Institute for Computer Science and Control
Hungarian Academy of Sciences

H-1111 Budapest, Kende u. 13-17, 1518 Budapest, Pf. 63.
Tel: 279-6159, Fax: 466-7503,
http://www.sztaki.hu/, e-mail: laszlo.monostori@sztaki.mta.hu

Annual Report 2016
on the Scientific Activity
at MTA SZTAKI

Budapest, 14 March, 2017

CONTENTS

I. Priorities and main tasks in 2016

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 tracebility, 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 contribute to the domains primarily supported by the EU Horizon 2020 Framework Program, and, how they are simultaneously aligned 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 and sustainable development; security and surveillance; networks, distributed computing and Future Internet are covered by separate sub-chapters.

THE MAIN DIRECTIONS IN BASIC RESEARCH

Computer Science
The research pursued in this area leverages the synergies of several interrelated fields, including the theory of algorithms and databases with emphasis on new parallel hardware architectures, data mining, information retrieval, machine learning, and 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, 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 2016:

- In the area of *parameterised algorithms*, one of the main directions of the research is the so-called square root phenomenon for planar graphs: i.e. the widely observed phenomenon that for many combinatorial algorithmic problems the optimal algorithm is exponential in the square root of the parameter. By substantially generalising and extending the earlier results in the literature, it has been established that the phenomenon holds for many algorithmic problems modelling the pattern search in planar graphs. Similar results were obtained for counting triangle meshes in 2D point sets.
- *Network design problems* are typically modelled by directed graphs. Two basic tasks are to find the minimum weight subgraph to reach all other nodes from a given node and to reach all nodes from all other nodes. While the two tasks appear very similar, their parametric complexity properties are very different. One may define a number of additional network design problems by including more reachability constraints. A full characterisation of all reachability constraints was provided when the task is solvable in uniform polynomial time and it was shown that the corresponding algorithmic problem is difficult to be solved in all other cases.
- *Algebraic algorithms*: randomized polynomial time algorithms were specified for computing the nontrivial zeroes of quadratic forms in more than three variables over fields of odd characteristics. The new method is based on splitting the input form into two ones that one can efficiently find values taken by both forms. The result is also based on bounds for the number of irreducible polynomials over finite fields that meet certain congruency constraints.
- Deterministic polynomial time algorithms for *noncommutative matrix rank computation* were suggested in the case when the elements of the matrix are multivariate linear polynomials. The noncommutative rank is defined by considering the matrix as a matrix over the free skew field generated by the variables.

These research activities were supported largely by high prestige grants: the *ERC Starting Grant* and the *MTA Momentum Grant*. SZTAKI's 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, methods 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 control 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. The conventional convex LMI/LTI design approaches are only applicable to LPV and qLPV problems in a very conservative way. Therefore, approaches based on the separation theory and IQC (Integral Quadratic Constraints) techniques are preferred. Using the dynamic IQC

theory, new results on robust control design methods capable to retain closed loop system stability were published. The role of the Potapov-Ginsburg transformation was classified and integrated in the stability retaining factorization theory. The geometric aspects of the Klein approach were successfully applied to the analysis of robust control problems. The principle of guaranteed closed loop stability and the properties of the related stability retaining operation of systems were sufficiently clarified and explained in a wider group theory context. Moreover, the relationship of Jordan algebraic problems with robust stability was highlighted. Examples were shown on the nontrivial application of a non-standard Youla parametrization technique in a geometric setting.

- New methods have been elaborated for the synthesis and analysis of fault tolerant control systems, using the approaches of *null space-based structural reconfiguration and fault detection* and isolation. Design methods of annihilator systems for LPV and qLPV cases were developed. Based on the null space techniques, design methods for fault tolerant reconfiguring algorithms were developed that guarantee stability and are capable to retain the performance of the system. The results were applied to a variety of complex control problems in ground and aerial vehicle dynamics.

- Additional significant research efforts were made with respect to the efficient modelling of *flexible engineering objects,* such as e.g. aircraft wings, by means of systematic model reduction techniques. New results were obtained for the reduction of many hundred-dimensional LPV and qLPV models using modal decomposition, state consistency check and Youla parametrization.

- In the *area of signal processing and system identification*: based on rational orthogonal basis the construction of a technique for the identification of the system poles was developed. The method is based on the hyperbolic distance of the poles and is capable to provide for model reduction in H2.

The results obtained in systems and control theory have been used primarily in the energy, transportation and vehicle industries (see later the sections: 'Vehicle and transportation systems', as well as 'Energy and sustainable development').

Engineering and business intelligence

The design, planning, and control of cyber-physical production and logistics systems, as well as the adaptation of their operation to the ever changing conditions calls for interdisciplinary research in a number of fields related to computational theory, operations research, manufacturing science and artificial intelligence. Main results in basic research obtained in 2016 are as follows:

- In collaboration with leading research institutes worldwide, SZTAKI has defined *cyber-physical production systems*, characterised their main features, challenges and future application opportunities, as well as pointed to the fact that the mutually stimulating and interacting development of manufacturing, information and communication sciences has opened a new era by now.

