.; Berizzi, F.; Kovacs, L.: Image Based Robust Target Classification for Passive ISAR, IEEE SENSORS JOURNAL, 19: 1, pp. 268-276. (2019) SZTAKI
14. Nagy, B.; Benedek, Cs.: 3D CNN Based Semantic Labeling Approach for Mobile Laser Scanning Data, IEEE SENSORS JOURNAL, 19: 21, pp. 10034-10045. (2019) SZTAKI
15. Németh, B.; Fényes, D.; Gáspár, P.; Bokor, J.: Coordination of Independent Steering and Torque Vectoring in a Variable-Geometry Suspension System, IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, 27: 5, pp. 2209-2220. (2019) SZTAKI
16. Rödönyi, G.: Heterogeneous string stability of unidirectionally interconnected MIMO LTI systems, AUTOMATICA, 103, pp. 354-362. (2019) SZTAKI
17. Venkataraman, R.; Bauer, P.; Seiler, P.; Vanek, B.: Comparison of fault detection and isolation methods for a small unmanned aircraft, CONTROL ENGINEERING PRACTICE, 84, pp. 365-376. (2019) SZTAKI
18. Zvara, Z.; Szabó, P.G.N.; Balázs, B.; Benczúr, A.: Optimizing distributed data stream processing by tracing, FUTURE GENERATION COMPUTER SYSTEMS, 90 pp. 578-591. (2019) SZTAKI