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## STUDENT PROJECTS

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WHAT:
Software for evaluating and developing evolutionary algorithms by using the Glicko-2 rating system and different techniques of visualisation.

PROBLEM:
In the era of Moore’s law, computational power is increasing exponentially. More computational power has opened doors for many different approaches for solving optimization problems. One of them is based on adopting Darwinian principles that were used in the design of new algorithms. One of the main characteristics of such algorithms, called evolutionary algorithms, is that they are stochastic. This characteristic makes evaluation and comparison of evaluation algorithms complex and time consuming. Consequently, many scientific results in the field of Evolutionary Computation are incomplete or incorrect. In order to facilitate the development and evaluation of evolutionary algorithms we have developed a framework, the Evolutionary Algorithms Rating System (EARS).

GOALS:
1. To simplify and increase the quality of computational experiments in applied evolutionary computing.
2. To create a tool that assists in the process of teaching and learning evolutionary algorithms.
3. To support novel statistical methods.
SOLUTION:
EARS supports:

1 **Development of new evolutionary algorithms**
   - Basic application programming interfaces
   - Support for single and multi-objective algorithms
   - Basic algorithm tuning mechanisms

2 **Experiment support**
   - Selecting different standard benchmarks, and their settings
   - Set of already implemented evolutionary algorithms
   - Performance analysis
   - Novel method for statistical analysis: Chess Rating System for Evolutionary Algorithms (CRS4EAs)
   - Visualisation of the evolutional process

3 **Results’ presentation**
   - Creating standard reports (Tables and graphs)

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**Figure 2**
Time frame of multi-objective optimization process visualisation.

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The EARS framework has already been used in many scientific papers in the field of Evolutionary Computation, as well as an indispensable assistance in the educational process.
WHAT:
Since 2012, the collaboration between the Power Engineering Laboratory and Laboratory for Geometric Modelling and Multimedia Algorithms at UM FERI has yielded novel state-of-the-art methods and tools for region-wide photovoltaic resource assessment. Between 2015–2016 the methodology was extended with region-wide PV potential estimation, where economic, environmental and electricity distribution network influential factors were considered.

PROBLEM:
Solar energy is an increasingly popular renewable energy option due to decreasing photovoltaic (PV) system prices and better efficiency, even when subsidies, based on feed-in tariffs, were decreased. In order to find the most suitable location for the installation of PV systems, a methodology is required for the assessment of photovoltaic resources in the region of interest. It should include the assessment of PV potential, as well as existing infrastructure in the form of electricity networks. There are many challenges for estimating photovoltaic resource assessment accurately, where the economic, environmental and electricity distribution network influential factors must be considered over high-resolution geospatial data.

These challenges include accurate representation of the topography, accurate capture of the climatological parameters from long-term solar radiation, inclusion of shadowing from wider terrain-based surroundings and vegetation, anisotropic diffusion and reflective irradiance, photovoltaic system efficiency, as well as electricity network configuration and possibilities for its reconfiguration.

GOALS:
1. Accurate representation of the urban topography and its microclimate.
2. Estimation of photovoltaic potential by considering the nonlinear characteristics of photovoltaic systems and solar irradiance based on anisotropic diffuse model and shadowing.
3. Economic and environmental analysis based on region-wide statistical data of feed-in prices and CO₂ emissions.
4. Consideration of the electricity distribution network based on time-dependent loading profiles, PV-generation profiles, network configuration and possibilities for its reconfiguration.
5. To rate the available roof surfaces regarding their suitability for installation of PV systems.
**SOLUTION:**

The core steps of the developed assessment methodology are as follows:

1. Remote sensing data preprocessing into a suitable topological grid structure, where high-resolution LiDAR (Light Detection and Ranging) data is used as input.

2. Climatological parameters are estimated over the micro-location by calculating a Typical Meteorological Year, where long-term diffuse and direct irradiance measurements are considered.

3. Solar potential is estimated for each surface of the topological structure. This is performed with the estimation of surface topography, position of the Sun, shadowing and anisotropic diffuse irradiance.

4. PV potential is estimated over segmented surfaces by using the nonlinear efficiency characteristics of PV modules and an inverter.

5. Economic and environmental assessment is performed over segmented surfaces by estimating net present value, CO₂ emission rate and energy payback time, based on a complete lifecycle assessment.

6. Electricity distribution network inclusion by considering network configuration, possibilities for its reconfiguration, time-dependent PV generation profiles and loading profiles.
WHAT:
Pilot laboratory device for vacuum drying of sludge.

PROBLEM:
Sustainable technology in sludge drying (Figure 1) is crucial in maintaining economically efficient and environmentally friendly sludge management. Natural drying by solar energy or with thin layers in landfills cannot be applied in most parts of the world. Some other types of drying should be applied for this reason. Contact dryers are used most commonly to dry fruits, timber, explosives (low temperature), inorganic industrial sludge etc. The common feature of this process is the use of a heating, usually with liquid (oil, water) or high temperature steam (water – above 80°C; steam – over 120°C) that circulates inside the double wall of a dryer’s drum.