- In *grid computing* environments, the improvement of various well-known scheduling strategies by combining tasks was analysed.

- *Approximation schemes* for parallel machine scheduling problems augmented with non-renewable resources have been created, along with the definition of the necessary conditions for the existence of such schemes. With these new results, the approximability of the maximum timespan objective is fully understood in single and parallel machine environments.

- New linear-programming based *exact methods for the resource-constrained shortest path problem* have been developed. One of the interesting observations of the

computational experiments is that most of the widely used benchmark problem instances can be easily solved by simple pre-processing.

- The classes of *cutting planes* for mixed-integer linear programming (MILP) were analysed. In collaboration with Egon Balas it was shown that the generalised intersection cuts defined recently by Balas and Margot are equivalent to the well-known lift-and-project cuts, and also provide sufficient conditions for such generalised intersection cuts which are significantly different in quality from the standard cuts used in MILP software packages.
- A new identification method was developed as a more robust version of the previously proposed *SPS (Sign-Perturbed Sums)* non-asymptotic, distribution independent identification algorithm. The new method can construct guaranteed confidence regions for parameters of dynamic systems even in case of non-symmetric noise distributions. The SPS algorithm was also extended to cover LAD (*least absolute deviation*) based approaches.
- A hierarchical approach was introduced for solving *assembly process planning* problems using combinatorial optimisation and geometric reasoning methods. The goal is sequencing the assembly tasks and assigning them to resources in the most efficient way, while satisfying all relevant technological, geometrical, stability, and etc. constraints.
- A method was developed for solving *trajectory planning problems* for *redundant industrial robots* with multiple degrees of freedom. The method transforms the operations specified in the coordinate system of the workpiece or workcell into motion in the robot's joint space, while it exploits the redundancy of the robot's kinematic chain to optimise a given objective function (e.g. cycle time).
- A new method based on a Stackelberg game model and bi-level programming was proposed for *tariff optimisation* in *smart energy grids*. In this game theory model, the grid operator sets the tariff considering the model of the consumers' different groups in such a way that the grid-level consumption, determined by the consumers' demand response, follows a given target consumption set by the operator, as closely as possible.

Most of the above research was carried out in the frameworks of national and EU supported research projects. In some cases, the institute acted as consortium leader. The theoretical results provided a solid foundation for subsequent industrial applications (see later sections on Production informatics and logistics, as well as on Energy and sustainable development).

Machine perception and interaction

Novel solutions in projective geometry: A new theoretical framework has been developed for view registration, where the point based correspondences between images were enhanced by taking into consideration the transformations of the projected patches between stereo images. The first-order approximation of these transformations is given by affine transformations. While the standard methods in the field of projective geometry only consider locations in images, it has been shown that the corresponding affinities can also be utilised in 3D reconstruction and camera calibration. It has been proven that the camera parameters, spatial locations, and surface normals are strongly related to both the point locations and the corresponding affine transformations between stereo images.

- A description has been given for the algebraic relation of the plane-plane homography and the local affine transformations. It has been shown that only one affinity and the coordinates of the related point correspondence exactly determine the homography if the epipolar geometry is known for a stereo image pair. It has also been proven that at least two affine correspondences are required for this task in the case of unknown

epipolar geometry.

- It has also been shown that the affinity, usually represented by four parameters, has only two degrees of freedom (DoF) for known epipolar geometry. An optimal method has been proposed to compute the closest valid affinity considering the epipolar constraint, where validity means consistency with the camera motion. The solution is obtained very fast as the estimation is transformed into a six-dimensional inhomogeneous linear system of equations.
- An optimal method was developed to compute the surface normal for calibrating an image pair if both point locations and the related affine transformation are given. It has been justified that the camera calibration is more accurate if the affine transformations are also exploited during the calibration in conjunction with the point locations.
- In order to compare the feature matcher algorithms proposed in the literature, researchers have developed a structured-light scanner-based 3D reconstruction algorithm generating highly accurate *ground truth* point trajectories.

Evaluation of multimodal remote sensing image data: a new theoretical model has been introduced for efficient analysis of multimodal data (including 2D satellite images and 3D LIDAR point clouds), together with change detection tracking in multi-temporal image sequences.

Deep-learning for image analysis and pattern recognition: Deep Convolution Neural Networks have been developed for natural-like colouring of grey-scale images and for efficient usage of big image databases.

Modern intraocular lens, which are generally applied as surgical replacement of the crystalline lens in cataract patients, provide multifocal imaging and this way ensure near and far distance vision of enhanced acuity without the need of the application of any additional correction glasses. By the application of special multifocal video recordings and neuromorphic simulation tools, it was investigated how the performance of the human visual system changes if both the sharp and blurred versions of the same object are projected to the retina at the same time. Based on the simulations the visual saliency maps were calculated and compared for the single and multifocal cases. The results show, that in normal circumstances there is no considerable difference between the single and multifocal versions of these maps. This way, it is found that the special imaging properties of the multifocal intraocular lens usually do not disturb substantially the visual attention functions.

