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D 2.5 Final Exploitation Plan of SmartLab and the AComIn Foreground

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EXECUTIVE SUMMARY

According to the Technical Annex of AComIn, Deliverable D2.5 (month 36) contains the final Exploitation Plan of Smart Lab and the AComIn foreground, including measures to sustainably preserve the connections between IICT-BAS and the AComIn User Communities.

This report contains information about AComIn achievements as follows: it

- (i) Defines the project foreground in term of new knowledge, generated as result of the research activities in months 1- 36. Lists of most representative publications support the claims for innovation and originality;
- (ii) Describes plans for using the AComIn foreground in further research activities;
- (iii) Presents plans for further exploitation of Smart Lab devices as means to keep sustainable connections to AComIn Users. The high-level long-term plans integrate SmartLab in a vision for extending the IICT-BAS infrastructure. The specific short-term plans are related to tasks involving Users that will be implemented in the near future.

It is interesting to note that recently IICT-BAS has established itself as a non-formal transfer center, making successful connections between business and academia. Involving Users, talking to them, organising contact groups with mail-lists and regular meetings are future activities in the institute's Agenda for supporting liaisons with the existing User Communities.

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Summary	This Report defines the project foreground in term of new knowledge, generated as result of the research activities in months 1- 36. It describes plans for using the AComIn foreground in further research activities as well as plans for further exploitation of SmartLab devices as means to keep sustainable connections to AComIn Users.	
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1 ACOMIN FOREGROUND IN MODERN IT AREAS

The project delivers original fundamental and applied results in a variety of IT fields. In this section we briefly present them with lists of related representative publications.

1.1 Wigner Monte Carlo Algorithms for Quantum Transport in Nanoelectronics

Efficient Monte Carlo Methods (MCM) are of great importance for the analysis of large-scale computer models. Because of their robustness, MCM is the only viable method for a wide range of high-dimensional problems ranging from Atomic Physics to Finance. MCM is a powerful tool for sensitivity analysis of large and very large mathematical models.

Our research in the frame of AComIn is focused on ground-breaking applications like studying of special nano-structures considered as potential candidates for future quantum computers, where we have considered technologically produced structures. The miniaturisation of devices did bring the developers in the realm of quantum transport. While technologically important quantum effects were only seen as perturbations in the past, today they are so relevant that specialists are exploiting them as principal effects to make new innovative devices work. The MCM has been extremely successful in the description of such devices and effects. The outcomes could be of great impact in the semiconductor community giving the creation of the first fully quantum simulator able to take into account also scattering effects. That could lead to the simulation of 3D devices like FinFETs, nanowires, multi-gate FETs, i.e. devices that are the most likely to be the candidates to substitute the MOSFET technology that is suffering from the miniaturisation effects. Those devices are already considered by industries such as Intel and AMD, as publicly advertised. The code that implements our MC algorithm is parallelised using the MPI library. This allows us to maintain the portability among different operating systems and/or architectures including available computational infrastructure at IICT-BAS.

The applications we are sealing produce advancements of three species: Development of physical insights in the field of Silicon based quantum computing devices; Development of a completely new numerical technique for the time dependent simulation of chemical systems; Development of mathematical advancements and insights in the theories of quantum transport. The following research activities were performed: (i) The research has been focused on the development of a time-dependent MC algorithm. Our MCM represents the first successful attempt in the world to simulate the Wigner equation time-dependently and multi-dimensionally. Groups at the University of Antwerp (Belgium) and in TU-Wien (Austria) are now using this new method on a daily basis. (ii) The two-dimensional Wigner MCM (ballistic regime) has been applied to the study of ordered and disordered arrays of dopants in order to explain the experimental results of various groups (in particular the Shinada's group from ASMeW, Japan). The results are able to explain the experimentally observed enhanced transport characteristics obtained by ordered arrays. (iii) A sensitivity analysis of the coherence length in the Wigner MCM has been carried with success using the concepts of L1, L2 norms and the cosine similarity. The aim of this work is to show the efficiency of sensitivity studies of the design of semiconductor devices. (iv) A modification to Density Functional Theory to include the one-body Wigner MCM has been developed and validated in the cases of Hydrogen molecules in different geometrical configurations, Boron and Lithium. This is a very important achievement since the use of single body Wigner MCM allows for the first time the use of the Wigner formalism in the study of complex chemical systems. Let us mention that the many-body quantum problem was considered (before appearing the Wigner MCM) as unsolvable because of the non-polynomial growth of the computational complexity when other methods are used.

IICT-BAS won as a coordinator a related competitive grant: Efficient Parallel Algorithms for Large-Scale Computational Problems, Bulgarian NSF Grant DFNI-I02/20, 2013. The reported results for 2013-2015 are published in more than 20 papers with IF and SJR rank as follows:

- (i) J. M. Sellier and I. T. Dimov. *Toward solotronics design in the Wigner formalism*, Physica A: Statistical Mechanics and its Applications, Volume 417, 2015, pp. 287–296, doi:10.1016/j.physa.2014.09.057, ISSN: 0378-4371, **IF: 1.722** (2013).
- (ii) J. M. Sellier and I. T. Dimov. *A sensitivity study of the Wigner Monte Carlo method*, Journal of Computational and Applied Mathematics, Volume 277, 2015, pp. 87- 93, doi:10.1016/j.cam.2014.09.010, ISSN: 0377-0427, **IF: 5-Year IF: 1.672**.
- (iii) J. M. Sellier and I. T. Dimov. *On the simulation of indistinguishable fermions in the many-body Wigner formalism*, Journal of Computational Physics, Volume 280, 2015, pp. 287–294, **Five-Year Impact Factor: 3.184, IF (2013): 2.138, SJR (2012): 1.921**.
- (iv) J.M. Sellier, M. Nedjalkov, I. T. Dimov, S. Selberherr. *A Comparison of Approaches for the Solution of the Wigner Equation*. Mathematics and Computers in Simulations, Volume 107 (2015), pp. 108–119, Elsevier, ISSN: 0378-4754, doi:10.1016/j.matcom.2014.06.001, **Five-Year IF: 1.033, IF (2012): 0.836**.
- (v) J.M. Sellier, I. Dimov, *Wigner functions, signed particles, and the harmonic oscillator*, Journal of Computational Electronics, Volume 14, Issue 4, pp 907-915 (2015), **IF (2014): 1.520**.
- (vi) J.M. Sellier, D.Y. Ivanova, I. Dimov, *Molecular descriptors and quasi-distribution functions*, Computers and Mathematics with Applications, doi:[10.1016/j.camwa.2015.06.037](https://doi.org/10.1016/j.camwa.2015.06.037), (2015), **IF (2014): 1,697, 5-Year IF: 1.894**.
- (vii) I.T. Dimov, S. Maire, J. M. Sellier. *A New Walk on Equations Monte Carlo Method for Linear Algebraic Problems*, Applied Mathematical Modelling, Volume 39, Issue 15, 1 August 2015, Pages 4494–4510, **IF (2014): 2,251, 5 Year IF: 1.674**;
- (viii) J.M. Sellier, M. Nedjalkov, I. Dimov, *An introduction to applied quantum mechanics in the Wigner Monte Carlo formalism*, Physics Reports, Volume 577, 12 May 2015, Pages 1 -34, <http://www.sciencedirect.com/science/article/pii/S0370157315001982>, (2015), **IF (2013): 22.91**.
- (ix) J.M. Sellier, R.F. Sviercoski, I. Dimov, *On the Wigner Monte Carlo Method Coupled to Pseudopotential Models*, Journal of Computational and Applied Mathematics, Volume 293, February 2016, Pages 217–222, <http://www.sciencedirect.com/science/article/pii/S037704271500045X>, (2015), **IF (2014): 1.266**.
- (x) J. M. Sellier, I. T. Dimov. *The many-body Wigner Monte Carlo Method for time-dependent Abinitio quantum simulations*, Journal of Computational Physics, Volume 273, (2014), pp. 589–597, ISSN: 0021-9991, **Five-Year IF: 3.184, IF (2013): 2.138, SJR indicator (2012): 1.921**.
- (xi) J.M. Sellier, I. T. Dimov. *The Wigner-Boltzmann Monte Carlo Method applied to electron transport in the presence of a single dopant*. Computer Physics Communications, Volume 185 (2014), pp. 2427–2435, Elsevier, ISSN: 0010-4655, <http://dx.doi.org/10.1016/j.cpc.2014.05.013>, **5-Year IF: 3.212, IF (2013): 3.078**.
- (xii) Jean Michel Sellier, Ivan Dimov. *The many-body Wigner Monte Carlo Method for time-dependent Ab-initio quantum simulations*. <http://dx.doi.org/10.1016/j.jcp.2014.05.039>, Journal of Computational Physics, Vol. 273, pp. 589-597, (2014), Impact Factor: 2.851, **IF (2013): 2.138, SJR(2012): 1.921**.
- (xiii) J.M. Sellier, I. T. Dimov. *A Wigner Approach to the Study of Wave Packets in Ordered and Disordered Arrays of Dopants*, Physica A: Statistical Mechanics and its Applications, Volume 406 (2014), pp. 185–190, Elsevier, 2014. ISSN: 0378-4371, DOI:10.1016/j.physa.2004.04.121, **5-Year IF: 1.651, IF(2012): 1.676, SJR indicator (2012): 0.634**.
- (xiv) J.M. Sellier, I. T. Dimov. *A Wigner Monte Carlo Approach to Density Functional Theory*, Journal of Computational Physics, Volume 270 (2014), pp. 265–277, Elsevier, ISSN: 0021-9991. **5-Year IF: 2.851, IF (2013): 2.138, SJR indicator (2012): 1.921**.
- (xv) J.M. Sellier, S.M. Amoroso, M. Nedjalkov, S. Selberherr, A. Asenov, and I. T. Dimov. *Electron dynamics in nanoscale transistors by means of Wigner and Boltzmann approaches*, Physica A: Statistical Mechanics and its Applications, Volume 398 (2014), Pages 194–198, doi:10.1016/j.physa.2013.12.045, **5-Year IF: 1.651, IF (2012): 1.676, SJR indicator (2012): 0.634**.
- (xvi) J.M. Sellier, M. Nedjalkov, I. Dimov, and S. Selberherr, *Decoherence and Time Reversibility: The Role of Randomness at Interfaces*, Journal of Applied Physics (**IF: 2.220**), 2013, accepted, ISSN 0021-8979, **5 Year IF 2.22**.
- (xvii) J.M. Sellier, M. Nedjalkov, I. T. Dimov, S. Selberherr. *A benchmark study of the Wigner Monte-Carlo method*, Monte Carlo Methods and Applications, Volume 20, Issue 1 (Mar 2014), Pages 43–51, ISSN (Print) 0929-9629, De Gruyter, 2014. DOI: 10.1515/mcma-2013-0018, Mathematical Citation Quotient: 0.12, **SJR(2012): 0.224**,
- (xviii) P Schwaha, M Nedjalkov, S Selberherr, JM Sellier, I. T. Dimov, and R. Georgieva. *Stochastic Formulation of Newton's Acceleration*, Large-Scale Scientific Computing, Lecture Notes in

Computer Science, Volume 8353, Pages 178-185 (Editors: Ivan Lirkov, Svetozar Margenov, Jerzy Waśniewski), ISBN: 978-3-662-43879-4 (Print) 978-3-662-43880-0 (Online) 2014, pp. 186-193, **SJR(2014): 0.339**

- (xix) JM Sellier, M Nedjalkov, I. T. Dimov, and S. Selberherr. *The role of annihilation in a Wigner Monte Carlo approach*, Large-Scale Scientific Computing, Lecture Notes in Computer Science, Volume 8353, Pages 186-193 (Editors: Ivan Lirkov, Svetozar Margenov, Jerzy Waśniewski), ISBN: 978-3-662-43879-4 (Print) 978-3-662-43880-0 (Online) 2014, pp 186-193, 2014, **SJR (2014): 0.339**
- (xx) M. Nedjalkov, P. Schwaha, S. Selberherr, J.M. Sellier, D. Vasileska. *Wigner Quasi-Particle Attributes: An Asymptotic Perspective*. Applied Physics Letters, AIP Publishing, Vol. 102 (16), 2013, id. 163113 (4 pages). ISSN: 0003-6951. E-ISSN: 1077-3118. DOI: 10.1063/1.4802931. **5-Year IF 3.817, IF (2013): 3.794, SJR (2012): 1.938**

1.2 Robust Finite Element Methods and Algorithms for Advanced Computer Simulations

The modern Finite Element Methods (FEM) provide a computational technology for solving important classes of multiscale and multiphysics problems in science and engineering. The obtained results concern such challenging topics as novel FEM discretization techniques and robust scalability for problems with extremely heterogeneous and anisotropic coefficients.