GOALS:
1. Decrease the price of sludge drying below 100 EUR/ton.
2. Disinfection of dried sludge.
3. Automated controlled process.

SOLUTION:
In our case, vacuum technology was used for municipal sludge/digestate drying. A small scale SDDU is a batch type that can dry up to 50 kg of raw sludge in one drying cycle (Figure 2). The sludge volume is, consequently, defined by the mechanical components, contact area and volume of the drum to about 150 dm$^3$. The concept of the SDDU utilises low temperature heating/cooling under low vacuum conditions, as can be seen in the water phase diagram.

The newly designed vacuum dryer consists of a horizontally mounted drum (evaporator) with a double wall for heating, a rotary stirrer with adjustable blades inside, a dust filter, a vertically mounted condenser with a double wall for a cooling medium and a separate tank used as a condensate collector. The double wall of the evaporator is heated by water with a temperature between 30°C and 40°C. This maintains the inside temperature of stirred sludge between 25°C – 30°C. The condenser is cooled with a water temperature lower than 20°C, so that the water vapours from the evaporator (through a dust filter) condense on the inner walls of the condenser and flow into the condensate collector tank.
To maintain the evaporation/condensation process, an absolute pressure inside the dryer has to be maintained between 30-70 mbar (low vacuum). In our case, we used a two-stage rotary vacuum pump. The vacuum pump also had a gas discharge function, to draw the gases out of the dryer (fermentation gases slow down the evaporation), through an air filter and into the atmosphere.

We used thermal drying as a disinfection method. When disinfection, or pathogen reducing, had started, the sewage sludge was heated to 70°C for 30 minutes. After the mentioned period of 30 minutes, the pressure in the vacuum chamber was decreased to approximately 500 mbar, so the water in the sludge started to evaporate and, therefore, the energy for heating was not lost. By decreasing the temperature of the sludge in the vacuum chamber to 35°C, the pressure was also decreased to 40 mbar, so evaporation was maintained at the highest rate.

Experiments were carried out to determine the optimum drying-process parameters needed for automated control. All the experiments were conducted in a laboratory with the aim of developing a sludge-drying technology in a vacuum that will have a minimum impact on the local environment (odourless, clean condensed water output). Figure 3 shows the important processing values during the drying process experiment during the almost three day long period.
**WHAT:**
Detailed motor activity analysis in muscles after nerve transplantation for the purpose of intuitive control of a bionic arm.

**PROBLEM:**
There are approximately 3 million people with an amputated arm worldwide and the average amputation incidence is 1.5 per 1,000. Prosthetic arms have the potential to compensate for the lost arm functionalities and have been under intense technological development. Today’s most sophisticated bionic arms support mechanical movements with up to 20 degrees of freedom, but suffer from ineffective and unintuitive movement control that requires relatively large mental effort of the affected person. This burden of movement control can be reduced partly by a surgical procedure called Targeted Muscle Reinnervation (TMR), in which the nerves that originally controlled movements of the amputated arm are transplanted to the muscles remaining after the amputation. After TMR, the neural commands sent by brains to control the movement of the amputated arm are amplified electrically by the reinnervated muscles and can be detected noninvasively on the surface of the skin. Recorded signals are highly interferential and need to be decomposed to contributions of individual functional units of skeletal muscles, so called Motor Units.

**GOALS:**
We analysed activity of individual Motor Units after TMR and the feasibility of bionic arm control with surface electromyograms recorded from reinnervated muscles.

**SOLUTION:**
Five TMR patients and nine healthy subjects participated in the study, which was conducted in cooperation with the Laboratory for Restoration of Extremity Function (Division of Plastic and Reconstructive Surgery, Medical University of Vienna, Vienna, Austria), Institute for Neurorehabilitation Systems (Bernstein Center for Computational Neuroscience, University Medical Center Göttingen, Georg-August University, Göttingen, Germany) and Department of Systems Design Engineering (University of Waterloo, Waterloo, Canada).

Two-dimensional arrays of 8×8 electrodes with interelectrode distance of 10 mm (Figure 1) were used to record high-density surface electromyograms (EMG) from the healthy (able-bodied subjects) and fully reinnervated muscle (TMR patients). Different movements of the amputated/healthy arms were recorded, such as wrist flexion and extension and hand opening and closing. Recorded EMG signals were analysed by the Convolution Kernel Compensation (CKC) technique, developed in our laboratory, and characteristics of individual Motor Units were assessed in reinnervated muscles.
We demonstrated that reinnervated Motor Units share approximately the same firing behaviour, but are detectable on a statistically significantly smaller area of the skin than the Motor Units in the able-bodied subjects (Figure 1). In TMR patients, the areas of Motor Units that were active during the different intended movements of an amputated arm overlapped significantly, hindering movement discrimination by simple EMG processing techniques. Therefore, more sophisticated algorithms, such as CKC are required to recognise movement intentions from the recorded electrical activity of reinnervated muscles and to control bionic arms intuitively.