A critical step in the *holographic imaging* is the focusing which means the identification of the depth of the inspected object in the sample. A method based on the posterior changing of the numerical aperture by manipulating the hologram in the frequency domain was developed in the field of numerical optics that can extract the boundaries of the objects. The focus on these modified images can be improved efficiently even by using the traditional focusing algorithms which perform poorly on the regular holographic images.

RESEARCH AND DEVELOPMENT ACTIVITIES

Vehicle and transportation systems

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

Land vehicles and road transportation systems
- Energy optimisation in the design of the speed profile of heavy road vehicles was investigated in the *SEPPAC project* with regard to the requirements and infrastructure development of future intelligent transportation systems. Beyond the traditional delivery time optimisation, the minimisation of fuel consumption is included in the design criterions. The solution is capable of handling a large number of various limiting factors and parameters such as the effects of road geometry, traffic restrictions and weather conditions. The efficiency of the control methods were verified and validated by computer simulations and vehicle measurements performed in real traffic situations.
- *Hybrid control methods of road vehicles*: hierarchical distributed control strategies were developed ensuring improved effectiveness of the control of hybrid and electric road vehicles. Design methods were developed for control tasks relevant to improved road stability, road safety and energy efficiency based on smart sensors, as well as sensor fusion and communication networks.
- *Camera sensor based driver's assistance system* for the detection of road signs and the duly acquisition of various environmental parameters for the support of safe and dependable driving performance was made with close collaboration with the Robert Bosch Knowledge Centre. The solution for the control of partially automated vehicle platforms was invented together with Knorr-Bremse Ltd, which, beyond the control performance issues, takes the operational effectiveness of the platoons into consideration.
- *Photosensitive imaging sensor lattices* were designed and used for the detection of movement and measurement of speed of fast moving objects. According to simulation studies and preliminary measurements, the lattice is capable simulatneously to produce sharp images and determine the speed of moving objects with great accuracy from a single exposition. The low-cost device is positioned for smart city applications and automated transportation systems.
- *Location detection with geographical information system (GIS) support:* A new algorithmic methodology has been developed for the integration of GIS technology in vehicular systems applications in an attempt to exploit the accurate 3D point cloud maps produced by them. Thus, vehicles with state-of-the-art inbuilt detectors may retrieve relevant information in real time to support fast navigation. It was also demonstrated that vehicle sensor readings can update GIS databases.

Avionics applications
- The *VISION project* aims at the enhancement of safety of air transport systems by applying novel technologies in the control and navigation systems of aircrafts. The goal is to extend aircraft navigation systems with machine vision technology and advanced mathematical methods capable of forecasting. Electronic imaging, image processing and sensor fusioning methods potentially useful in automatic landing systems were investigated. The application of the novel technology makes the detection of landing fields of given geometry effectively feasible. Moreover, the estimation and monitoring of the distance from the landing threshold can be effectively supported in real time.
- *Automatic landing algorithms of unmanned aerial vehicles* were considered in various fault tolerant reconfiguration strategies. The algorithms were adapted to control regimes subject to the failure of the ILS and GPS sensors. The performance of the algorithms was verified by computer simulations, specifically designed for this task.
- Relying on the benefit of an *on-board vision system,* a navigation device fully based on visual information was constructed. The device is capable to enhance of accuracy of inertial navigation of robotic flying machines (drones) by a real time estimation of the

horizon line. Moreover, the visual navigation system is able to determine efficiently even in case of malfunctioning sensors in the sensor grid whatever the vehicle position and its spatial direction are while approaching the airstrip when landing, thus increasing the landing safety considerably.

These results attained in national and European research projects, focussing on the practical applicability thereof, were beneficial in various industrial projects accomplished in close cooperation with respected industrial partners such as, e.g. Airbus, Bosch and Knorr-Bremse. The most important utilisations of these methods include the design of fault tolerant architectures for onboard vehicle control systems, the coordinated control solutions for vehicle fleets, the various sensor fusioning methods and the integrated use of electronic breaking and steering systems solutions.

<u>Production informatics and logistics</u>

Research, development and innovation in *production informatics and logistics* focus on the configuration, modelling and operational control of production, service provider and logistics systems. In this field, the institute aims at closely following the current trends in cyber-physical production systems and adapting them to the real environments at the shop floor, company and network levels. Key results obtained in 2016 are as follows:

- A new design and management methodology was defined and implemented to minimise total lifecycle costs of *modular reconfigurable assembly cells*, by predicting and considering the anticipated operational costs of the system already in their early design stage.
- A *robust production and capacity planning methodology* was developed for flexible, manual assembly lines, resulting in cost-minimising executable plans which are robust against stochastic processing times and uncertain reject rates.
- The *custom-tailored production planning system* developed for Audi Motor Hungaria Kft was validated, fine-tuned and deployed for pilot testing on all production lines at the facility.
- In collaboration with Hitachi's Manufacturing Technology Research Center and Fraunhofer IPA, Stuttgart, a distributed system based on the so-called *Manufacturing Service Bus* (MSB) has been developed for the easy and secure interlinking and control of geographically dispersed manufacturing resources. The system supports the sharing of production and logistics information, as well as the planning, forecasting and real-time monitoring of operations.
- In the case of organisational heterogeneity - especially in dynamically changing networks - the *data-interoperability* and *real-time data processing* are supported by a newly developed common data-type language, a type-inference algorithm that verifies the dataflow network, as well as a reactive dataflow-execution framework. All these enabling technologies of CPPS have been adapted to a logistics network, too.
- The future development trends of new information technology architectures conforming to the processes and complexity of the productions systems apt to react to the ever increasing and unique market demands, were analysed and the requirements of *interoperability* have been re-defined.
- *Artificial neural network* models developed and trained for the Anton AQ company were built into the controllers of the machines operating on the shop floor where they routinely identify critical situations and states of the process steps in real time.
- For Opel Szentgotthárd Kft, a *business intelligence software system* was developed which is capable to collect, store and analyse shop floor data, as well as to generate intuitive and configurable reports and summaries. This solution is considered as an example to be used in the entire multinational company group.

The activities pertaining to applied production informatics and logistics were carried out in the framework of the *Fraunhofer-SZTAKI Project Center for Production Management and Informatics* established in 2010.

Energy and sustainable development

A fundamental precondition of sustainable development is the capability to adapt the energy production, transfer and transformation systems to the changing demands and available facilities. In the area of control and surveillance of these systems, one of the key preliminaries is the increased data processing, storage and transmittance capacity of the applied IT devices opening thus new opportunities also to enhance automation and efficiency; however, also generating new problems to face. In this context the following topics were addressed with special focus:

- As part of the traditional industrial activities of the institute, the continued partnership with the *Paks Nuclear Power Plant* is the basis of its strategic collaboration with the energy sector. Background expertise for the refurbishment of existing control systems (e.g. the Protection System of the Nuclear Plant and the Control and Safety Protection System), as well as for the preparation and technical establishment of future projects aiming at the lifetime extension of equipment was provided. With its strong knowledge in systems control, the institute effectively supported the lifetime extension and capacity preservation projects of the power plant. It took also part with its IT experts in the preparatory work of the planned new power generation units.
- A *cloud-based analytical module*, commissioned by GE Hungary, was developed as part of *a smart city* project. It applies modern signal processing and statistical learning techniques to analyse the measurements coming from a wireless multi-sensor network installed on the public lighting system in the XIIth district of Budapest. The module produces short-term forecasts and intensity maps, both accompanied by reliability estimates.
- A central controller architecture was proposed for *intelligent public lighting systems* that enables controlling the lighting system, monitoring the system and its environment, providing the collected data to external parties, and optimising the energy management of the system. Crucial technical and economic questions of such systems were investigated using data from a physically built prototype which is operated as a routine service.
- The development of the special mathematical solution package for an efficient *energy management* platform with the sponsorship of the *EC Joint Research Centre (JRC)* has been completed. The final result is an optimalisation engine capable to solve efficiently large-scale linear and second-grade conic programming tasks. Additionally, an interface was created between the optimalisation engine and the AIMMS modelling system.

Security and surveillance

- In conjunction with the *European Campaign on Cyber-security*, complex analytical and coordinating tasks of how to handle a coordinated cyber-attack extending over several countries were accomplished.
- Typical hyperspectral cameras nowadays apply 4-25 spectral bands only, due to technology limitations. A numerical method was developed to bridge this gap which, exploiting the 'a priori' information that the spectrum is locally smooth and contains positive values only, restores the entire spectrum. By using appropriate optical filters the error of the spectrum reconstruction can be greatly reduced within one range and the calculated continuous spectrum thus becomes usable in medical, food inspection and agricultural applications.
- *The combination of the fluorescent microscopy and digital holographic microscopy* led to a new microbiological measurement method and tool. This patented new technology expands the traditionally planar fluorescent microscopic imaging to volumetric (3D) imaging that enlarges the volume of the sample by two orders of magnitude. The algae

in the samples contain fluorescent dies which are detected by the fluorescent imager and the system projects their position to the holographic image constructed.

Networks, network systems and services, future Internet

- *Shared Risk Link Group (SRLG)* is a key concept in *communication networks*. An SRLG is such a set of connections where the network must tolerate their simultaneous failure. When designing a basic network, the list of SRLGs is a key factor which significantly affects the reliability of the network. In a regional failure, more than one network elements in physical proximity fail. It is generally believed that the number of potential regional failures is so large that they cannot be enumerated as a SRLG. This belief has been disproved in an important case where the diameter of regional failures is limited. A fast algorithm was found to enumerate all possible SRLGs and a favourable upper bound on their number as a function of the basic network parameters was specified.
- *Occopus based cloud orchestration*: In order to improve the usability of cloud systems higher level tools were investigated by which users can dynamically deploy complex virtual infrastructures in clouds in a scalable way. As part of this investigation the Occopus cloud orchestrator tool was significantly enhanced and 4 new versions therof were released.
- In order to support the more and more popular *docker container based applications,* a fast and efficient way of creating docker clusters in both the MTA Cloud system and the generally accessible relevant academic and commercial cloud systems used in Europe was elaborated.
- *Precision agriculture*: a research infrastructure for supporting precision agriculture that is unique and exceptionally large in the region was further developed. This Big Data and cloud oriented infrastructure established in 2016 collects agriculture related data from nearly 1000 sensor columns placed over 8000 hectares of more than 50 farmers in order to create an efficient agricultural decision making system.

b)   Science and society

MTMT (The Repository of Hungarian Scientific Publications) is a national bibliographic register which has to meet special security and usage requirements. The institute had been developing the new digital archiving software system of this scientific publication registration service. In the project, the final version of the system has been completed, and the testing and the integration processes have started. The new system is to be installed in 2017.