The FEM discretization is based on conforming or nonconforming approximations. In both cases, the FEM basis functions should have a local support, ensuring sparsity of the matrices of FEM linear systems. The obtained new discretization/approximation results include: (i) interpolation, cubature rules, and least squares fitting of harmonic functions based on Radon projections; (ii) mixed finite element methods based on weighted Hdiv bilinear forms and equivalence between mixed and nonconforming FEM discretization. The robustness of mixed FEM discretization is studied in terms of uniform boundlessness of the constant in the inf-sub condition and the related LBB (Ladyzenskaja-Babuška-Brezzi) inequality.

Many of the nowadays real-life applications involve large-scale parallel processing of FEM linear systems with millions or even billions of degrees of freedom (unknowns). Such huge computational problems are beyond the scope of commercial software tools. The obtained new results are in the field of scalable preconditioned conjugate gradients (PCG) iterative solution methods. They include new or significantly improved multilevel, multigrid and domain decomposition methods, namely: robust algebraic multilevel iteration (AMLI) and semi-coarsening AMLI methods for strongly anisotropic problems; auxiliary space multigrid method based on additive Schur complement approximation; spectral analysis of geometric multigrid methods and full multigrid schemes for isogeometric analysis; finite element tearing and interconnect (FETI) solvers for non-standard finite element equations based on boundary integral operators.

The obtained results allow for advanced computer simulations and studies of complex processes and phenomena in science and high technologies. Among others, the robust solvers are tested on worldwide recognized SPE (society for petroleum engineering) benchmarks. The applications staying beyond the above theoretical achievements include industrial flows in porous media, as well as advanced civil engineering, biomedical engineering, environmental engineering, etc. simulations.

Some algorithms based on the numerical investigation for the seismic analysis of tall reinforced concrete (RC) Civil Engineering structures, which have been degraded due to extreme environmental actions and are strengthened by cable elements are developed. The effects of multiple earthquakes on such RC building frames are computed. Damage indices are estimated in order to compare the seismic response of the structures before and after the retrofit by cable element strengthening, and so to elect the optimum strengthening version.

A new computational model is developed for the mathematically rigorous analysis of Civil Engineering structures, which have been environmentally damaged and subsequently strengthened by cable-elements. The problem is treated as an inequality one, where the governing conditions are equalities as well as inequalities. The cable behavior is considered as nonconvex and non-monotone and is described by generalized subdifferential relations including loosening, elastoplastic-fracturing and other effects. Using piece-wise linearization for the cable behavior, a linear complementarity problem, with a reduced number of unknowns, is solved by optimization algorithms.

The reported results are published in scientific papers in highly ranked journals and volumes with Impact Factor and SJR rank:

- (i) Ang. Liolios, At. Karabinis, Ast. Liolios, St. Radev, K. Georgiev, I. Georgiev, A computational approach for the seismic damage response under multiple earthquakes excitations of adjacent RC structures strengthened by ties, *Computers and Mathematics with Applications* (2014), doi:10.1016/j.camwa. 2015.08.012. **(IF 1.697)**
- (ii) I. Georgiev, S. Margenov, Semi-coarsening AMLI preconditioning of anisotropic trilinear FEM Systems, *Computers and Mathematics with Applications*, 68(12) (2014), 2103-2111. **(IF 1.697)**
- (iii) I. Georgieva, C. Hofreither. Interpolation of harmonic functions based on Radon projections, *Numerische Mathematik*, 127(3) (2014), 423-445. **(IF 1.608)**
- (iv) I. Georgieva, C. Hofreither. Interpolating solutions of the Poisson equation in the disk based on Radon projections, *Journal of Mathematical Analysis and Applications*, 423(1) (2015), 305—317. **(IF 1.12)**
- (v) I. Georgieva, C. Hofreither. Cubature Rules for Harmonic Functions Based on Radon Projections, *Calcolo*, 52, (2015), 153–166. **(IF 0.808)**
- (vi) J. Kraus, M. Lyubery, S. Margenov, Robust algebraic multilevel preconditioners for anisotropic elliptic problems, *Springer Proceedings in Mathematics and Statistics*. Vol. 45, 217-246. **(IF 0.405)**
- (vii) J. Kraus, M. Lyubery, S. Margenov. Auxiliary space multigrid method based on additive Schur complement approximation. *Numerical Linear Algebra with Applications* (2014), DOI: 10.1002/nla.1959. **(IF 1.322)**
- (viii) Ang. Liolios, A. Elenas, Ast. Liolios, St. Radev, K. Georgiev, I. Georgiev, Tall RC buildings environmentally degraded and strengthened by cables under multiple earthquakes: A numerical approach, *Numerical Methods and Applications*, Springer LNCS, Vol. 8962 (2015), 187-195. **(SJR 0.339)**
- (ix) I. Georgieva, C. Hofreither, R. Uluchev, Least Squares Fitting of Harmonic Functions Based on Radon Projections, *Mathematical Methods for Curves and Surfaces*, Springer LNCS, Vol. 8177 (2014), 158—171. **(SJR 0.339)**
- (x) C. Hofreither, U. Langer, C. Pechstein. FETI solvers for non-standard finite element equations based on boundary integral operators, *Lecture Notes in Computational Science and Engineering*, Vol. 98 (2014), 729-737. **(SJR 0.260)**
- (xi) C. Hofreither, W. Zulehner, Spectral Analysis of Geometric Multigrid Methods for Isogeometric Analysis, *Numerical Methods and Applications*, Springer LNCS, Vol. 8962 (2015), 123-129. **(SJR 0.339)**
- (xii) C. Hofreither, W. Zulehner, On full multigrid schemes for isogeometric analysis, *Domain Decomposition Methods in Science and Engineering XXII, Lecture Notes in Computational Science and Engineering*, Vol.104 (2015), accepted. **(SJR 0.260)**
- (xiii) N. Kosturski, S. Margenov, P. Popov, N. Simeonov, Y. Vutov, Performance Analysis of Block AMG Preconditioning of Poroelasticity Equations, *Large-Scale Scientific Computing*, Springer LNCS Vol. 9374, accepted. **(SJR 0.339)**

1.3 Advanced Computing in Dynamical Analysis of Elastic Structures

Understanding in details the dynamical behavior of elastic structures provides valuable information for the engineers, which can be used in the design, maintenance and health monitoring. The parametric study in frequency domain by the concepts of nonlinear normal modes (NNM) and nonlinear frequency-response function (NFRF) presents such knowledge that describes completely the dynamical characteristics of the structure. The necessity of obtaining reliable and accurate results requires consideration of nonlinear physical models and development of proper mesh discretization

methods, e.g. finite element methods. As a consequence, the whole process of computing the NNM and NFRF becomes computationally expensive and cumbersome. Its effective parallel implementation on high performance computers is essential and unavoidable for the future development of new technologies for design, optimization and health monitoring of engineering structures.

New parallel algorithms for computing numerically the NFRF and NNM of dynamical systems are developed. The numerical methods are applied to large-scale dynamical systems that arise from space discretization of real-life elastic structures. New results, which show the optimal scalability of the proposed parallel implementation, are obtained.

The proposed numerical approach for dynamical analysis presents an iterative process for computing periodic responses of nonlinear systems by varying a parameter (such as frequency of vibration), determination of stability of the periodic solution, establishment of bifurcation points and following the secondary branches of solutions that arise from the bifurcation points. The computation of the NNM or NFRF is achieved by combination of finite element method, shooting and continuation methods. The application of the finite element method to elastic structures, considering geometrical type of nonlinearity, results into nonlinear system of second order ordinary differential equations. The shooting method computes the initial conditions that lead to steady-state periodic response of the dynamical system while the continuation method defines a prediction for the next point from the bifurcation diagram and enables to pass turning points (cyclic-fold bifurcation points). Additionally, the shooting method requires a time integration scheme, achieved by Newmark's method and solution of nonlinear algebraic system, achieved by Newton-Raphson's method.

New parallel realization of the shooting method is developed. The parallel process involves simultaneously efficient algorithms and basic matrix operations for sparse and dense matrices. Effective implementation on high performance computers considering equal distribution of computations and memory among available processors is obtained. New results with optimal parallel speedup and efficiency of the shooting method applied to nonlinear dynamical systems are achieved.

The proposed new technology gives the opportunity to academia and industry to compute efficiently the dynamical properties of real-life applications on high performance computers.

The results are published in scientific papers in highly ranked journals and volumes:

- (i) S. Stoykov, S. Margenov, Numerical computation of periodic responses of nonlinear large-scale systems by shooting method, *Computers & Mathematics with Applications* 67 (2014) 2257-2267. **(IF 2.170)**
- (ii) S. Stoykov, S. Margenov, Nonlinear Vibrations of 3D Laminated Composite Beams, *Mathematical Problems in Engineering* (2014), DOI: 10.1155/2014/892782. **(IF 0.762)**
- (iii) P. Ribeiro, S. Stoykov, Forced periodic vibrations of cylindrical shells in laminated composites with curvilinear fibers, *Composite Structures* 131 (2015) 462–478, DOI: 10.1016/j.compstruct.2015.05.050. **(IF 3.500)**
- (iv) S. Stoykov, S. Margenov, Scalable parallel implementation of shooting method for large-scale dynamical systems. Application to bridge components, *Journal of Computational and Applied Mathematics* 293 (2016) 223-231. **(IF 1.365)**
- (v) S. Stoykov, E. Manoach, S. Margenov, An efficient 3D numerical beam model based on cross sectional analysis and Ritz approximations, *ZAMM - Journal of Applied Mathematics and Mechanics*, accepted. **(IF 1.162)**
- (vi) S. Stoykov, G. Litak, E. Manoach, Vibration energy harvesting by a Timoshenko beam model and piezoelectric transducer, *European Physical Journal Special Topics*, accepted. **(IF 1.399)**
- (vii) S. Stoykov, S. Margenov, Nonlinear forced vibration analysis of elastic structures by using parallel solvers for Large-Scale Systems, *Large-Scale Scientific Computations*, Springer LNCS, Vol. 8353 (2014), 381-388. **(SJR 0.339)**
- (viii) S. Stoykov, C. Hofreither, S. Margenov, Isogeometric Analysis for Nonlinear Dynamics of Timoshenko Beams, *Numerical Methods and Applications*, Springer LNCS, Vol. 8962 (2015), 138-146. **(SJR 0.339)**
- (ix) S. Stoykov, S. Margenov, Scalability of Shooting Method for Nonlinear Dynamical Systems, *Large-Scale Scientific Computing*, Springer LNCS 9374 accepted **(SJR 0.339)**.