Figure 1 Recording of high-density surface EMG signals in a TMR patient (left) and territories of five representative Motor Units (MUs) per intended movement of an amputated arm (elbow flexion, wrist extension and hand closing) as seen by different electrode arrays (M1 to M5). Motor Units were identified by the CKC technique that was applied independently to surface EMG signals from each electrode array separately. Territories of Motor Units that are activated in different movements overlap significantly and cannot be distinguished easily. The bottom right panel compares the sizes of identified Motor Unit territories in five TMR patients (blue) and nine able-bodied subjects (red).
WHAT:
Managing the complexity of business process diagrams by introducing Opacity-Driven Graphical Highlights (ODGH).

PROBLEM:
The main purpose of business process diagrams is to provide a mean for a standardised and more effective communication between process related stakeholders. To perform effective ‘diagrammatic communication’ it has to be ensured that diagrams remain simple, which is often challenging, because business processes and the corresponding workflows commonly represent complex systems.

GOALS:
The goal of our ongoing research is, therefore, to investigate the understandability of business process modelling notations and the resulting diagrams, as well as to propose novel techniques for addressing the complexity of business process diagrams.

Figure 1  Empirical validation of the intuitiveness of process diagrams.
SOLUTION:

1. In light of the complexity of notations and diagrams an empirical research was conducted, with the goal to validate the intuitiveness of the diagrams empirically, modeled in the most commonly used process modeling notations, i.e. Unified Modeling Language 2.0 Activity Diagrams (UML AD), Business Process Model and Notation (BPMN) and Event Driven Process Chain (EPC).

The experimental results demonstrated that, in the case of low-complexity processes, BPMN diagrams were outperformed by EPC and UML AD - based diagrams, which opens new challenges and opportunities in enhancing BPMN. However, when the complexity of processes was higher, participants using EPC diagrams performed significantly worse than those using the UML AD and BPMN diagrams.

2. A second branch of research is dedicated to addressing the complexity of business process diagrams actively with a novel approach and a corresponding tool that aims to decrease the complexity of business process diagrams without changing the notation or existing approaches by introducing ODGH.

Opacity enhances business process diagrams in light of the structural and behavioral opacity-driven highlights, while not interfering with specification of the modeling language or existing complexity-coping mechanisms. A performed case study demonstrates that the usage of ODGH decreases the cognitive load by highlighting only relevant elements of business process diagrams. The ODGH-tool was implemented in the PHP programming language, along with AngularJS and Bootstrap.

The outcomes of the research have implications for our domestic and international projects with the focus on business process analysis and redesign (e.g. 100+ BPMN related deliverables produced for Good e-Learning, founded in London, UK).
PROTEIN FOLDING OPTIMIZATION UNDER AN HP MODEL

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WHAT:
Evolutionary Algorithm for the Protein Folding Optimization in a Hydrophobic-Polar Model and Cubic Lattice.

PROBLEM:
The problem of protein structure prediction represents the computational problem of how to predict the native structure of a protein from its amino acid sequence. Protein function is determined by its structure. With the wrong structure, a protein cannot fulfill its function correctly. With current algorithms and computational resources, it is possible to predict the native structures of relatively small proteins and to help in drug design and proteomics. The protein structure prediction problem is one of the more important challenges of this century and, because of its nature, it attracts scientists from different fields, such as Physics, Chemistry, Biology, Mathematics, and Computer Science.

GOAL:
Within the protein structure prediction problem, the protein folding optimization represents a computational problem for simulating the protein folding process and to find the correct fold of an amino acid sequence.

Figure 1
The sequence HPHHPHPHH in a cubic lattice. The H monomers are shown in white and the P monomers in dark. Hydrophobic-hydrophobic contacts between two nonconsecutive monomers that occupy adjacent lattice points are shown with numbered black lines.

Figure 2
The local movement of one monomer.
SOLUTION:

The development of a new Evolutionary Algorithm for constructing the native tridimensional structure of a given amino acid sequence under an HP model and cubic lattice. This algorithm belongs to the ab initio protein prediction type of methods, which predict structures from scratch and do not require any information about related protein structures. The developed evolutionary algorithm is extended with local search, crowding, clustering and repair mechanism. The crowding is employed for maintaining the diversity of the population and for preserving good solutions to the end of the evolutionary process. The clustering is used to divide a whole population into more subpopulations that can locate different good conformations. The repair mechanism transforms infeasible conformations to feasible ones. A local search was integrated within the algorithm in order to speed up the convergence.

The developed algorithm achieves better structures for longer sequences and requires significantly less time to achieve the native structures for shorter sequences in comparison to the state-of-the-art evolutionary and swarm algorithms.

Figure 3 The local movement of two monomers.

Figure 4 Conformation for sequence T64.5.