The concept of the *MTA Cloud system* was presented and its production version was rolled-out for the researchers of MTA on the 1st of October 2016. By the end of 2016 the MTA Cloud services were used by 18 projects from 8 academic research institutes. Negotiations about collaboration were started with the organisation EGI.org that is responsible for coordinating grid and cloud infrastructures in Europe. The goal is to make MTA Cloud part of the EGI Federated Cloud infrastructure in the long term.

As in the past 21 years, the unique *KOPI Plagiarism Search* online service is continuously operated, as well as the *SZTAKISzótár (SztakiDictionary),* to which the Chinese dictionary was added in 2016. Additional languages will follow soon as part of the expansion programme.

In May 2016, the *Ipar (Industry) 4.0 National Technological Platform* (I4.0 NTP) was founded under SZTAKI's leadership with the participation of several dozens of Hungarian research institutions, educational institutions, companies and professional associations having premises in Hungary. SZTAKI organised two plenary meetings of the platform in 2016,

participated in the activities of its seven working groups, and specifically, as leader of the Strategic Planning working group coordinated the drafting of a short term I4.0 action plan for the government and has been managing the preparatory work for a nationwide I4.0 survey.

On the annual *Industry's Day* exhibition at the HUNGEXPO fair the institute organised a workshop entitled "*Industry 4.0: New challenges and opportunities*" where their latest R&D results were presented in five lectures (24 May, 2016).

The SZTAKI-coordinated *RobustPlaNet FP7* project presented its main results successfully at the *Hannover Fair* in April 2016. A special session was organised at the fair, where researchers and developers of the project demonstrated the results achieved in the fields of production and capacity planning, as well as the reconfiguration and optimisation of production systems.

The European Week of Robotics with its more than 800 registered events was considered one of the most important European programmes for disseminating IT knowledge to the public. In order to inform the generations of the future, even young guests from kindergartens were received by the institute on this occasion.

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 2016 the institute outperformed the previous years by issuing 60 press releases and having nearly 250 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 2016 by a series of articles in *Forbes, Computerworld, GyártásTrend, Techstory, Techmonitor, Piac és Profit, Magyar Idők*, 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, index.hu, origo.hu*, *hvg.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.

At the end of 2016 the new webpage of the institute was launched, refurbished completely in design, technology, structure and contents to match the usual academic level, the 21st century expectations and the contents consumption needs of its target audience.

As a result of the continuous enhancement of the *GUIDE@HAND* application set for smartphones, today there are 60 applications in the family which are mostly to be downloaded free of charge from the applications stores (*AppStore, GooglePlay*), covering areas like preservation of the cultural heritage, tourism, education, sport, culture and science. A sample of the outstanding examples comprises: the Széchenyi István University, the Industry 4.0 National Technology Platform, the Pop History Educational Path, the application presenting the events of the World Day of the Water or the Night of Museums, the application D+ Sport supporting health and active lifestyle, then the applications for real or virtual promenades like 'The Ferencváros district in the revolution', the 'Pauline Tour', the 'Festive Sonnet Wreath' developed for the Day of Hungarian Poetry, or 'An Adventurous Time Journey in the Past' presenting the first historical computers.

III. Domestic and international relations in 2016

Organising international and outstanding domestic events

Between 26 and 28 May, 2016 the *29th Conference* of the *European Chapter on Combinatorial Optimization* (*ECCO 2016)* was held in Budapest in co-organisation with ELTE.

The *8th Hungarian Conference on Computer Graphics and Geometry* was co-organised in 2016 by the institute who was later again a cooperating partner of ELTE, Faculty of Informatics, who hosted the *Conference "Informatics Europe"* in October 2016.

In September 2016 it was our institute that hosted the General Assembly of *IMEKO (International Measurement Confederation)* and later, in October the Annual Meeting of *ERCIM (European Research Consortium on Informatics and Mathematics),* as well as the workshop of the *European Manufuture High Level Group.*

The 2016 competition of the well-known *RecSys Challenge* was managed by the institute using the social media XING. XING is extensively used in Germany and offers facilities both to advertise and, to search for, job vacancies. Currently, XING has 15 million users and stores 1 million job advertisements. Its goal is to select for the user the job offerings fitting the best. In the competition the participants had to solve this task in the possible most exact way. The closing event took place at the *ACM RecSys 2016 Conference* in Boston.