1.4 Advanced Methods, Algorithms and Innovations Based on 3D Digitisation and Prototyping

A key topic in this area is the voxel data processing based on computed tomography (CT) images of microstructures. The addressed advanced applications vary from fabless technologies for design of new composite and/or porous materials, through quality control of technological processes and nondestructive defectoscopy, to high-tech innovations in biomedical engineering.

Accurate segmentation of 3D CT data of porous media is crucial for the numerical simulations and the computation of the material/object's macro characteristics at the next stage. Due to the highly irregular structure of the segmentation phases and the presence of noise in the image, the classical methods are not reliable and the results of different standard algorithms may differ drastically (even on up to 50% of the data). A completely new direction of image segmentation is investigated, where some physical properties of the scanned specimen are incorporated in the segmentation process as constraints. In particular, the volume of the solid phase can be determined from the material's density and weight measurements and can be a priori prescribed (mass conservation), while the solid phase itself, should be connected whenever the specimen is a single material piece.

Two different families of 2-phase image segmentation methods are proposed, analyzed and implemented. The conducted numerical experiments are promising in terms of both improved accuracy and decreased computational time. The computational efficiency is further optimized. MPI parallel implementations of the new algorithms on the high performance cluster at IICT-BAS are developed. It is important to notice, that experimental measurements of the macro characteristics of porous materials could be rather expensive and not always possible. In such cases, virtual material design is a modern research direction that significantly speeds up the analysis and the derivation of new porous materials with a priori given physical properties.

New methods, algorithms and software (including parallel) implementations for numerical upscaling are developed. The computed anisotropic tensors of material properties are beyond the nowadays abilities of the lab equipment for measurements and testing. The reported applications include: (i) numerical homogenization (upscaling) of heterogeneous anisotropic linear elastic materials; the studied specimens vary from innovative porous metals (lighted aluminums) to trabecular bone tissues, where the impact of osteoporosis is inspected; (ii) calibration of biomechanical characteristics of hepatic tissues and related parameters for radio-frequency tumor ablation simulation.

A completely new innovative methodology of 3D digitalization and prototyping is developed. Here, we are able to report the obtained extremely promising results concerning a lightweight 3D printed polymer prototype antenna, metallization and experimental test at 14-18GHz.

Results are currently published in scientific papers as follows:

- (i) I. Georgiev, E. Ivanov, S. Margenov, Y. Vutov, Numerical Homogenization of Composite Materials, Numerical Methods and Applications, Springer LNCS, Vol. 8962 (2015), 130-137. (**SJR 0.340**)
- (ii) S. Margenov, S. Stoykov, Y. Vutov, Numerical homogenization of heterogeneous anisotropic linear elastic materials, Large-Scale Scientific Computing, Springer LNCS Vol. 8353, (2014), 347-354. (**SJR 0.339**)
- (iii) N. Kosturski, S. Margenov, Y. Vutov, Calibration of Parameters for Radio-Frequency Ablation Simulation, Large-Scale Scientific Computing, Springer LNCS Vol. 8353, (2014), 611-618. (**SJR 0.339**)
- (iv) Georgiev, S. Harizanov, Y. Vutov, Supervised 2-phase Segmentation of Porous Media with Known Porosity. Large-Scale Scientific Computing, Springer LNCS Vol. 9374, accepted. (**SJR 0.339**)
- (v) S. Harizanov, S. Margenov, L. Zikatanov, Fast Constrained Image Segmentation Using Optimal Spanning Trees, Large-Scale Scientific Computing, Springer LNCS Vol. 9374, accepted. (**SJR 0.339**)

1.5 Language and Semantic Technologies

Automatic Processing of Image Annotations in Large-Scale Image Databases. The main challenge in the emerging area “Language and Vision” is how to produce (automatically) high quality annotations that describe the image semantics, with least effort and minimal costs. Automatic assignment of keywords to images is a rather difficult task and current solutions based on machine learning are unsatisfactory.

We proposed an approach for post-editing of keywords which are assigned to images. The suggested post-editing tackles “noisy” tags: mistakes, inflexions, doublets, normalization of keywords-names, abbreviations, and various linguistic and punctuation phenomena that occur at token level. Further we suggested employing linguistic resources that define English lexical semantics (WordNet) for consolidation of tags by removing “unnecessary” annotations.

The emotional classification of images depends on the individual opinion of each person but we proposed and investigated an idea how to compute image sentiment scores using external resources. We presented an approach for analysis of sentiments and emotions in image tagging using SentiWordNet as an external linguistic resource of emotional words. Calculating a “sentiment score” for each image, the system classifies images into three classes (positive, negative, and neutral). Our approach works with 63.53% precision, 58.7% recall and 61.02% F-measure which is coherent with the results reported for sentiment analysis in general.

Automatic tag sense disambiguation is another hot issue in the “Language and Vision” field. In general automatic tag disambiguation is a fundamental issue for modern management of digital resources because content objects with identical tags can be linked together allowing users to search for similar or related content in blogs, videos, image collections, learning objects or categories of web-pages. Tags ambiguity leads to inaccuracy and misunderstandings. We proposed an integrated method for tag disambiguation of images and showed its effectiveness for arbitrary tags in English with nominal and verbal senses using WordNet as an external resource defining tag senses. The main advantage of the method is the combination of known approaches which ensures some non-zero result for all annotation keywords belonging to WordNet. The evaluation is done on a corpus of about 5,600 tags with some 10,000 senses and showed that the correctly disambiguated tags are 95% for professional images and 87% for social images (that are often annotated manually).

Application of Educational Data Mining for Analysis of the eLearning Portal UCHA.SE.

Educational Data Mining allows the discovery of new knowledge based on learners’ usage data in order to help validate and/or evaluate educational systems, to potentially improve some aspects of the quality of education and to lay the groundwork for a more effective learning process. Its potential explains the significant interest it raised in the educational community and the developers of online learning environments. A pilot research projects was carried out in the frame of AComIn. We applied educational data mining to the most popular Bulgarian educational site, UCHA.SE, which offers instructional videos and practice exercises in Bulgarian language. The site can be used to support formal and informal education, that is, in schools and for self-learning. Currently it offers more than 4,300 video lessons in 17 subjects, including the basic K-12 subjects, as well as Introductory level English, German, French, and Spanish, and Introduction to Programming. As of September 2015, the site has more than 400,000 registered users - students (including college students), teachers, and parents. The lessons are seen more than 13 mln times.

The goal of the project was to improve the quality of educational services and the subscription rate for the site by leveraging educational data mining. In order to achieve these goals we extracted a “learner model” by applying BITool (business intelligence software supporting a multidimensional data model) to UCHA.SE relational database in which system logs and students’ performance data are

stored. As a result the constructed “learner model” contained 30 attributes that reflect four type of information:

- general information about the user (e.g. age, gender, etc.),
- information related to user activities (e.g. “Percent of the total number of all taken exercises”, “Average length watched videos per day”, “Consecutive days the user has accessed the site”, etc),
- information related to user knowledge and skills (e.g. “Percentage of all attempts of these exercises, for which the total score exceeds the threshold of 75 points”, “Percent of the watched videos, which the user also commented”, etc, and
- information about the use of some gamification elements proposed by the site (e.g. “leadership level”, “charisma”, “influence”, etc.).

The goal for increasing the site subscription rate was reformulated as a classification task for predicting whether the user will renew his current subscription in the period of 3 month after its expiration. The classification task was solved by means of a machine learning approach. The training data reflects the user model and was constructed as of a concrete moment in time (end of February 2015). Since the learning data was highly unbalanced (only 18% of all data represented “positive” examples, i.e. the users who renewed their subscription in due time). The learning dataset was improved by combination of subsampling and undersampling methods. The predictive model was created as a combination of rules learned by two machine learning algorithms - JRIP and CN2, as JRIP rules generalized “positive” examples, and CN2 rules – the “negative” ones.

The predictive quality of this easily understandable to the end-users rule-based model, has classification accuracy 86.1% and F-measure 68%, respectively, which is close to the predictive quality of the model produced by one of best classification algorithms - SVM (87% and 68%). However, the SVM model is not understandable by the end-user.

News Media Analysis and Creation of Language Resources. The contemporary Natural Language Processing (NLP) applications, such as the analysis and extraction of relevant information from huge streams of data as well as context-aware Machine Translation, require high quality knowledge-rich processing. The Web provides an extensive volume of relevant knowledge, but most of it is in a textual or semi-structured format. Also, in the last decades the language and culturally specific information constantly increase. This calls for the development of language technology and resources (LTR) for national and local languages. These LTR need to reflect the language and culture specific features of the raw data. In order to support the interaction with rest of the world they are aligned by rule with LTRs for other languages.

Together with partners from Vrije Universiteit, Amsterdam (Computational Lexicology and Terminology Lab (CLTL)) we have been adapting the IICT-BAS in-house NLP processor for Bulgarian to analyse the events and stories in big news media data.

The NLP processor performs the following analyses: tokenization, POS and morphosyntactic tagging, lemmatisation, syntactic parsing, named entity identification and semantic analysis. Our efforts have been invested mainly in the last step as the most complex component of the processing chain. The semantic tagging includes the following submodules: (i) assigning the correct sense from the BTB WordNet on verbs, nouns, adjectives and adverbs; (ii) assigning the correct semantic role.

The first submodule uses the BTB WordNet, which was developed and is being extended within ACOMIN. It has been made freely available at the following link: <http://compling.hss.ntu.edu.sg/omw/>

The second submodule was developed through the WordNet verb semantic classes that were mapped onto the Bulgarian valency frames. The initial general semantic role labels have been distributed over BulTreeBank (BTB), and now the specialization process is in progress. Additionally, the first automatic transfer of Predicate Matrix (<http://adimen.si.ehu.es/web/PredicateMatrix>) was performed on Bulgarian data from the Setimes parallel corpora.

For the purposes of semantic annotation and disambiguation, the knowledge-graph tool UKB, developed by the IXA group, Basque country, was used. The experiments have been done with Bulgarian (BuTreeBank) and English data (SemCor). The results show improvement when syntactic relations are added for both languages.

Language Technologies Applied for Generation of a Diabetes Register. This pilot project for large-scale application of language technologies was performed jointly with the University Specialised Hospital for Active Treatment of Endocrinology "Acad. Ivan Penchev" (USHATE), Medical University – Sofia. USHATE is authorised by the Bulgarian Ministry of Health to host an anonymous Register of diabetic patients in Bulgaria. This Register contains 28 indicators of diabetic patients including age, sex, codes of diagnoses of diabetes and its complications, diabetes duration, risk factors, data about compensation, laboratory results, hospitalisations and prescribed medication. The AComIn experienced researchers helped for the automatic construction of the Register using language technologies and business analytics tools.

The register is automatically generated from a Repository of more than 112 million pseudonymised reimbursement requests (Outpatient records, ORs) submitted to the National Health Insurance Fund (NHIF) in 2012-2014 for more than 5 million citizens, including 436,000 diabetic patients. ORs are semi-structured in XML format; in each file some tags contain free-text fields with important explanations about the patient: "Anamnesis", "Status", "Clinical examinations" and "Therapy". In AComIn, pilot prototypes for large scale processing of Bulgarian clinical texts were developed that extract automatically most essential data.

We developed a drug extractor using regular expressions to describe linguistic patterns. There are more than 80 different patterns for matching text units to ATC drug names/codes and NHIF drug codes. This extractor identifies the medication name, dosage, frequency and route of admission. Currently, it handles 2,239 drug names included in the NHIF nomenclatures. For treatment effect assessment we provide a comparative study of patients with insulin therapy, incretine-based therapy and oral medications therapy.