Figure 5 Conformation for sequence T64.8.
07 AUTOMATIC COMPLEX MISSIONS` PLANNING FOR DEEP SEA EXPLORATION

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WHAT:
Underwater glider path optimization in sub-mesoscale eddy sampling by using constrained differential evolution optimization for real-world underwater glider path planning missions.

PROBLEM:
The real-world implementation of constrained underwater glider path planning over a dynamic and changing environment in deep ocean waters requires complex mission planning under very high uncertainties. The remote human pilot of these autonomous unmanned deep-sea vehicles meets several time limitations. These limitations are emphasised even more when piloting of multiple vessels is required at once. Adding the requirement to sample the ocean structures under specific constraints, like borders of eddies, introduces high attendance overheads to such pilots.

GOALS:
Namely, when sampling non-linear structures, the pilot needs to plan and provide timely new way-points to each vessel during the limited time interval for the satellite uplink from the vessel. After that, the vessel glides autonomously for a few hours, each time being propelled by buoyancy displacement under water, performing data gathering and other mission tasks.

Such mission is also influenced to a large extent by the remote sensing to forecast weather models' outcomes used to predict spatial currents in deep sea, further limiting the available time for accurate run-time decisions by the pilot, who needs to re-test several possible mission scenarios in a short time, usually a few minutes.

Moreover, an approach was also developed for tackling constrained underwater glider sub-mesoscale path planning.
SOLUTION:

Therefore, a hybrid system was designed as a real-world implementation of such complex mission planning. An algorithm for path optimization considering the ocean currents model predictions, vessel dynamics, and limited communication, yields potential way-points for the vessel. Many relevant optimization algorithms were considered for this, and are ranked to suggest the performance of these algorithms on this challenge with several typical real scenarios. There is also one new specific algorithm developed for this purpose, based on nature-inspired collective intelligence of the constrained differential evolution with epsilon constraints’ handling. The optimization algorithm prepared builds upon studies in recent advances in modern nature-inspired algorithms and some additional real-world applications, like hydro-thermal power plants’ scheduling algorithms and spatial tree morphology reconstruction algorithms which have served very well for testbed domains in developing optimization algorithms’ approaches.

1. A real case glider vessel mission was commanded using the proposed approach.
2. Underwater glider kinematic simulation with daily and hourly sea currents’ prediction.
3. The feasible path area was defined as a corridor around the border of an ocean eddy.
4. A differential evolution algorithm was applied to underwater glider path planning.
5. The suggested configuration outperformed compared optimization algorithms and ranked top.
6. Experimental set with trajectories avoiding islands and changing scenarios spatially.
7. An approach for tackling constrained underwater glider sub-mesoscale path planning.
9. Two new benchmark sets with 24 or 28 different specialised scenarios defined the challenge.
10. Per-scenario and aggregated performance analyses of different mechanisms’ new configurations.

Figure 3 Example mission scenario - simulated trajectories.

Figure 4 Definition of the feasible circular eddy border area.
WHAT:
Innovative protocols and solutions to address the key challenges of secure IT and Internet of Things (IoT). Several innovative security protocols were developed which form the basis for secure electronic communication and enable a safe and, consequentially, privacy oriented IoT. These security protocols address the majority of security challenges, including authentication, confidentiality and integrity. At the same time, they demand less computational and communication resources than existing solutions.

Figure 1  The IoT provokes new security challenges.
PROBLEM:

Mobile and ubiquitous solutions and services are influencing our daily lives greatly. Tightly related is the concept of the IoT which makes devices, solutions and services much more diverse. New ways and areas of application have emerged and, thus, also provoked new challenges/problems in the field of Information Security.

Additionally, security and privacy also include societal aspects, not only technical ones. More precisely, today’s societies are increasingly more mobile and internationalized, which also demand new multicultural and multilingual skills.

GOALS:

1. Create security protocols that are secure in regard to well-established security requirements and demand less resource in respect to computational and communication cost.

2. Create privacy-aware mutual authentication protocols compatible with specific restrictions.

3. Present a systematic and comprehensive overview of the security and privacy aspects of the IoT, as well as the challenges and open problems related to the IoT.

4. Identify skills of cultural awareness in order to incorporate the cultural component into the specific scientific area.

SOLUTION:

The developed security protocols form the basis for secure electronic communication and enable a safe and, consequentially, privacy oriented IoT. These security protocols address the majority of security requirements, including authentication, confidentiality and integrity. At the same time, they demand less computational and communication resources than existing solutions, and are, therefore, well-suited for practical application scenarios.

Additionally, an innovative privacy-aware mutual authentication protocol compatible with specific restrictions has been developed which demonstrates that privacy in the IoT can be achieved without proprietary protocols and on the basis of existing Internet standards.

The research also resulted in an overview of the security and privacy aspects of the IoT, as well as the challenges and open problems related to the IoT. The key challenges in the research field are provoked by the ubiquity and the type of data collected and processed - sensitive data, e.g. location data, patient data.