In cooperation with the OTP Bank SZTAKI organised the most relevant European conference on machine learning, the *ECML/PKDD Discovery Challenge 2016 Competition on Bankcard Usage Analysis.* The task was to predict the behaviour of the card users. There were over 30 local and international teams participating. The results were presented at the *ECML/PKDD 2016 Conference* in Italy.

We participated in organising the *MOL Bubi* (the municipal bike-sharing rental network) *data analysis competition*, too.

<u>International relations</u>

Members of the institute play an active role in the leadership of the most significant international societies relevant to their research domain (including *IEEE, CIRP, IFAC, IMEKO, IAPR*), as well as in the working committees thereof and, also in preparing their conferences and workshops.

The institute's successful participation in the EU research programmes continued in 2016: within the 7th Framework Program the institute participated in 45 grant winning projects, in 8 cases it had even the role of the consortium leader. In the Horizon 2020 program, up to now 12 winning projects may be reported with the consortium leadership in 3 of them.

The proposal on *Centre of Excellence in Production Informatics and Control (EPIC)* which was submitted to the most prestigious, so-called *Teaming* call of the Horizon 2020 Widening Programme was ranked as second in the overall European competition. Hence, the Institute, the German Fraunhofer Gesellschaft, as well as two faculties of the Budapest University of Technology and Economics can shortly establish an institutional European cooperation. EPIC will continue and leverage the existing activities of the Fraunhofer-SZTAKI Project Center on Production Management and Informatics (FhG PMI) and will become an internationally acknowledged centre of excellence of cyber-physical systems.

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.

The traditional research collaboration with *Hitachi's Manufacturing Technology Research Center* was continued that resulted also in this year in joint publications and two patents applications, as well as in a common research project of SZTAKI, Hitachi and Fraunhofer IPA.

In a strategic cooperation partnership, the institute operates an outstanding national competence centre for Siemens' product lifecycle management software package called Technomatix.

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.

R&D relations with industrial companies

The collaboration with the *Manufacturing Technology Research Center, Hitachi Ltd.* dating back to 10 years by now was pursued this year too. Also, one of the local domestic competence centres for the Tecnomatrix product family of the SIEMENS PLM software is operated by the institute.

Applied research and development related to production informatics and logistics were carried out in the framework of the *Fraunhofer-SZTAKI Project Center for Production Management and Informatics*. Beyond performing contract-based research for small and medium-sized enterprises, major results were commissioned by world-class manufacturing companies such as Hitachi (distributed control), Audi Motor Hungaria (production planner system), GE Hungary (smart city), Opel (business intelligence), Volvo (human-robot symbiosis in the assembly), Knorr-Bremse Fékrendszerek Kft (manufacturing system configuration), Festo, BPW, AQ Anton, Aventics Hungary, Hoya (digital manufacturing).

In the framework of the Centre of Excellence in Research of Vehicle Technologies (J3K), operated by MTA SZTAKI at the campus of the Széchenyi István University, Győr on behalf of the Hungarian Academy of Sciences, the institute contributes with the results of its discovering research work in the vehicle industry to the outstanding scientific R&D&I activity in the Győr region. The operation of the Centre is secured by the joint support of MTA, Audi Hungaria, the university and the City of Győr.

SZTAKI's 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 contributed also 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 measurements and regulation of the traffic licencing of self-driving vehicles on public roads.

In the nuclear energy field, concerning the safe lifetime extension of nuclear reactors, the continued collaboration with the Paks Nuclear Power Plant, Hungary should be mentioned. The capacity reservation efforts with special respect to its control technics aspects were made in close cooperation with MVM Paks II Power Plant Development Company and MVM ERBE ENERGETIKA Mérnökiroda Zrt.

Following the founding of the Győr affiliation, the institute has established a new one in Kecskemét in 2016.

<u>National relations, participation in higher education</u>

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.

In 2016 a cooperation agreement was signed with BME and ELTE to launch and manage jointly MSc courses in autonomous vehicle engineering.

IV.   Summary of the most relevant national and international grants won in 2016

EPIC   Centre of Excellence in Production Informatics and Control
              (EU H2020 Teaming, 5 158 750 €, *2017-2024)*
The goal of the project is to establish an Industry 4.0 focused research and innovation Centre of Excellence in coordination of the NRDIO (National Research, Development and Innovation Office) and participation of several Fraunhofer Institutes and two faculties of BME.

SYSTEMATICGRAPH Systematic Mapping of the Complexity Landscape of Algorithmic Graph Problem
              (ERC, 1 532 000 €, *2017-2022)*
The project bid is about to investigate the efficient solvability of calculation problems of graphs and networks, thus aiming to contribute to the success of the potential application areas.

COLA   Cloud Orchestration at the Level of Application
              (EU H2020, 455 000 €, 2017-2019)
The main objective of the project is to create a cloud based framework that enables the fast and efficient adaptation of a large set of different commercial applications for the most important cloud systems by using special application templates developed by the project.

Linking   Transnational, multimodal traveller information and journey planning for
Danube   environmentally-friendly mobility in the Danube Region
              (INTERREG EUROPE, 344 512 €, 2017-2019)
The aim is to foster the transnational environment-friendly mobility in the Danube Region by producing a multi-purpose traveller information and journey planning system.