For extraction of clinical examination we designed a Numeric value extractor that processes lab and test results. Using collocation extractor we generate patterns for clinical exam data. After analysis of the positive and negative examples for such data we define the clinical exam data language \mathcal{L} by a context-free grammar. For parsing clinical examination data we propose a hybrid method inspired by dependency grammars, constituents and Government and binding theory. The obtained result is a list of attribute-value pairs. For monitoring the compensation of Diabetes Type 2 and risk factors we extract values for body mass index (BMI), weight (W), blood pressure (BP), glycated haemoglobin (HbA1c), blood glucose (GLU), etc.

To identify complex relations between Diabetes Mellitus Type 2, its complications and other chronic diseases we defined a Data mining module for finding (i) frequent patterns and (ii) frequent temporal sequences of chronic diseases. For task (i) we apply modification of the classical frequent itemsets mining algorithms dEclat and association rules generation. We proposed a cascade method that reduces the search space for task (ii). In task (ii) several experiments were done – with no limitations for the distance between events (only the order matters), and with different window limitations between events – 1 to 3 months, etc.

Speech Processing. Modern state-of-the art speech recognition systems crucially use a beam search method in huge graph that combines acoustic model probabilities and language model probabilities. A disadvantage of all beam search methods is that they find a suboptimal, but not the best, path in the search space. This leads to propagation of the recognition errors. We have introduced a novel method for real-time lattice rescoring in speech recognition. It improves the performance of speech recognition systems by providing the option to partially compile the word lattice into a deterministic finite-state automaton, making it suitable for the rescoring step in the speech recognition process. In contrast to

the widely used n-best approach our method permits the consideration of significantly larger number of alternatives within the same time-constraint thus providing better recognition results. A description of the new method is presented together with empirical evaluation of its performance in comparison with the n-best method. The achieved WER reduction is up to 3.77% at a p-value below 3%. An important advantage of our method is its applicability for real-time speech recognition. A pilot prototype of speech-to-text system for Bulgarian is demonstrated.

AComIn supported also the development of a novel effective method for searching similar audio segments in large audio collections. This method is based on original ideas for similarity search and ensures high reliability in noisy environments and exclusively high speed of searching for similar audio records. A pilot prototype for reliable automatic annotation of subtitled audio signals at phonemic level is demonstrated as well.

Annotated corpus of Bulgarian speech: using the Speech Lab (purchased in AComIn) a multi-signal corpus of Bulgarian speech was developed. The corpus incorporates sounds, laringograph signals and physiological signals for some of the readers. The sentences in the corpus are segmented automatically by original software with manual correction of the accuracy. The resource is available at <http://lml.bas.bg/BulPhonC>.

These results are currently published in scientific papers as follows (further papers in preparation):

- (i) Kanishcheva, O. and G. Angelova. About Emotion Identification in Visual Sentiment Analysis, In Proceedings of the 10th International Conference on "Recent Advances in Natural Language Processing" RANLP 2015, 7-9 September 2015, Hissar, Bulgaria, 258-265, ISSN 1313-8502 <https://aclweb.org/anthology/R/R15/>
- (ii) Kanishcheva, O. and G. Angelova. A Pipeline Approach to Image Auto-Tagging Refinement, Proceedings of the 7th Balkan Conference on Informatics Conference, Craiova, Romania, 2015, ACM Proceedings Series, ACM New York, ISBN: 978-1-4503-3335-1, doi:[10.1145/2801081.2801108](https://doi.org/10.1145/2801081.2801108)
- (iii) Van-Hieu Vu, Hai-Son Le, O. Kanishcheva, and G. Angelova. Fine-tuning SIMPLE based Content Based Image Retrieval system, Proceedings of the Sixth International Symposium on Information and Communication Technology (SoICT 2015), Hue, Vietnam, ACM Proceedings Series, ACM New York, ISBN: 978-1-4503-3335-1, doi: [10.1145/2833258.2833273](https://doi.org/10.1145/2833258.2833273)
- (iv) Dicheva D., Dichev Ch., Agre G., and G. Angelova. Gamification in Education: A Systematic Mapping Study. Educational Technology & Society, 18 (3), 2015, 75-88, ISSN 1176-3647 **(IF 1.34)**
- (v) Wandelt, S., Deng, D., Gerdjikov, S., Mishra, S., Mitankin, P., Patil, M., Siragusa, E., Tiskin, A., Wang, W., Wang, J., Leser, U., State-of-the-art in string similarity search and join, SIGMOD Record, 43 (1), 2014, 64-76, ISSN: 0163-5808 **(IF 0.955)**
- (vi) Boytcheva, S., G. Angelova, Z. Angelov, and D. Tcharaktchiev. Text Mining and Big Data Analytics for Retrospective Analysis of Clinical Texts from Outpatient Care. Cybernetics and Information Technologies, Vol. 15, № 4, 2015, Pages ISSN 13144081 Doi. [10.1515/cait-2015-0055](https://doi.org/10.1515/cait-2015-0055) **(SJR 0.170)**
- (vii) M. Dobreva, G. Angelova, and G. Agre. Bridging the Gap between Digital Libraries and eLearning, Cybernetics and Information Technologies, Vol. 15, № 4, Pages ISSN 1314-4081 Doi. [10.1515/cait-2015-0057](https://doi.org/10.1515/cait-2015-0057) **(SJR 0.170)**
- (viii) Dichev, Ch., Dicheva, D., Agre, G., and G. Angelova. Trends and Opportunities in Computer Science OER Development. Cybernetics and Information Technologies, Vol. 15, № 3, 2015, pp. 114-126, ISSN 1311-9702. DOI: [10.1515/cait-2015-0045](https://doi.org/10.1515/cait-2015-0045) **(SJR 0.170)**
- (ix) Dichev Ch., Dicheva D., Angelova G. and G. Agre. From Gamification to Gameful Design and Gameful Experience in Learning. Cybernetics and Information Technologies, Vol. 14, № 4, 2014, pp. 80-100, ISSN 1311-9702 DOI: [10.1515/cait-2014-0007](https://doi.org/10.1515/cait-2014-0007) **(SJR 0.212)**
- (x) Nikolova, I., D. Tcharaktchiev, S. Boytcheva, Z. Angelov and G. Angelova. Applying Language Technologies on Healthcare Patient Records for Better Treatment of Bulgarian Diabetic Patients. Artificial Intelligence: Methodology, Systems, Applications, Lecture Notes in Artificial Intelligence 8722, Springer 2014, pp. 92–103, DOI [10.1007/978-3-319-10554-3_9](https://doi.org/10.1007/978-3-319-10554-3_9), ISSN: 0302-9743 **(SJR 0.310)**
- (xi) Dichev, Ch., D. Dicheva, G. Agre, and G. Angelova. Current Practices, Trends and Challenges in K-12 Online Learning. Cybernetics and Information Technologies, Vol. 13, № 3, 2013, pp. 91-110, ISSN 1311-9702 DOI: [10.2478/cait-2013-0028](https://doi.org/10.2478/cait-2013-0028) **(SJR 0.101)**

1.6 Signal and Image Processing

Neuro-fuzzy Approach. In the considered period a theoretical investigation of effect of Intrinsic Plasticity (IP) improvement of Echo State Networks (ESN) reservoirs were summarised and commented. It was observed that IP training “captures” input data structure into the reservoir steady state in a way that could be useful for clustering purposes. In search of explanation of these results the Memory Capacity of Reservoir Equilibrium State (MCRES) was introduced. Achieved due to IP tuning MCRES of ESN reservoirs with different sizes was investigated using three benchmark artificial data sets. Two applications of neuro-fuzzy approach were realised. The first one visualises 3D acoustic waves propagation based on multi-dimensional data clustering. The second one implements adaptive critic designs for optimisation of fuzzy rule base parameters, designed to adapt the measurement noise covariance matrix. The proposed approach assures fast tuning of Kalman filter and improvement of the quality of its estimates in changing working conditions of the MEMS in real time application.

Enhancement of Acoustic Noise Source Localization and Identification. Results in several directions are achieved:

- Generation of the acoustic images in range - cross range - elevation coordinates. The approach enables to determine automatically the range to source (Acoustic camera software require measuring it in advance). The approach enables to localize the source with frequency bandwidth about 10 kHz, which is processed simultaneously;
- Enhancement of angular resolution of the acoustic images up to 2.72 (2.56) times in respect to "delay and sum" beamforming (built-in standard beamforming). The resolution enhancement was obtained for center frequencies from 1 kHz to 18 kHz, at bandwidth 10% and 23% of the center frequency. It was obtained based-on modified Capon`s approach, at range span comparable to dimensions of microphone array of the Acoustic Camera;
- A software tool for bearing noise estimation is prepared. It was applied for development of new tools for non-destructive testing of the bearings;
- Improvement of resolution of SONAH method in high frequency range, based on virtual microphones. The small number of microphones in Acoustic Camera limits SONAH method resolution. Virtual microphones are defined by using autoregressive relation for signal interpolation. In this way measurement surface density and/or area are numerically enlarged and resolution improvement of SONAH has been achieved;
- Fast direction of arrival estimation. A single frequency can be calculated on the basis of at least three data samples. Having a set of local frequencies one can calculate a set of direction angles and draw several rays from corresponding points. Estimation of the shift parameter of the distribution of these points gives the source coordinates;
- Multichannel frequency estimation. The task considers estimation of the power spectral density matrix, which consists of elements related to auto-spectrums and cross-spectrums for each pair of channels. By using the maximum likelihood approach the autoregressive parameter estimator has been synthesized. It has been shown that in the single channel case it is equivalent to the known modified covariance method obtained by a least squares approach. The simulation results demonstrate that the new estimator has similar precision in the middle frequency range to a simple one averaged by multiple channels, but the proposed method becomes much better at low frequencies. Additional attention has been paid to influence of the impulsive noise. The proposed solution assumes removing of noise impulses by the separation of the input sample and interpolation of the detected corrupted values. It has been shown that the proposed approach has advantage over the conventional filtering techniques. Statistical model of the signal sample, description of the detection criterion, flowchart of the filtering procedure and comparison results are published.

These results are published as follows:

- (i) Koprinkova-Hristova, Petia, On effects of IP improvement of ESN reservoirs for reflecting of data structure, in Proc. International Joint Conference on Neural Networks (IJCNN), 2015, pp.1-7, doi: [10.1109/IJCNN.2015.7280703](https://doi.org/10.1109/IJCNN.2015.7280703)
- (ii) Nevena Popova, Geogi Shishkov, Petia Koprinkova-Hristova, Kiril Alexiev, 3D Visualization of Sound Fields Perceived by Acoustic Camera, Cybernetics and Information Technologies, Volume 15, No 7, 2015, Online ISSN: 1314-4081, to appear (**SJR 0.170**).
- (iii) Volodymyr Kudriashov, Non-stationary Random Wiener Signal Detection with Multistatic Acoustic System, Proceedings 4th International Conference on Telecommunications and Remote Sensing, pp. 1-5, Rhodes, Greece, 17-18 September 2015.
- (iv) Konstantin A. Lukin, Volodymyr V. Kudriashov, Pavlo L. Vyplavin, Volodymyr P. Palamarchuk and Sergii K. Lukin, "Coherent radiometric imaging using antennas with beam synthesizing", International Journal of Microwave and Wireless Technologies, Volume 7, Special Iss. 3-4, pp. 453-458, June 2015 (2013/2014 **IF 0.456**). DOI: [10.1017/S1759078715000550](https://doi.org/10.1017/S1759078715000550).
- (v) V.V. Kudriashov, "A Modified Maximum Likelihood Method for Estimation of Mutual Delay and Power of Noise Signals by Bistatic Radiometer", Comptes rendus de l'Académie bulgare des Sciences, Vol. 68, Iss. 5, pp. 631-640, 2015. (2014 **IF 0.284**, **SJR 0.214**).
- (vi) Chyrka, Iu., A Narrowband Sound Signal Frequency Estimation with Impulsive Noise Filtering, Proceedings of the Balkan Conference on Informatics: Advances in ICT, BCI-2015, 2-4 September 2015, Craiova, Romania, pp. 40-44. Available at <http://ceur-ws.org/Vol-1427/paper6.pdf>
- (vii) Chyrka, Iu., Fast Direction-of-Arrival Estimation for Single Source, International Conference on Telecommunications and Remote Sensing, ICTRS-2015, 17-18 September 2015, Rhodes, Greece.
- (viii) Chyrka, Iu., Acoustic Fields Reconstruction, Cybernetics and Information Technologies, Volume 15, No 7, 2015, Online ISSN: 1314-4081, to appear (**SJR 0.170**).
- (ix) Chyrka, Iu., I. Omelchuk, Multichannel modified covariance estimator of a single-tone frequency, Cybernetics and Information Technologies, Volume 15, No 7, 2015, Online ISSN: 1314-4081, to appear (**SJR 0.170**).