In scope of the research a list of cultural awareness skills was identified that incorporate the cultural component into this specific area of security and privacy in IoT. In this way, aspects of security and privacy can profit.
WHAT:
EDGE is a data mining Application Programming Interface (API) developed by the Laboratory for Geometric Modeling and Multimedia Algorithms at UM FERI for Solverminds Solutions & Technologies (shortly SVM), a software and analytics solution company from India specialised in providing enterprise application and analytical solutions for various industries.

PROBLEM:
In recent years, we have been witnessing a rapid growth of heterogeneous data sources and streams, which poses new challenges for efficient visualisation and knowledge discovery. Recognising relations and hidden patterns within the data is still a major challenge in machine learning and data mining.

EDGE addresses these problems by decomposing the data into a cluster hierarchy, on top of which various machine learning algorithms fit geometrical surfaces, by which prediction of targeted attributes are made. Moreover, new visualisation and statistical analysis is performed over the hierarchy in order to provide better understanding of the underlying relationships within the data.

GOALS:
1. Develop a data mining platform which is capable of searching for hidden relationships and patterns within large high-dimensional multimodal data.
2. Represent the data in novel ways, understandable and useful to the data owner with new visual and statistical analytics.
3 Provide predictive analytics of the target attributes in support of data driven decision making.

4 Can be integrated easily into many application domains, ranging from the shipping industry, which is among the main SVM priorities, to DNA analysis, where SVM is looking to extend their market.

**SOLUTION:**

Based on the goals, the core solution of EDGE contains the following main functionalities:

1 **Data preprocessing** transforms and consolidates input data into a structured form, appropriate for data mining. This is achieved by organising the high-dimensional datasets into hierarchical clusters based on geometric similarity between the different substructures present within the data.

2 **Data mining** combines various machine learning and reasoning methods for finding patterns in very large datasets. Furthermore, prediction of the future trends can be performed based on the current state of the data variables.

3 **Statistical analytics** supports identification of hidden knowledge and patterns. Various statistical tools are offered to the user in order to search for linear and nonlinear correlations between multiple variables.

4 **Knowledge representation** is realised with various advanced visualisation techniques. The visualisation is performed in real-time by employing various levels of detail.
WHAT:
A set of advanced methods and algorithms, based on bio-inspired approaches, aimed at existing challenges of data analytics.

PROBLEM:
The development of Information Technology has brought us to a period of increasingly rapid creation, sharing and exchange of information. Aware of the importance of knowledge hidden in the abundance of data, decision makers are, nowadays, faced with the challenging task of data analysis and extracting relevant information out of data. As the amount of data surpasses the ability of high-performance computing systems to process it adequately using traditional approaches, the solution to this problem lies in the creation of advanced data analytics algorithms, methods and tools.

GOALS:
To developed a set of advanced methods and algorithms aimed at existing challenges of data analytics, which are based on bio-inspired approaches, such as evolutionary computation, artificial neural networks and swarm intelligence:

1 Allocation method for wise partitioning of data, which improves classification accuracy, precision and recall of large datasets significantly.

2 A Multi-Population evolutionary algorithm, which provides significantly more balanced classification results.
3 A semi-supervised algorithm based on self-training for enlarging available training sets with the help of information from unlabelled and unstructured data.

4 A binary particle swarm optimization method for the selection of informative attributes in high-dimensional data.

SOLUTION:

The methods were developed with the user’s (data analyst’s) benefit in mind. They provide transparent and balanced knowledge models with low levels of complexity, which allows the validation of discovered knowledge. Additionally, the methods require almost no user interaction.

To apply the developed methods, we have designed and developed an intelligent data analytics system in the form of a web application for our industrial partner. It collects data from a number of web sources, searches for relevant news articles and extracts the needed information from those articles. The system was tested on the problem of gathering the news about infrastructural business investments around the world. The system utilises the power of both traditional machine learning techniques (such as Random Forest) and modern deep learning methods (such as recurrent and convolutional neural networks) and combines it with our developed data analytics methods. By applying neural language processing methods for finding specific entities from the text, the system is able to learn to collect and extract relevant information automatically. The system is supplemented with the web application for managing the system, evaluating the results and tuning the settings accordingly.

Figure 4 Data analytics tool for automatic collecting and extracting of information about infrastructural business investments.
MODELLING OF MAGNETIZATION DYNAMICS INSIDE SOFT MAGNETIC STEEL SHEETS

Asst. Prof. Dr. Martin Petrun, Dr. Vojko Podlogar, Prof. Dr. Drago Dolinar, Simon Steentjes, Prof. Dr. Kay Hameyer

WHAT:
A model for prediction of magnetization dynamics and power loss inside Soft Magnetic Steel Sheets (SMSSs).

PROBLEM:
When modelling magnetization dynamics in SMSSs the static description of the material's magnetic properties is not sufficient due to the high electrical conductivity of the material. This constitutive property enables the generation of unwanted eddy currents inside the SMSSs due to the alternating magnetic field. Induced eddy currents not only increase the power losses inside the SMSS, but also influence the distribution of the magnetic field and, consequently, the shape of the dynamic hysteresis loop in a highly non-linear manner.