INTRO4.0   Methodology for preparing the implementation of the Industry 4.0 technology at SMEs
              (EU EUREKA, 32 908 €, 2016-2018)
This project aims to design solutions for implementing the Industry 4.0 technologies, with the

focus on the SME sector.

OWETIS   Observation of Local Wetland Areas from Satellite Imaging
(European Space Agency, 119 999 €, 2017-2018)
By analysing hyper-spectral satellite images and conducting on-site validation measurements, the project aims to explore the rare and lonely locations / spots of bio-diversity.

Ipar 4.0   Industry 4.0 research and innovation centre of excellence
(GINOP-2.3.2, 1 835 792 eFt, 2016-2020)
The project targets those areas of peak technology where the need for outstanding basic research must be handled together with the urgent demand for practical solutions in an integrated way.

Biomimicry   DNA encoded, 3D printing ready polymer dissolving only in high ion content
3D   liquid, and a hybrid UAV-UUV drone prototype made from the developed material ready for commercial applications
(GINOP-2.2.1, 44 754 eFt, 2017-2019)
Within the project MTA SZTAKI is responsible for the autopilot architecture and all its avionics components including HW and SW. Sensor fusion and navigation methods are another area in which SZTAKI is contributing.

OTKA   Deep learning of morphological structure
(OTKA, 44 000 eFt, 2016-2020)
In the past few years, methods of deep learning have yielded breakthrough results in several areas, yet there remains one problem area, i.e. the analysis of word-internal structure (morphological analysis) that is still dominated by manually written rule systems.

OTKA   Exploration of the environment in dynamic scenery from partial views
(OTKA, 35 516 eFt, 2016-2019)
One main goal of the project is to improve the conventional Simultaneous Localisation and Mapping calculus by statistically optimising the models of changing parts: objects and events. Another important enhancement is expected from using a network of diverse scanning devices that they can continuously build the model of a given local environment, using co-motion statistics for describing the foreground.

OTKA   Instant environment perception from a mobile platform with a new generation geospatial database background
(OTKA, 47 952 eFt, 2016-2020)
The main goal of the project is to facilitate the joint exploitation of the measurements from the cars' instant sensing platforms and offline spatial database contents of the newest GIS solutions.

MTA   Ranking with paired comparisons: theory and applications
Prémium   *(MTA Prémium, 27 525 eFt, 2016-2019)*
The research applies an axiomatic approach to the ranking of objects based on their paired comparisons: what are the logical connections between different properties and under what conditions are they satisfied by popular methods. The results can be used for a novel solution of various ranking problems in sport, scientometrics and the comparison of universities.

V.   List of the most significant scientific publications in 2016

<u>Books</u>

1.   Kecskeméti G, Kertész A, <u>Németh Zs</u> (ed.): Developing interoperable and federated cloud architecture. Hershey: IGI Global, 2016. 398 p. (ISBN:9781522501534)

2. Tettamanti T, Varga I, <u>Csikós A</u>: Közúti mérések: Eszközök és módszerek a közúti járműforgalom megfigyelésére. Budapest: Typotex, 2016. 292 p. (ISBN:978-963-279-916-2)

3. <u>Vámos T</u>, Bars R, <u>Bokor J</u>, <u>Szabó Z</u>, <u>Gáspár P</u>: Sysbook: Rendszerekről mindenkinek, egyetemi hallgatóknak és a rendszertudományok művelőinek. Sokfelületű e-könyv. Budapest: MTA SZTAKI, 2016. http://sysbook.sztaki.hu/

4. <u>Zarándy Á</u>: Cellular processor arrays for topographic calculations: Architecture, programming, efficiency, and implementability. Saarbrücken: Lambert Academic Publ. (LAP), 2016. 172 p. (ISBN:978-3-330-01502-9) http://eprints.sztaki.hu/8999/

<u>Publications in professional periodicals</u>

5. Ács B, <u>Szederkényi G</u>, Tuza Zs, Tuza A A: Computing all possible graph structures describing linearly conjugate realizations of kinetic systems. COMPUTER PHYSICS COMMUNICATIONS, 204: 11-20. (2016) http://eprints.sztaki.hu/8938/

6. Balas E, <u>Kis T</u>: On the relationship between standard intersection cuts, lift-and-project cuts, and generalized intersection cuts. MATHEMATICAL PROGRAMMING, 160: 85-114. (2016) http://eprints.sztaki.hu/8898/

7. <u>Bozóki S</u>, Csató L, Temesi J: An application of incomplete pairwise comparison matrices for ranking top tennis players. EUROPEAN JOURNAL OF OPERATIONAL RESEARCH, 248: 211-218. (2016) http://eprints.sztaki.hu/8996/

8. <u>Cao YX</u>, <u>Marx D</u>: Chordal Editing is Fixed-Parameter Tractable. ALGORITHMICA, 75: 118-137. (2016) http://eprints.sztaki.hu/9048/

9. <u>Egri P</u>: Information elicitation for aggregate demand prediction with costly forecasting. AUTONOMOUS AGENTS AND MULTI-AGENT SYSTEMS, 30: 681-696. (2016) http://eprints.sztaki.hu/8877/