Research results achieved in **Biometric Authentication**:

- **Ear Biometrics** is a young topic that is intensively investigated recently. Even if ear has a uniform distribution of color, human external ear characteristics are considered enough unique to each individual and permanent during the lifetime of an adult, almost like fingerprint and/or iris data, but ear data can be gathered without any discomfort for people. A new method representing most essential data of human ear has been proposed, namely the matching potential for ear discrimination was tested via Extended Gaussian Image (EGI) representation and experimentally proved using 3D ear data gathered via the 3D Scanner of the AComIn SmartLab. Another approach to Biometrics Authentication by Ear has been proposed based on an original CBIR (Content Based Image Retrieval) method of IICT-BAS for rapid and reliable recognition of 3D objects using a database of precedents. Each object of interest for recognition is presented in the DB through a sufficient number of 2D projections (images), each from a different view point. Input images for recognition are obtained from conventional 2D cameras, and the most appropriate ear data are retrieved from the DB through the CBIR method to access that is fast enough and noise resistant. We have already applied successfully this appearance-based approach two times: (i) for recognition of palm signs from a sign language alphabet and (ii) for human face recognition. The effective application for human ears became possible thanks to the 3D scanning technology available in the SmartLab of IICT-BAS (in the frames of AComIn project).
- **Speech Detection**: A new robust feature for contour-based speech endpoint detection is proposed. It is called Group Delay Mean Delta (GDMD) feature and combines the properties of the known Modified Group Delay Spectrum (MGDS) and the original Mean Delta (MD) approach. The effectiveness of proposed feature is experimentally evaluated in the fixed-text Dynamic Time

Warping (DTW) - based speaker verification task with short phrases of telephone speech. In comparison with three well know features - Modified Teager Energy (MTE), Energy-Entropy (EE) and MD feature - the experiments have shown that the GDMD feature demonstrates the best performance in endpoint detection tests in terms of verification rate.

- **Signature verification:** A combined off-line signature verification approach is proposed using Neural networks, where global and grid signature features are combined to generate specific feature sets, one for each person represented in the verification system.

Video Stabilisation. A method and robust algorithm for fast 2D video stabilization for handheld devices in real-time is proposed. The BSC (Boundary Signal Computation) chip of TI (Texas Instruments) is essentially used (or emulated herein) for searching of correlations between the 1D integral projections, horizontal and vertical ones, by a SAD (Sums of Absolute Differences) approach. The proposed method is based on an accurate vector model allowing interpretations of increasing complexity for the transformations among frames. Experiments, conducted on testing video clips, are very promising for the future R&D of the method. This method has been extended for the problem of video stabilisation 'in a point', related to providing a static background for correct measurements with high-speed industrial cameras, like the one available in the SmartLab of AComIn. This new approach is called "3x3OF9x9" and combines (fuses) the basic method we use with the most lightweight version of the known Optical Flow approach, applying simple Otsu segmentation for eliminating the influence of moving objects in the video. The obtained results show better stabilisation (low that 1% instability for frame size of 640x480) in comparison with commercial software packets, like Warp Stabilizer of Adobe After Effects CS6.

The results are published in several papers as follows:

- (i) Cantoni, V., D. T. Dimov, and A. Nikolov: 3D Ear Analysis by an EGI Representation. In: Cantoni, V., D. T. Dimov, and M. Tistarelli (Eds.) Biometric Authentication, Springer LNCS Vol. 8897, pp. 136-150, Print ISBN: 978-3-319-13385-0, DOI: 10.1007/978-3-319-13386-7_11, (2013 **SJR 0.310**)
- (ii) Dimov, D.T., V. Cantoni: Appearance-Based 3D Object Approach to Human Ears Recognition. In: Cantoni, V., D. T. Dimov, and M. Tistarelli (Eds.) Biometric Authentication, Springer LNCS Vol. 8897, pp. 121-135, Print ISBN: 978-3-319-13385-0, DOI: 10.1007/978-3-319-13386-7_10, (2013 **SJR 0.310**)
- (iii) Ouzounov, A.: Noisy Speech Endpoint Detection using Robust Feature. In: Cantoni, V., D. T. Dimov, and M. Tistarelli (Eds.) Biometric Authentication, Springer LNCS Vol. 8897, pp. 105-117, Print ISBN: 978-3-319-13385-0, DOI: 10.1007/978-3-319-13386-7_9, (2013 **SJR 0.310**)
- (iv) Boyadjieva, D., G. Gluhchev: Neural Network and kNN Classifiers for On-Line Signature Verification. In: Cantoni, V., D. T. Dimov, and M. Tistarelli (Eds.) Biometric Authentication, Springer LNCS Vol. 8897, pp. 198-206, Print ISBN: 978-3-319-13385-0, DOI: 10.1007/978-3-319-13386-7_16, (2013 **SJR 0.310**)
- (v) Dimov, D., A. Nikolov: Real Time Video Stabilization for Handheld Devices. In: Rachev, B., A. Smrikarov (Eds.) Proceedings of CompSysTech'2014, ACM International Conference Proceeding Series, Vol. 833, pp. 124-133, ISBN: 978-1-4503-2753-4, DOI: [10.1145/2659532.2659631](https://doi.org/10.1145/2659532.2659631)
- (vi) Nikolov, A., D. Dimov. 2D Video Stabilization for Industrial High-Speed Cameras, Cybernetics and Information Technologies, Volume 15, No 7, 2015, to appear (**SJR 0.170**).

1.7 Optimisation and Intelligent Control

A New Type of Chemical Nickel Coatings Including Nano Elements. The research on this topic includes a comprehensive study of abrasive wear and starting friction of nickel chemical coatings containing nanosized particles of silicon carbide (SiC) and aluminum oxide (Al₂O₃) of various sizes. It was carried out with the purpose of replacing old and non-ecological industrial technologies for laying a chrome based coating on different working surfaces. As a result, an advanced technology is developed and tested for renovation of extruding shafts used in industrial manufacturing of sheet

materials, i.e. PVC, Plexiglas, other plastics, etc. The commonly used renovation technologies in this area are known to be exclusively harmful due to the waste cyanide products. Our innovative approach overcomes this drawback by applying advanced nanotechnology for nonelectric chemical laying of a nickel coating with included nanoparticles. Enhanced tribological characteristics are obtained due to the embedded micro- and nanosized particles. The technology is environmentally harmless and the new coating features an increased hardness and wear resistance. A special mechanical manipulator is developed as a part of a robotized systems for inspections of coatings with high mechanical wear-resistance and surface-smoothness.

These results are published in scientific papers as follows:

- (i) Kandeveva, M., D. Karastoyanov, B. Ivanova, and V. Pojidaeva, Influence of Nano-Diamond Particles on the Tribological Characteristics of Nickel Chemical Coatings, Tribology in Industry, Vol. 36, No. 2, pp. 181-187, 2014, **(2014 SJR: 0.4)**
- (ii) Assenova, E., M. Kandeveva, and D. Karastoyanov, Self Organization Effects of Lubricants and Additives Impact on Tribologica, I Systems Quality, International Journal of the Balkan Tribological Association, (in print), **(2013/2014 IF: 0.321)**
- (iii) Kandeveva, M., T. Grozdanova, D. Karastoyanov, B. Ivanova, and A. Vencl. Wear Under Vibration Conditions of Spheroidal Graphite Cast Iron Microalloyed by Sn. International Journal of the Balkan Tribological Association, (in print), **(2013/2014 IF: 0.321)**

Intelligent Methods for Technical Diagnostics. Technical diagnostics is a classical interdisciplinary area where results from narrow scientific sciences and specific trends are applied: probability and statistics, pattern recognition, decision making, mathematical logic. Modern industry requires efficient fault discovering and isolation solutions in process equipment service which is a real-world problem of typically ill-defined systems, hard to model, with large-scale solution spaces. Design of precise models is impractical, too expensive, or often non-existent. To cope with this problem, methods and tools are developed for intelligent diagnostics, monitoring and decision making for real detection of potential abnormalities in technological processes without applying expensive diagnostic apparatus. Especially the usage of AI-based methodologies enables us to deal with imprecise, uncertain data and incomplete domain knowledge typically encountered in practical applications. Several types of diagnostic approaches with different structures are applied to a mill fan device in the Bulgarian Maritsa East 2 Thermal Power Plant being the largest thermal power plant on the Balkan Peninsula. The possibility to predict eventual damage or wearing out without switching off the device turns out to be of great importance for providing faultless and reliable work of the plant. The results are presented in the following papers:

- (i) Vassileva S., L. Doukovska, V. Sgurev - AI-Based Diagnostics for Fault Detection and Isolation in Process Equipment Service, International Journal of Computing and Informatics, Bratislava, Slovakia, vol. 33, №2, ISSN 1335-9150, pp. 387-409, 2014 **(IF: 0.319, 2014 SJR: 0.351)**.
- (ii) Doukovska L., S. Vassileva - Intelligent Methods for Process Control and Diagnostics of Mill Fan System, Cybernetics and Information Technologies, vol. 14, №1, pp. 151-160, 2014, Print ISSN 1311-9702; Online ISSN 1314-4081, DOI 10.2478/cait-2014-0012 **(SJR: 0.212)**.

Traffic Optimization in Communication Networks. In communication networks, a crossbar switch node routes traffic from the input to output where a message packet is transmitted from the source to the destination. The randomly incoming traffic must be controlled and scheduled to eliminate conflict at the crossbar switch. The goal of the traffic-scheduling for the crossbar switches is to maximize the throughput of packet through a switch and to minimize packet blocking probability and packet waiting time. In this area of research, new models of the incoming traffic in crossbar switch nodes are proposed including several families of input traffic patterns. As compared to the modeling methods and techniques available in the current literature, an important advantage of our models is that the generation of the traffic patterns does not depend on the type of hardware and software tools. Simulation studies and evaluations for the throughput of a switch node by the proposed family of patterns are performed using the grid-structure of the ICT-BAS. A numerical procedure for

computation of the upper bound of the throughput is suggested which enables us to estimate the maximal throughput of the switch for different traffic scheduling algorithms. The results are presented in the following publications:

- (i) Tashev, T., and V. Monov, Large-Scale Simulation of Non-Uniform Load Traffic in Studying the Throughput of a Crossbar Packet Switch, "Large-Scale Scientific Computing", I. Lirkov et al. (Eds.): LSSC 2013, June, 2013, Sozopol, Bulgaria. In: Lecture Notes in Computer Science, LNCS 8353, Springer, pp. 644-651, 2014, DOI 10.1007/978-3-662-43880-0_74, **(2014 SJR: 0.339)**.
- (ii) Tashev, T., and V. Monov, A numerical study of the upper bound of the throughput of a crossbar switch utilizing MIMA-algorithm, "Numerical Methods and Applications" I. Dimov et al. (Eds.): NMA 2014, August 2014, Borovets, Bulgaria, In: Lecture Notes in Computer Science LNCS 8962, Springer, pp. 295-303, 2015, DOI 10.1007/978-3-319-15585-2_33, **(2014 SJR:0.339)**.