Figure 1 Spatial discretization of the SMSS and non-linear distribution of the magnetic field.
GOALS:

The model was developed for use in Applied Engineering, therefore it requires the following properties:

1. It is based on a sound physical background.
2. It enables prediction of dynamic hysteresis and power loss components, as well as power loss distribution inside an SMSS under arbitrary magnetization conditions.
3. It can be used for a calculation that is based either on the applied voltage or current in the excitation winding.
4. It can be applied easily into different circuit simulation software packages.
5. The complexity of the model is adapted easily for the calculation needs with adequate spatial discretization according to the excitation dynamics.
6. It gives advantages over existing models: Simplicity, parametric basis, flexibility and computational efficiency.
7. It can be extended further to include additional phenomena inside SMSSs.

SOLUTION:

In the developed Parametric Magneto-Dynamic (PMD) model each SMSS is discretized spatially into $N$ slices, where the magnetic field in each slice is described with its average values. Most importantly, the distribution of induced eddy currents and their feedback on the magnetic field inside the SMSS is accounted for. The PMD can be expressed as a system of non-linear Ordinary Differential Equations (ODEs) in the form of a matrix differential equation. The proposed PMD model enables effortless implementation of different inverse static hysteresis descriptions. The size of the obtained ODE system depends on the discretization of the observed SMSS, i.e., the number of slices $N$. In the case when only one slice is used, the PMD model gives the classical low-frequency eddy current approximation. In addition, the discussed model can be applied to voltage, as well as current driven problems.
WHAT:
Design of a test procedure by means of functional safety and to enhance the aircraft cockpit with a haptic feedback that makes the operation more intuitive, easy to use and reduces the pilot workload.

PROBLEM:
A serial hybrid drive allows two independent sources of energy, namely the battery system and the generator system. In case of failure of either component, the other can supply reserve power. Furthermore, the electric motor, which is the exclusive propulsion unit of a serial hybrid system, offers increased reliability and reduced maintenance compared to a piston-powered engine. In order to control the hybrid in a way that is both safe and energy efficient, a special human-machine interface shall be designed, developed and validated. The interface allows a pilot to exploit intuitively all the benefits of hybrid propulsion while, at the same time, reducing the pilot's workload as compared to managing a piston engine.

GOALS:
The aim of the HYPSTAIR project was to design and validate serial hybrid drive components for all-electric aircraft propulsion. The components were designed with the aim of functioning as a part of a complete airframe and hybrid drive system. The sizing of all components was done in such a way that the focus was
not only on their individual efficiency, but also on the expected total system efficiency and performance. This involved balancing weight and efficiency aspects of components with the goal of overall platform efficiency while considering the envisaged aircraft mission profiles.

**SOLUTION:**

1 **Consortium**

The HYPSTAIR partnership consisted of two SMEs, two universities and a Large Enterprise (LE), all active in research and technology development in the field of Aeronautics and Electrical Engineering, originating from 3 different EU member countries.

The Partners of the project are:

- Pipistrel, d. o. o., Ajdovščina (PPS): SME, Slovenia
- Siemens AG (SAG): LE, Germany
- University of Maribor (UM), Slovenia
- MBV Vision di Massimiliano Pinucci (MBV): SME, Italy
- University of Pisa (UP), Italy

2 **Testing procedure and functional safety**

The components were designed with the aim of functioning as a part of a complete airframe and hybrid drive system. The sizing of all components was done in such a way that the focus was not only on their individual efficiency, but also on the expected total system efficiency and performance. This involved balancing weight and efficiency aspects of components with the goal of overall platform efficiency while considering the envisaged aircraft mission profiles. The functional safety issues were first emulated in the ‘baby’ version of the power-train system which was built in the Laboratory for Power Electronics. Some of these issues were also tested on the ‘Panthera’ platform delivered by the Pipistrel Company.

3 **Haptic Power Lever**

Haptic Power Lever has been developed in the Laboratory for Industrial Robotics within the HYPSTAIR Project. Afterwards, the haptic power lever was integrated and tested in the human machine interface of a serial hybrid aircraft propulsion system and was designed in order to enable the operation of such aircraft in a pilot friendly manner. The pilot controls the power of a hybrid electric powertrain with a power lever and monitors the system’s status and output on a cockpit display.

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Figure 2 Principle Scheme of the Management System with Haptic Power Lever.
WHAT:
An Improved High-Reliability and High-Performance Autonomous Charge Equalization Circuit for use with in-Series Connected Battery Cells.