10. <u>Erdős G</u>, <u>Kovács A</u>, <u>Váncza J</u>: Optimized joint motion planning for redundant industrial robots. CIRP ANNALS-MANUFACTURING TECHNOLOGY, 65: 451-454. (2016) http://eprints.sztaki.hu/8893/

11. <u>Farkas Z</u>, <u>Kacsuk P</u>, <u>Hajnal A</u>: Enabling workflow-oriented science gateways to access multi-cloud systems. JOURNAL OF GRID COMPUTING, 14: 619-640. (2016) http://eprints.sztaki.hu/8987/

12. <u>Gáspár P</u>, <u>Németh B</u>: Integrated control design for driver assistance systems based on LPV methods. INTERNATIONAL JOURNAL OF CONTROL, 89: 2420-2433. (2016) http://eprints.sztaki.hu/8940/

13. <u>Gőzse I</u>: Optical Indoor Positioning System Based on TFT Technology. SENSORS, 16: Paper 19. (2016) http://eprints.sztaki.hu/8821/

14. Hegedűs I, Berta Á, <u>Kocsis L</u>, <u>Benczúr A A</u>, Jelasity M: Robust Decentralized Low-Rank Matrix Decomposition. ACM TRANSACTIONS ON INTELLIGENT SYSTEMS AND TECHNOLOGY, 7: 1-24. (2016) http://eprints.sztaki.hu/9074/

15. <u>Horváth M</u>, <u>Kis T</u>: Solving resource constrained shortest path problems with LP-based methods. COMPUTERS & OPERATIONS RESEARCH, 73: 150-164. (2016) http://eprints.sztaki.hu/8915/

16. <u>Karnok D</u>, <u>Kemény Zs</u>, <u>Ilie-Zudor E</u>, <u>Monostori L</u>: Data type definition and handling for supporting interoperability across organisational borders. JOURNAL OF INTELLIGENT MANUFACTURING, 27: 167-185. (2016) http://eprints.sztaki.hu/8890/

17. <u>Karoczkai K</u>, <u>Kertész A</u>, <u>Kacsuk P</u>: A meta-brokering framework for science gateways. JOURNAL OF GRID COMPUTING, 14:(4) 687-703.(2016) http://eprints.sztaki.hu/8984/

18. Kerepesi Cs, Szalkai B, Varga B, Grolmusz V: How to direct the edges of the connectomes: Dynamics of the consensus connectomes and the development of the connections in the human brain. PLOS ONE, 11 (6): 1-8. (2016) http://eprints.sztaki.hu/8866/

19. Kovács A, Bátai R, Csáji B Cs, Dudás P, Háy B, Pedone G, Révész T, Váncza J: Intelligent control for energy-positive street lighting. ENERGY, 114: 40-51. (2016) http://eprints.sztaki.hu/8875/

20. Lipták Gy, Szederkényi G, Hangos K M: Kinetic feedback design for polynomial systems. JOURNAL OF PROCESS CONTROL, 41: 56-66. (2016) http://eprints.sztaki.hu/8732/

21. Luspay T, Kulcsár B, Péni T: Set-theoretic analysis of the isolated ramp metering problem. INTERNATIONAL JOURNAL OF ROBUST AND NONLINEAR CONTROL, 26:(6) 1246-1266. (2016) http://eprints.sztaki.hu/8823/

22. Monostori L, Kádár B, Bauernhansl T, Kondoh S, Kumara S, Reinhart G, Sauer O, Schuh G, Sihn W, Ueda K: Cyber-physical systems in manufacturing. CIRP ANNALS-MANUFACTURING TECHNOLOGY, 65: 621-641. (2016) http://eprints.sztaki.hu/8869/

23. Péni T, Seiler P: Computation of lower bounds for the induced L2 norm of LPV systems. INTERNATIONAL JOURNAL OF ROBUST AND NONLINEAR CONTROL, 26: 646-661. (2016) http://eprints.sztaki.hu/8943/

24. Tapolcai J, Rónyai L, Hosszu É, Gyimóthi L, Ho P-H, Subramaniam S: Signaling Free Localization of Node Failures in All-Optical Networks. IEEE TRANSACTIONS ON COMMUNICATIONS, 64: 2527-2538. (2016) http://eprints.sztaki.hu/9006/

25. Zarándy Á, Németh M, Nagy Z, Kiss A, Sántha L, Zsedrovits T: A real-time multi-camera vision system for UAV collision warning and navigation. JOURNAL OF REAL-TIME IMAGE PROCESSING,12: 709-724. (2016) http://eprints.sztaki.hu/8035/

26. Zsedrovits T, Bauer P, Hiba A, Nemeth M, Jani Matyasne Pencz B, Zarandy A, Vanek B, Bokor J: Performance Analysis of Camera Rotation Estimation Algorithms in Multi-Sensor Fusion for Unmanned Aircraft Attitude Estimation. JOURNAL OF INTELLIGENT & ROBOTIC SYSTEMS, 84: 759-777. (2016) http://eprints.sztaki.hu/8945/