Target Detection and Parameter Estimation. The research on this topic includes a thorough study of the latest trends in the design of highly efficient and fully automated systems for processing radar data in terms of a priori uncertainty about the targets and disturbances. Parameter estimation and high-speed small targets detection in randomly arriving impulse interference environment is a challenging task in radar systems design. Conventional radar detection architectures like spectral discrimination and non-coherent integration have been considered and used but with limited success. Within this framework, an improved target detection architecture is developed making use of highly efficient Hough velocity estimation technique. The proposed algorithm is based on a Track-Before-Detect processing method, which allows for the previously collected data to be used in the target detection process and parameter estimation. The presented technique has a lot of advantages compared to traditional ones. The obtained results can be successfully applied for radar target parameter estimation as well as in the existing communication network receivers making use of pulse signals. The results are presented in the following publication:

- (i) Doukovska L. Track-Before-Detect Procedure using Hough Velocity Estimation Technique, Comptes rendus de l'Academie bulgare des Sciences, Vol. 68, № 9, pp. 1153-1160, 2015, ISSN 1310-1331 **(IF: 0.284)**.

A Mechatronic Systems for Industrial Automation and Robotics. The investigation on this topic is aimed at developing new mechatronic systems incorporating mechanical constructions, electronic modules and intelligent software for automation of technological processes and operations. Main subjects of study are robots, dedicated for multisensory environment perception and exploration, measurements and samples taking, discovering and putting a mark on the objects as well as environment interactions like transportation, carrying in and out of equipment and objects. An important result obtained in this area is an advanced modular system developed for the mechanical construction of the mobile robots. It includes special programmable logical controllers for robot control and electronic modules for the wireless communication. New methods, means and algorithms for adaptive environment behaviour and group control of mobile robots are also examined. An innovative application of the international standard BDS ISO 10825 in mechanical transmissions is also proposed. The results are presented in the following publication.

- (i) Abadjiev, V., G. Dimchev, E. Abadjieva, and D. Karastoyanov. One Application of the International Terminological Standard BDS ISO 10825 for the Damage Identification on the Teeth of Gear Transmissions., 6th Int. Conf. on Mechanics and Material Design M2D'2015, July 2015, Portugal, International Journal of Mechanics and Materials in Design, ISSN 1569-1713 (in print) **(2014 IF: 1.196)**

Intelligent Transportation Systems. The work on Autonomic transportation aims at meeting the challenge of engineering autonomic behavior in Intelligent Transportation Systems. The research integrates approaches from the disciplines of traffic engineering and autonomic computing. Autonomic computing is inspired by a biological example of body's autonomic nervous system and it allows for a more efficient management of heterogeneous distributed computing systems. This type of systems are

endowed with a number of properties that are generally referred as “self” properties, including self-configuration, self-healing, self-optimization, self-protection or in general term self-management. In this domain, an advanced approach is developed providing a new formal description of the traffic control policy. More complicated formalization is applied for the control of urban traffic systems using bi-level optimization. Such an approach gives potential for increase of the control space of the control problem. The new formalization of the control policy allows for the traffic flows to be controlled in urban networks not only by the green light duration of traffic lights as it is the common manner, but simultaneously by changing the duration of the traffic lights cycle obtained as solution of optimal control problem. This innovation benefits minimization of the waiting time of the vehicles in the urban network, maximization of the traffic outflows, decrease of traffic congestions, minimizing time for travel. The results are presented in the following articles:

- (i) Stoilov T., K. Stoilova, M. Papageorgiou, and I. Papamichail. Bi-Level Optimization in a Transport Network, *Cybernetics and Information Technologies*, vol.15, No 5, pp 37-49, 2015, Print ISSN: 1311-9702; Online ISSN: 1314-4081 DOI: 10.1515/cait-2015-0023, **(SJR: 0.284)**.
- (ii) Ivanov V. Using a PicoBlaze processor to traffic light control. *Cybernetics and Information Technologies*, vol.15, No 5, 2015, pp. 131-139. Print ISSN: 1311-9702; Online ISSN:1314-4081 DOI: 10.1515/cait-2015-0023, **(SJR: 0.284)**.

Numerically Effective Kalman Estimator Algorithm for Urban Transportation Network. The research on this topic addresses a problem of vehicles amount estimation in queues, which appear in front of controlled junctions in a congested Urban Transportation Network. The innovative result of the research is an approach, which leads to an effective numerical algorithm of building steady-state Kalman estimator for the store-and-forward urban transportation network model. The evaluation of the numerical algorithm shows its efficiency and applicability for on-line computations in the urban intelligent transportation system. The research presents an original approach, which uses a special structure of the optimization problem data and expands method of resolvent for constructing a stabilizing solution of discrete algebraic Riccati equation. The results are presented in the following publication:

- (i) Balabanov, A., Building of Numerically Effective Kalman Estimator Algorithm for Urban Transportation Network, International Conference “Advanced Computing for Innovation 2015” (submitted).

2 EXPLOITATION PLANS FOR USING ACOMIN FOREGROUND

2.1 Wigner Monte Carlo Algorithms for Quantum Transport in Nanoelectronics

The research carried out in AComIn was focussed on ground-breaking applications that support building up and structuring of a new interdisciplinary scientific community in emerging themes dealing with radically new future technologies. For instance our results involve studying of special nano-structures viewed as potential candidates for future quantum computers *(i)*, *(ii)*, and especially *(iii)*, where we have considered technologically produced structures.

- (i)* J. M. Sellier, I. T. Dimov. The many-body Wigner Monte Carlo Method for time-dependent Abinitio quantum simulations, *Journal of Computational Physics*, Volume 273, (2014), pp. 589–597.
- (ii)* Jean Michel Sellier, Ivan Dimov. The many-body Wigner Monte Carlo Method for time-dependent Ab-initio quantum simulations. *Journal of Computational Physics*, Vol. 273 (2014), pp. 589-597.
- (iii)* J.M. Sellier, I. T. Dimov. A Wigner Approach to the Study of Wave Packets in Ordered and Disordered Arrays of Dopants, *Physica A: Statistical Mechanics and its Applications*, Vol. 406 (2014), pp.185-190.

In this way we have studied experimentally nano-structures which are considered as a candidat for a quantum computer. Our research in this fiels directly supports innovations in semiconductor devices. That could lead to the simulation of 3D devices like FinFETs, nanowires, multi-gate FETs, i.e. devices that are the most likely to be the candidates to substitute the MOSFET technology that is suffering from the miniaturization effects. Those devices are already taken into account by industries such as Intel and AMD, as publicly advertised. IICT-BAS plans joint research with Technical University Wien which is particularly focused on magnetic field, entangled electronics, and parallelisation algorithms. A systematic derivation of simulation models accounting for the magnetic field in the Wigner picture is still missing. A major challenge is the incorporation of the electromagnetic potentials and the choice of the gauge. A computationally feasible theoretical approach is pursued, which allows an efficient inclusion of the vector potential in the signed particle method. Entanglement characterises the state evolution in electron lenses, mesoscopic (Aharonov-Bohm) rings, and Quantum Point Contacts (QPC's). Electron transport in such structures comprises phenomena with yet not explored physical and application aspects. For instance, there is no relevant theory which can explain the experimentally observed behaviour in QPC's. All these issues are included in our research agenda for the near future.

2.2 Robust Finite Element Methods and Algorithms for Advanced Computer Simulations

The future plans for research will target top achievements in robust FEM discretization and solution methods. The obtained theoretical results for strongly heterogeneous elliptic problems of high contrast and high frequency will be further developed to the case of coupled problems including models of fluid-structure interactions, flows in deformable porous media, thin plates and shells, etc. The expected new results will play a key role in such high tech applications as new constructive materials, clean technologies, nano membranes, energy efficient combustion in inert porous media. The related problems are inherently nonlinear, three dimensional in space and time dependent. This means that HPC will be without alternative in many of the real life applications. The big challenge here concerns the development of scalable parallel algorithms for the new generation heterogeneous systems including GPU and MIC accelerators.

2.3 Advanced Computing in Dynamical Analysis of Elastic Structures

The research plans for next period will be focused on development of efficient methods, algorithms and codes for dynamical analysis of more complicated structural elements. The first step will address the related problems in the theory of plates. The standard model is described by PDE of fourth order which means that the FEM approximations should provide higher smoothness of the test functions. Even for linear problems this leads to serious increase of the size of discrete problem from one side and robustness problems from another. One alternative approach (which will be preferred) is based on development of efficient methods and algorithms in terms of Mindlin–Reissner plate theory. Mixed FEM, nonconforming and reduced integration FEM will be studied. The obtained results will be generalized to the case of shells. In both cases, plates and shells the methods should be robust with respect of the thickness which is assumed by default to be small. The parallel implementation of the algorithms (e.g. the shooting algorithm) will be required in many real life applications in machine and civil engineering.

2.4 Advanced Methods, Algorithms and Innovations Based on 3D Digitisation and Prototyping

This is a completely advanced topic. Some of the reported results are really pioneering. There are (at least) two kinds of challenges in the future research and development activities. The first one is related to the extremely fast development of the equipment for 3D digitalization and prototyping. The sub-micro computed tomography is already available. This means in particular new qualitative and quantitative requirements to the algorithms for segmentation of CT images. Even the formulation of the problem of mass conservative segmentation for multicomponent porous media is a separate challenge. The next plans in the related field of numerical upscaling will be targeted to homogenization of nonlinear properties. The results in the field of numerical upscaling of anisotropic materials have a strong potential for generalizations in the general case of unstructured Big Data analytics. Considering the future plans in prototyping we should notice the new opportunities provided (or expected to appear) in the on-line control of 3D printing with respect to, e.g., changing the material or/and controlling the density etc.

2.5 Language and Semantic Technologies

Automatic processing of image annotations in large-scale image databases. Integrating Language and Vision in general requires better understanding of the annotation processes and the psychology of personal behavior in social media where users often assign emotional tags to their photos. Therefore we believe that considerable success in automatic tag disambiguation can be achieved in specific niches e.g. collections of professional images that document mostly material objects denoted by nouns. We plan to extend the present results in the area of disambiguation by integration of further external resources that provide reference sets of senses: like Wikipedia and DBPedia. Then there will be a voting scenario where different disambiguation platforms propose the correct tag sense. Further we plan to make experiments with embedding fine-tuned tags in the image recognition phase when the decision of automatic annotation is made.

Application of Educational Data Mining for Analysis of the eLearning Portal UCHA.SE. We study the user model in UCHA.SE with respect to their subscription rate. We build a vector of characteristics of each user and, with the means of machine learning algorithms, we try to identify the specific features in their behaviour which signal readiness to subscribe again for the portal services. Currently we have experimented with data from a concrete moment in time; due to the seasonal nature of the usage of UCHA.SE we need to adjust our model to be applicable to various periods. In

addition to studying the user model we shall also make a deeper analysis of the available resources on the website since their quality reflects directly into the user satisfaction and the subscription readiness respectively.

News Media Analysis and Creation of Language Resources. The results achieved in AComIn will be integrated in the development of a Language Technology and Resources Centre for Linked Open Data. This includes: (i) Further extension of the BTB WordNet through reliable (semi)automatic processes; (ii) Alignment of BTB WordNet with English and other languages wordnets as well as world knowledge databases such as DBpedia, Freebase and other datasets from Linked Open Data cloud; (iii) Further improvement of the knowledge graph performance through the addition of new relations; (iv) Developing of ensemble and supervised methods for solving several language technology tasks; (v) Crosslingual event analysis and information extraction for big news data in Bulgarian and English (also possibly Dutch); as well as (vi) Deployment of the semantic tagging into an MT system between Bulgarian and English.