PROBLEM:
A reliable battery balancing system is needed to conserve a battery pack consisting of in-series of connected batteries. The balancing circuit manages the batteries in such a way that it equalizes the State Of Charge (SOC) of the batteries. The goal was to achieve an autonomous system without the use of any regulation loops, therefore, a combination was used of a forward and fly-back converted topology. Several design constraints needed to be followed in order to be highly tolerant to radiation. An additional design constraint was to limit the use of components to only Commercial-off-the-Shelf (COTS) components.
GOALS:
The key benefits of such design are:
1. High reliability and compact design.
2. High efficiency.
3. Good voltage and SOC equalization.
4. Constant operation suitable for turn on and forget systems.
5. The use of COTS components.
7. Power transfer control with a PWM signal.

SOLUTION:
The system was prototyped and its conversion efficiency and voltage equalization performance were evaluated. The system achieved a peak efficiency of 88% with a maximal battery voltage difference of only 3 mV. The balancing circuit was also modified to achieve higher energy transfers and, therefore, decrease the time required to achieve balance.
WHAT:
A High-Performance and High-Reliability Analog Maximum Power Point Tracking Algorithm suitable for use on a Spacecraft meant for use in a Low Earth Orbit.

PROBLEM:
As an extension of the TRISAT nanosatellite project, a reliable Maximum Power Point Tracking (MPPT) design was developed, which was implemented as an analog circuit for use on a satellite relying on solar power generation within a Low Earth Orbit (LEO). The environment was evaluated within which such a spacecraft system would function.

GOALS:
The following design constraints, which differ from terrestrial MPPT implementations, were followed:

1. The MPPT needed to be tracked in rapidly varying illumination and temperature conditions.
2. The whole system needed to be implemented in an analog form with as little complexity as possible.
3. The system must perform satisfactorily even with small solar panels (down to 8W nominal power), to be suitable for use with nanosatellites.
SOLUTION:
A modified Perturb and Observe (P&O) Maximum Power Point Tracking algorithm was selected. A further increase in reliability was achieved by only using carefully selected analog components which are suitable for use within a space environment. The following innovations were incorporated into the analog MPPT implementation:

1. A circuit consisting of discrete analog parts was used to increase the reliability of the MPPT circuit in the context of a spacecraft using solar panels for power generation.
2. Carefully selected Commercial-off-the-Shelf (COTS) components were used instead of expensive radiation hardened components.
3. The number of different parts used was minimised.
4. The power converter was implemented in a way that allows the use of a low complexity MOSFET gate driver.
5. The MPPT algorithm was implemented in an analog form and then optimised for use with COTS components operating in the scope of a LEO spacecraft.
6. An analog implementation of a variable-time delay circuit was incorporated into the optimised MPPT algorithm design, which increased the accuracy of the algorithm while allowing operation in a wide range of environmental conditions.

The system was prototyped and its power conversion performance characterised using a custom built measurement setup. The system tracked the Maximum Power Point successfully through all the performed measurements. The results from the measurements suggest that the prototyped system has a nominal regulator efficiency of 88% and a nominal tracking accuracy of 96%.
WHAT:
SpinRCP is an Integrated Development Environment (IDE) for the popular Spin model checker that is used for verifying the correctness of concurrent and distributed systems.

PROBLEM:
Model checking is a powerful approach towards ensuring the correctness of concurrent and distributed systems. It is an automated formal verification method that, given the finite-state model of a system and a formal property, checks systematically whether this property holds for that model. The main strengths of model checking are the following ones: It is a general technique that is applicable to a wide range of systems (e.g., communication protocols, software, hardware), it allows partial verification (only the more relevant properties are checked), it is not harder to find less likely errors than the more likely ones, it provides a counterexample in case a property is invalidated, and several software tools exist. One of the most successful model checkers is Spin. It is a command line tool, and its use may be challenging and discouraging, especially for newcomers who are not yet well acquainted with Spin commands. A user-friendly graphical environment for Spin would be of considerable benefit for experienced users as well.
SpinRCP is available publicly at lms.uni-mb.si/spinrcp and used at many universities and research institutions worldwide.

GOALS:
1. To develop a stand-alone user-friendly IDE for the Spin model checker.
2. To simplify the use of Spin.
3. To make SpinRCP IDE freely available to Spin users.
4. To support all of today’s operating systems and computer platforms.

SOLUTION:
SpinRCP has the following functionalities:
1. Promela model editor with syntax highlighting, code folding, and content assist.
2. Syntax check of a model with marking the places of syntax errors.
3. Redundancy check of a model with suggestions on how it could be revised to use less memory.
4. Production of the symbol table information for a Promela model.
5. Graphical representation of processes and never claims derived from the specified properties in the form of non-deterministic FSMs.
6. Formal verification of a model for a given property.
7. Random, guided, and interactive simulation including graphically displayed Message Sequence Charts.
8. Conversion of Spin simulation output to the standard Message Sequence Chart text file formatted according to ITU-T Z.120.
9. Integrated Help contents.
10. CVS file version management.
STUDENT Projects
REAL-TIME DATA ACQUISITION, PROCESSING AND VISUALISATION

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Figure 1  Raspberry Pi 2 B+ embedded device.

WHAT:
System for high frequency real-time data acquisition and processing on the EtherCAT network using the embedded device Raspberry Pi 2 B+.