Language Technologies Applied for Generation of a Diabetes Register. The language technologies used at present will be at first extended for automatic extraction of values in the section "Patient Status" in the Outpatient records submitted to the National Health Insurance Fund. Then the plan is to extend the extractors to further chronic diseases in order to generate other registers: like Diseases of the circulatory system, Malignant neoplasms, Mental and behavioural disorders, etc. In addition to the Outpatient records, the extractors should process selected zones in other types of clinical narratives: e.g. Discharge letters and Reports about Clinical examinations issued by Independent Medical Diagnostic Laboratories. A major challenge is the automatic processing of temporal information in clinical narratives: recognition of absolute and relative temporal markers, and ordering them in timelines.

Speech Processing. A disadvantage of all beam search methods is that they find a suboptimal, but not the best, path in the search space. This leads to propagation of the recognition errors. To the best of our knowledge a method that finds the best path is not known so far. Such a method could significantly improve not only the state of the art of speech recognition systems, but also any other system based on beam search like statistical machine translation systems, optical character recognition system etc. Despite of the fact that the open problem for the best path is considered very hard, we plan further research in this direction that could lead to better quality in comparison with beam search methods. In these ambitious tasks we rely on our previous experience and successes in efficient computations.

2.6 Signal and Image Processing

Theoretical Research with Acoustic Camera in SmartLab. The acoustic camera is high-quality equipment but belongs to the entry-level due to comparatively low number of microphones and small aperture's size. The number of microphones could not be easily increased (the hardware price depends mainly of number of channels/microphones). The main ideas about acoustic camera improvement are directed to aperture modification and implementation of different algorithms for resolution enhancement, enlargement of applicable frequency band, smart feature extraction and so on. The already purchased microphone connectors and cables provide the necessary hardware for experimenting with new configurations of microphones on newly designed apertures.

Near-field Acoustic Holography (NAH) is one of two main acoustic array signal processing techniques, that allows localization of sound sources by reconstruction of the acoustic field in front of

the measurement plane. The main challenges in this field are increasing of upper operational frequency limit, enhancing of spatial resolution and reduction of computational intensity.

Therefore, the main goal is to enhance its performance in resolution and frequency range. Precision of reconstruction and method resolution can be improved by acoustic field interpolation and extrapolation that is also called a virtual microphone technique. This means that measurement surface density and/or area are numerically enlarged. Research results showed that it can be simply done for a single narrowband source by using an autoregressive model of the sinewave. Such method improves resolution in a middle to high frequency range, because it makes microphone grid denser, what is suitable for high-frequency signals. As a further development of it, the regularization or "symmetrization" of the aperture can be applied in order to extend spatial working area of the method, which at the moment is limited by a relatively small zone near the center of the array.

Another considered approach for the virtual microphone technique is rather the extrapolation than interpolation, because it allows calculation of the signal value in the any arbitrary point on the measurement plane. It can be easily predicted after estimation of the source position, its frequency, power and instantaneous phase. Research results showed that it allows to reduce shift of a pressure peak that usually occurs when source is located near borders of the array. Obviously, this method does not have such limitation in source position like previous one, but it also works only in high frequency range. But the strict mathematical explanation of such improvement still has to be given.

Both methods can be applied automatically after some detection and localization steps that show whether conditions are suitable or not for particular method. Such processing procedure can be used, as example, for suppression of several weaker sources near the main one or vice versa for amplification of them by step-by-step focusing and fusion of obtained images, but this opportunity must be additionally investigated, probably with another signal parameters estimation methods. Recently the corresponding experimental data were recorded and will be processed.

The important feature of the second interpolation approach is possibility to simulate signals from the array with regular geometry in the case of the single sound source. Actually, regular geometry is traditional for performing holography, and is necessary for the classic Fourier NAH.

Now the regular array by 4x4 microphones was physically implemented with using additional connectors. It will allow to directly run the traditional Fourier NAH method as well as other already implemented modern methods. Improvement of reconstruction precision, particularly in detection of two sound sources, is expected.

Comparison of the performance with the interpolated signal and a signal from a real rearranged regular aperture can help to get further improvement of the interpolation methods. The resolution improvement techniques also have to be tested on the real regular aperture.

Originally, both methods were invented as a trial of increasing the upper working frequency for holography that is limited by the microphone spacing distance. But in practice their current implementation can only improve precision of holography at high frequencies, but not overcome the top limit. This is yet another challenge that is waiting for its completion.

One more perspective direction of research is acoustic interferometry that can be combined with holography in order to measure distance to sources. Similarly to interferometry, the second interpolation method can be used for extrapolation not only tangentially, but normally to original measurement plane, that can allows improvement in resolution. Several data recordings with two and tree sources in different positions were obtained in order to experimental investigation of above mentioned ideas.

Beam Forming Method is usually used for acoustic measurements of remote sources. Newly developed or modified signal processing methods should be applied in order to improve noise source identification and mapping. The aim is to broaden the frequency pass band, to achieve improvement of a spatial resolution, to generate acoustic images in three-dimensional spatial coordinates and to

decrease the influence of human factor in recognition and rejection of ghost sources (to automate as much as possible this process).

In summary, we foresee to develop further the proposed **smart approach for features extraction** from the multi-dimensional data received by acoustic camera towards:

A) Refinement of initial features extraction procedures aimed at:

- Investigation of proper frequency ranges for specific diagnostic purposes using focalized spectra;
- Increasing of the resolution of the produced by our algorithm “acoustic picture” aimed at fine detection of sound sources.

B) Investigation of different kind of clustering/classification procedures aimed at:

- Increased accuracy of diagnostic;
- Improved visualization of multi-dimensional data.

Exploitation of the research results achieved in **Biometric Authentication** esp. **Ear Biometrics**: The plan is to disseminate on-line the 3D Ears Database created in IICT-BAS (for about 100 subjects). This would support the experiments carried out in the ear biometric research community which lacks *high accurate 3D ear mesh data*. The IICT-BAS team will continue developing and supporting this valuable resource, and will exploit it further in the development of methods and prototypes for Biometric Authentication.

2.7 Optimisation and Intelligent Control

New Technologies, Mechatronic Systems and Robotics. In AComIn an advanced nanotechnology was developed for laying of a nickel coating with included nanoparticles on the working surfaces of extruding shafts used in industrial manufacturing of sheet materials. In our future work, the technology will be used for development of new types of innovative metal coatings with increased hardness and wear resistance that can be used for renovation of different mechanical devices in industry and production processes.

A robotised system for inspections of coatings with high mechanical wear-resistance and surface-smoothness will be designed and put into exploitation.

The research on mechatronic systems and robotics will continue by studying and design of autonomous mobile robots intended for multisensory environment perception and exploration, transportation of equipment and objects and working in harmful environment.

New methods and algorithms for group control of mobile robots will also be developed and examined.

Intelligent Methods and Systems. In our studies we have suggested original methods for diagnostics and predictive maintenance of industrial assets using intelligent techniques for analysis of the facilities condition. As a next step these methods will be used in the development of complex intelligent systems for advanced technological and operational management of various industrial and manufacturing processes.

In the area of radar data processing and target detection, an advantageous method was proposed using a Track-Before-Detect processing technique, which allows for the previously collected data to be used in the target detection process and parameter estimation. The method will be further developed in order to increase the accuracy of the estimated moving target parameters in a dynamic radio location environment. Examination and development of new robust and reliable algorithms for simultaneous trajectory and target detection is also a perspective field of research.

The development of new algorithms that can be used to retrieve information about targets, applying a mathematical transformation on the received signals yielding estimates of the parameters of moving targets with extremely high precision in a dynamically changing radar environment is a new and very promising direction in modern information and communication technologies.

One of the most recent directions of the scientific research conducted by the intelligent control team within the project frame is the newly proposed Inter Criteria Decision Making approach. Further development and practical applications of this approach will support a decision maker in evaluating data or measurements of multiple objects against multiple criteria, to more profoundly understand the nature of the criteria involved and their correlation.

Information and Communication Systems. In the area of data transfer and optimisation in communication networks, we have proposed a family of models of the incoming traffic in a crossbar switch node together with algorithms for nonconflict scheduling and optimal data transfer as well as numerical procedures for estimating the maximal throughput of the communication node. Further exploitation of these results will include substantial improvements of the models in order to cope with complex traffic flows with different intensity and stochastic parameters, development of new scheduling algorithms, simulation studies including large scale computations in order to obtain precise performance evaluations of the communication network.

Important results obtained in course of the AComIn project also include a sensor system for meteorological data capturing using hierarchical cluster-tree topology and a software platform for smart sensor network data integration based on Service Oriented Architecture. The research work in this direction will continue by developing new software tools and mechanisms for cooperative data mining, self-organization, networking, and energy optimization in order to build higher level service structures.

Knowledge and experience acquired in the ICT sector within the project AComIn will be extensively used in the design of methods, algorithms and software products for local and web-based optimization and decision support systems, development of intelligent procedures and devices leading to innovative applications in industry, manufacturing, production planning and corporate business management.

Advanced Control of Transport Systems. Our work in the development of multilevel optimisation for transportation system has the potential to improve the control policies and the exploitation of traffic networks in intensive urban areas. The control policies always target reducing the congestions, which deteriorate traffic conditions. Applying multilevel optimization the control space is increased and additional goals can be achieved as minimization of waiting time and maximization of outgoing flows from the urban network.

Potential improvement and future prospects from the multilevel optimization can be expected by development of fast algorithm for solving such class of control problems. Provisionally this could be the derivation of appropriate coordination strategies, which reduce the computational workload for real time purposes. Future developments will be focused on: (i) derivation of analytical approximation of inexplicit relations, concerning the solution of upper and lower level optimization problems; (ii) development of coordination strategies, which reduce the information exchange between the upper and lower level problems.

Having powerful methods to solve in real time multilevel problem, the control policies for transportation system can benefit from the increased control space, which can contain both the duration of the traffic lights, time cycle and the offset between the traffic nodes. Additionally variable speed limits and information signs can be incorporated in the traffic control. The multilevel approach can support additionally the integration of the on-line traffic estimations and optimization of the control states. Thus the multilevel approach can support both control policies for free way traffic and ramp metering.

A mathematical model for improvement of the rail-way passenger transportation in Bulgaria will be developed as an academic response of IICT-BAS towards the request of the Ministry of Transport of Bulgaria for the definition of mathematical model for the future development and exploitation of the Bulgarian state railway passenger transport. This type of transport has to become a backbone for the transportation structure of Bulgaria and has to provide rearrangements and modifications to the current bus transportation systems on national, regional and community scales.

3 EXPLOITATION PLANS FOR USING SMARTLAB DEVICES

Plans for exploitation and enhancements of Smart Lab are built in the context of the forthcoming Operational Programme “Science and Education for Smart Growth”, where IICT prepares several (large) project proposals for submission.

3.1 A General View to the IICT Infrastructure and Extensions of SmartLab

SmartLab was created within AComIn as “intelligent periphery” surrounding the High Performance Computing (HPC) core of the institute (Figure 1). The idea was to purchase modern devices in order to acquire data about objects and processes that might be of interest for the Bulgarian high-tech industry. The SmartLab devices ensured the “data autonomy” of IICT-BAS (flow of real-world data for IICT-BAS research tasks) and enabled highly innovative scientific activities related to material sciences, energy, health, industrial control and optimisation, etc.

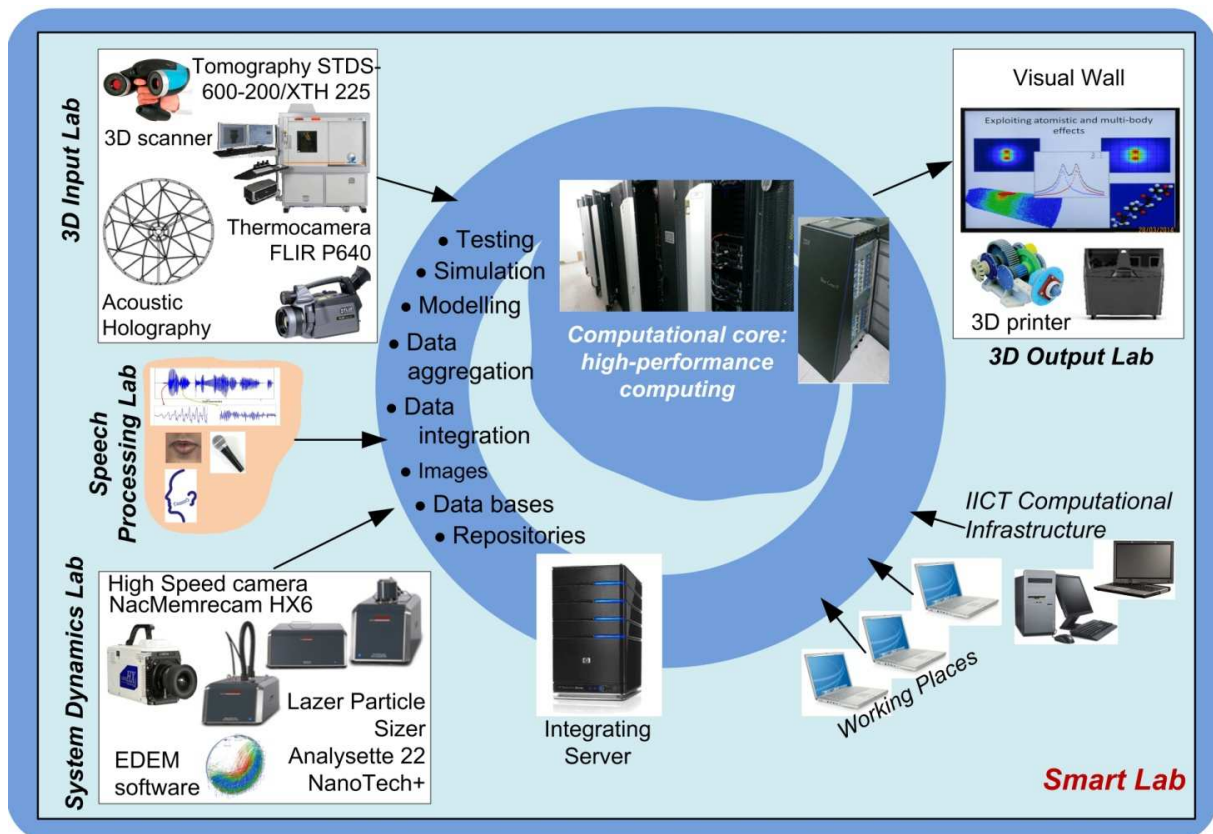


Figure 1 SmartLab Equipment

This idea proved to be quite fruitful. Today the IICT researchers develop an increasing number of applications where the HPC core infrastructure is used to process data coming from the modern labs for digitisation, image and signal processing, prototyping and visualisation, etc. Thus the synergy of the developed complex ICT methodology and practical approaches resulted in new kinds of innovative solutions.

Regarding the further development of the IICT-BAS core HPC facilities, the policy for sustainable future development of the infrastructure at IICT-BAS is aligned to the priorities of:

- (i) the Bulgarian Innovation Strategy for Smart Specialisation 2014-2020, especially to the priorities "Informatics and ICT" and "Mechatronics and Green Technologies";
- (ii) the Operational Programme "Science and Education for Smart Growth" 2014-2020; and
- (iii) the Updated National Roadmap for Research Infrastructure.

A new HPC cluster is currently installed in IICT-BAS as a core infrastructure of the National Centre for HPC and Distributed Computing, according to the National Supercomputing Roadmap. The architecture of this supercomputer is aligned to the European HPC Platform. The machine named Avitohol is currently in the Top 500 ranking, see the table below.

150 servers with 2 Intel Xeon E 2650 v2 CPUs and 2 Intel Xeon Phi 7120P coprocessors	
Site	IICT-BAS/Avitohol
Manufacturer	Hewlett-Packard
Cores	300(8+61) = 20 700
Interconnection	FDR Infiniband
Theoretical Peak Performance	410 Tflops in double precision
Memory	9600 GB
Operation System	Linux Red Had
Compiler	Intel Composer XE 2015
Lustre Storage systems	96 TD storage

Further information about Avitohol is available at <http://iict.bas.bg/avitohol/>.

The vision for exploitation and extension of SmartLab equipment is related to the opportunities provided by the funding instruments of the Operational Programme "Science and Education for Smart Growth" 2014-2020. It includes the expected calls for "Centers of Excellence" and "Centers of Competence in the thematic areas (i) Mechatronics and clean technologies, and (ii) Informatics and information and communication technologies. The currently identified targeted infrastructures include a new Data Centre as well as further development of the Labs for Digitisation and Prototyping.

3.2 Short-term (specific) Plans about Exploitation of SmartLab Devices – in Technology Transfer Initiatives, Related to Users

Speech Lab. There is an agreement between IICT-BAS and a TV-related Bulgarian company for contracted research in order to develop the first real-life application of the effective method for searching similar audio segments in large audio collections. In AComIn we created the Bulgarian Phonetic Corpus BulPhonC, <http://iml.bas.bg/BulPhonC>, which was used to improve and further develop an existing speech recognition system for Bulgarian language. We presented the system to the following Bulgarian companies: Ciela Norma LTD; Interactive Media Services LTD; Doli Media Studio LTD; NGO Civic participation and direct democracy; Sofia Municipality. They are interested in applications built on top of the speech processing technology. Interests to the speech recognition system developed in AComIn are expressed by other EU companies as well.

Acoustic Camera (Holographic Antenna) will be used in the following practical elaborations:

- Improvement of technical specifications of the acoustic camera through further development of created Matlab software and its incorporation within LabShop software;
- Deepening the knowledge of investigated problems of industrial partners: non-contact acoustic machinery testing, rolling bearing defect monitoring, detection and analysis of noise pollution, identification of noise sources, acoustic test of household products, determination of acoustic characteristics of rooms, etc.
- Accumulation of rich enough data bases using our contacts with different partners from industry.
- Continuing the collaboration and strengthen the relations with already established partners on the problems of joint interest.
- Widening the circle of partners with new ones. Search for new areas of application of the acoustic camera.

3D Laser Scanner will be used in various applications in the area of 3D modeling and virtual reality, 3D digitization of archeological and paleoanthropological artifacts, reverse engineering, dress and game design. Ongoing collaboration with colleagues from Academy of Music, Dance and Fine Arts (AMDFA) Plovdiv, National Institute of Archaeology with Museum at the Bulgarian Academy of Sciences, Institute of Experimental Morphology, Pathology and Anthropology with Museum at the Bulgarian Academy of Sciences. Moreover the 3D Laser Scanner will be used not only to extend the current 3D Ear DB, either as quantity (more than existing ~100 ear models on right ears only), or as quality of the models - for both ears of each person represented, as well as for gender, ages, etc. Technical refinements are planned for the 3D Ear DB development - for several resolutions of the scan, for conversion to 3D data from different type device, like Kinect, simple video camera, stereo camera, etc.

Laser Nano Particle Sizer and Thermo Camera. Using these devices, we plan further research of micro grains powders and nano based powders for producing of hard and wear resistant coatings including nano elements for increasing of hardness and wear resistant of the working surface of industrial bodies. The Analisette Nano Particle Sizer will support research of methods and means for producing of graphite fibers by continuous extension through hot high temperature zone of artificial and natural fiber materials (for getting of materials with high hardness against high velocity breaking and high thermo resistance), and their further usage for protection of industrial objects and biological subjects.

Industrial micro CT scanning. Strong interest for joint research is expressed from academic and industrial partners. It concerns a variety of applications in the areas of microstructure analysis of advanced composites, porous media, Non Destructive Testing of metal casting details and injection molding materials. We are also involved in joint projects of bone scanning, with biomedical and anthropological applications.

Using the Industrial Micro CT scanning and the High Speed Camera:

- We plan to continue the research of high speed processes and new types innovative drives for elastic and plastic metal deformations, briquetting of scrap and pilots fixing for application of new technologies, energy efficiency and environmental protection. Due to the large size of briquetting presses, large power consumption, and relatively low productivity, methods are investigated to improve the efficiency of this process. One such method is high velocity impact briquetting. Impact process can be recorded with a high-speed camera Nac Memrecam HX6. The video is processed with the software Vicsasso 2009 which defines impact speed and acceleration. The X-Ray tomography images of the briquettes (3D X-ray Nikon XTH 225 Tomograph) can be used for investigation of the density and poor quality of the briquettes. The arrangement and deformation of the chips is a clear illustration on the operation of vertical and horizontal plastic waves in the impact briquetting process.
- Another direction of exploitation is research and development of Assistive Computer Interface for helping people with reduced sight to work with graphical software for increasing the quality of life, which has high social impact. Until now we have 4 Bulgarian Patent Applications and one WIPO/PCT Patent Application for Graphical Braille screens with high speed linear electro magnetic micro drives and plan to continue the developments in this area.

3D Laser Scanner, 3D Software and 3D Printer. We have experience with Restoration of historical events for the Exhibition "The Battle of Pavia" (with Medieval Tapestries – 3D Printing of 3D Models of historical characters). We have also experience with 3D printing of pictures including Braille explanations in the figures (3D Tapestries about Pavia Battle for visually impaired people). We plan to take parts in future projects concerning 3D Modeling, Analysis and 3D Printing of Historical Figures, Objects and Scenes for Virtual museums and social platform on European digital heritage, memory, identity and cultural interaction using our 3D Scanner Handyscan 3D VIUscan Creaform, 3D EDEM (Discrete Element Method) Software and 3D Printer ProJet 460 Plus.

4 SUSTAINABILITY OF LIAISONS WITH ACOMIN USER COMMUNITIES

In fact, via AComIn, IICT-BAS managed to build a Network of Users from specific areas who want to increase their knowledge about modern ICT applications and to take part in pilot developments. Such a network existed before AComIn too, related to e.g. the Bulgarian GRID community, but AComIn and the installation of SmartLab accelerated significantly the process of formation of User Communities. The attracted participants in the Technology Transfer Seminars in AComIn year 3 (more than 400 people) will further disseminate the news about SmartLab potential in particular and IICT-BAS capacity in general. These figures show that the AComIn idea to focus on User Communities (among other objectives) was very successful too.

It is interesting to note that recently IICT-BAS has established itself as a non-formal transfer center, making successful connections between business and academia. News about the Doors Open Days in IICT-BAS are broadcasted on the national TV channels and the national radio (thanks to the PR-Department of the Bulgarian Academy of Sciences). Many pupils from high-schools come to the Days, as well as students.

Involving Users, talking to them, organising contact groups with mail-lists and regular meetings are future activities in the institute's Agenda for supporting liaisons with the existing User Communities. Following the examples of other organised Networks, IICT-BAS is establishing a kind of Sustainability Liaison Network for experts who are interested in further opportunities for communication and collaboration.

The Sustainability Strategy of IICT, proposed by AComIn to the Governing Bodies of the Institute in month 24 (D7.6) states that supporting and expanding a strong User Community is a key to the sustainable development of IICT-BAS. Future plans for extending SmartLab and integrating it in ambitious large projects with visible impact have to include the preservation and strengthening of the existing User Community built by AComIn.