PROBLEM:
A distributed network of heterogeneous measurement devices where each has multiple sensors and controllers attached. Fast data acquisition, processing and response - in precision of microseconds - presents a real challenge. At high acquisition frequency above 10 kHz additional problems appear, such as network bandwidth utilisation, efficient data forwarding to multiple monitoring clients, and displaying the acquired data in real-time. All this currently requires a fast network connection, a high performance PC and specialised software.
**GOALS:**

1. To create a cost-efficient embedded device and software solution that is able to acquire data above 10 kHz and respond in microseconds.

2. To create a new communication system that lowers the client’s performance and network bandwidth requirements.

3. To create a device and OS type independent user interface for measurement monitoring and control reducing the need for specialised PC software.

**SOLUTION:**

The Raspberry Pi 2 B+ embedded device with a Linux based system with customized kernel to enforce stringent response deadlines and kernel level EtherCAT network data acquisition. The data is then made available to network clients over a TCP socket over a custom communication protocol where the client is able to make demands for only the specific data channels currently needed and only receives updates as fast as required.

The device and OS type independent monitoring software for common use cases was implemented as an HTML5 Website as the only requirement was a modern browser that is, nowadays, available almost everywhere.
WHAT:
A new method for segmenting point clouds into subsets of points, where each subset describes a single face of an object.

PROBLEM:
In recent years, we have been witnessing an increasing trend in the digitalization of real objects. Digitalization of buildings is especially popular, as their 3D models are a vital part of various applications in tourism, 3D geographic information systems for urban planning, digitalization of cultural heritage, and augmented reality. The digitalization of buildings is usually performed with remote sensing systems, mostly with terrestrial Light Detection and Ranging (LiDAR) technology, which uses laser light in order to scan the geometry of objects’ faces. Segmentation of the scanned point cloud is the first step in automatic 3D modelling of buildings, on top of which objects’ topologies are built.

GOALS:
1 To develop a new graph-based method for point cloud segmentation.
2 To improve accuracy and computational efficiency in comparison to the state-of-the-art.
3 To validate the method using real-world point cloud data.

Figure 1
(a) Unsegmented point cloud and (b) The segmented point cloud. Points before and after segmentation are coloured by height and face membership, respectively.
SOLUTION:
The developed segmentation method is based on Locally Fitted Surfaces (LoFS) and achieves an accurate definition of objects’ faces. The method operates on an undirected graph, established over the otherwise unstructured point cloud. It was tested using the terrestrial LiDAR data of a real object and benchmarked against a widely used method from the popular Point Cloud Library (PCL). The results show that our method segments point clouds accurately and allows us to achieve over 5% higher precision, while reducing the computation time in comparison to the current state-of-the-art.

Figure 2
Segmented room corner with an open door where (a) is the ground truth data, (b) is our result with precision of 99.35%, and (c) is the result of the PCL method with 93.00% precision.

Figure 3
Segmented corner of a room with a curved ceiling where (a) is the ground truth data, (b) is our result with precision of 98.94%, and (c) is the result of the PCL method with 95.82% precision.
WHAT:
An interactive Augmented Reality system developed as an upgrade of the traditional music notation handbook for learning solfeggio, containing a set of songs and rhythmic exercises for methodical learning of songs.

PROBLEM:
In Slovenia and worldwide, the public-school system and music theory teaching (Solfeggio) lags behind from the technological viewpoint and it is rarely associated with the time of computer technology usage. The question of using the computer technology that learners are also entitled to with reference to learning Solfeggio, is left largely to the ingenuity of teachers and the capacity of the schools at which they work. Currently, there exist some foreign websites intended for teaching Solfeggio, but often they do not offer a realistic view of the content for which they exist. Therefore, it was necessary to examine the possibilities of computer-aided teaching of Solfeggio using new modern technologies such as Augmented Reality.

Figure 1
Application’s start page (first image) and the main page, where the user can see and hear the melody or singing of the notation (second image).
GOALS:

1. To create creative and innovative solutions for practical challenges in the corporate sector.

2. To design and develop an innovative interactive system for learning Solfeggio through mobile devices with the existing handbook.

3. To use Augmented Reality for educational purposes.

SOLUTION:
The project iSolfeggio included students from different Study Programmes – Computer Science, Media Communications and Music pedagogy. The aim of the project was to design and develop an innovative interactive system for learning Solfeggio which would allow students to use their mobile devices in order to be able to learn Solfeggio individually with the existing handbook. The target group were learners at the level of the 4th grade of Music School. The newly developed application iSolfeggio is an interactive Augmented Reality (AR) system developed as an upgrade of the traditional music notation handbook for learning Solfeggio, containing a set of songs and rhythmic exercises for methodical learning of songs. iSolfeggio can be used on a mobile phone or tablet along with the device’s video camera. The system works in a way that it improves understanding of the traditional music records in handbooks, so that the learner can inspect the playing on the screen individually and overlook his/her rhythmic and melodic knowledge.