Intelligent Space, intelligent robot

Final report

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Introduction

Recent advances in the fields of intelligent, artificial intelligence, soft computing, and anytime approaches, have resulted in efficient modeling and evaluation techniques in system theory. These methods are especially suitable to automatically solve complex problems requiring decisions based on complex, ambiguous and/or imperfect information.

These methods support the implementation of computer-based signal processing, diagnostics, monitoring, measurement, and control models, algorithms, and applications. For larger scale systems, the computational complexity related to these characterizations and computations might be critical from the point of view of implementation. Complex development, supervisor, and control systems of biomedical, robotics, and risk analysis systems aiming to improve the quality of life, together with their decision, evaluation, and diagnostics support, are typical examples. In modeling soft computing techniques, while in overcoming complexity issues, anytime techniques can be applied advantageously.

The purpose of the suggested project is to introduce new intelligent and soft computing based – fuzzy, NN, anytime, and hybrid – models and algorithms in the fields of intelligent space, digital signal and image processing, robotics, and risk analysis, which result in better performance, then that of the known methods; are able to make decisions and deductions, adaptation, learning; make possible to flexibly reduce the overall computational complexity, and furthermore, can result in the automatic operation, i.e. without any human intervention, of the methods.

In the project proposal, four internationally challenging research areas have been named to focus on:

1. System models of robot, safe robot track design, robot navigation, human-robot, robot-robot interaction, teleoperation, eto-robotics.
2. Design of multi-function supervision systems for the care of ill/disabled persons and for the control of persons doing sport activities at home. Modeling of risk analysis systems. Mathematical tools for the analysis of the interactions of risk factors. Communication and data/information transfer in hierarchical decision making systems.
3. Passive and active signal processing, measurement, and filtering models and algorithms suitable for the correction of color perception properties of color deficient persons. Models and methods for improving the quality of color perception.
4. Command detection, command processing, command interpretation, and command execution models/algorithms in ISpace. Adaptation, learning processes of ISpace.

Achieved results

1. ROBOTICS, ISPACE

Today, intelligent robots accompany humans in nearly every spheres of life. These machines make life easier and more comfortable, increase the independence of the persons, extend their possibilities, and improve the safety and quality of living. To be successful in developing intelligent robots and systems many problems have to be overcome in the fields of system models of robot, safe (collision free) robot path planning, robot navigation, human-robot, robot-robot interaction, teleoperation, eto-robotics, etc.

During the project period, we achieved the following results:

Mobile robots, control of robots:

We dealt with the problems of (single and multi-agent) path planning, robot control, controlling a number of robots accomplishing a task as a group, such as localization and map building, sensing and data processing, robot-robot and human-robot cooperation, and tele manipulation.

- We have introduced a new GA based algorithm for the robot exploration and mapping strategy. We have shown by simulations, that our result can successfully be used to solve cooperative control problems, which is also feasible from computational point of view [9].
- Several theorems of optimal path planning (smooth, fast, safe) have been introduced in single agent's domain [29].
- We have introduced a new method for potential field (PF) based map building on partly centralized multi-agent's domain. The 'partly centralized' expression indicates that the PF is built-up on a host computer; however the agents share their actual positions with each other [29].
- Based on our results achieved in single agent environment, we have presented a complex path planning model in multi-agent environment. The model building starts of a totally unknown environment, then the geometrical map of the "work space" is built-up. From this, the model determines the possible paths from which the time-optimal, dynamically optimal, and collision-free path is selected considering the movements of the other agents and the error of the navigation as well.
- We have presented a new Simulink model for robot navigation in unknown environment. The robot navigation is handled by two controllers. The pure pursuit controller computes a direct path from start to goal position without considering the obstacles in the path. For obstacle avoidance in robot navigation, the fuzzy logic controller is taken [111].
- We have also started developing a new robot navigation application. The main goal is having a Robai Pioneer 3DX robot to map the iSpace on the ground level using its sonar sensors and additional information derived from the images of 2 web cameras placed on the robot, in order to provide the iSpace with the detailed map of the area so it can control other robots (without such sensors) more efficiently. The robot mapping application uses a unique occupancy grid as the representation of the map: it consists of small map segments that can be added into the map on demand, thus it can be dynamically extended while only storing relevant information. The web cameras on the robot provide a depth map, which is used to counter the refraction errors of the sonar sensors: if the system finds an anomaly on the map (a single occupied cell), then the robot approaches it, and from the depth information it can either confirm it being

an obstacle or a mistake. We will publish our results in the near future.

- We have introduced a new technique based on reactive search optimization (RSO) integrating machine learning techniques into local and heuristics optimization for robot learning [113].
- We have introduced a new hybrid load balancing algorithm bonding the teaching-learning-based optimization algorithm (TLBO) and the grey wolves' optimization algorithm (GW) for an effective distribution of loads among agents [114].
- In order to minimize the effects of uncertainties on system performance of the control systems a wavelet based controller has been investigated. The control strategy is based on the multiresolution decomposition of the error signal [6].
- In designing control systems an important aim is minimizing the effects of uncertainties on system performance. The time-frequency characteristics of wavelets are useful for applications that require online response, such as controlling a process. We have investigated the multiscale representation of the error signal. It has been shown via simulations that the technique is very efficient in disturbance rejection. The results also show that the performance of the control scheme is very sensitive to the applied wavelets and the number of resolution levels [7].
- We have introduced a new supervisory fuzzy expert system for automatic wavelet shrinkage method selection for noise suppression of unknown signals. Simulation results show efficient performance of the system [24].
- We have presented that by combining anytime and soft computing techniques, the performance of the fuzzy supervisory expert system for online signal processing can be improved. We have introduced also an intelligent auto-healing module which guarantees precise reconstruction of slowly varying signals in case of data loss [25].
- We have designed and implemented a new tele manipulation system, using an Owi 535 manipulator with 5 DoF. The system realizes a classical master-slave configuration, where the master device is the operator's hand, while the slave device is the Owi manipulator. Our results have been published in [58].
- We have developed an autonomous robot agent (on a Robotino® robot platform), which is able to find objects with a specific color (given during the communication e.g. in machine or verbal instruction) and mark them as target positions of the robot's autonomous navigation system [48].
- We have proposed a new Radio Frequency Identification System (RFID) network which allows the tracking of objects and by this makes possible a higher level of cooperation among the agents and more efficient automation of logistics [81].
- A novel family of robust fixed point transformations (RFPT) generated from sigmoid functions has been suggested. It has been shown that the new construction is efficient and robust in the adaptive control of SISO systems [50]. We have generalized this approach for the adaptive control of MIMO systems [51]. It has been found that only one parameter of the controller, set according to the dynamic properties of the system under control, can provide acceptable solution within a wide range. However, the increase of this parameter may result in oscillations in the controlled system [52]. This has indicated us to reconsider the tuning algorithm. Instead of the parameter tuning, a simpler calculation has been developed which can serve as a reliable and far simpler alternative of Lyapunov's direct method [56].
- We have considered also the design of intelligent neural network (NN) controllers for nonlinear systems. According to our approach, the NN is combined with RFPT [42], [75].
- In the other direction, the NN is trained with the simultaneous perturbation stochastic approximation (SPSA) algorithm. The SPSA method requires only two objective

function measurements per iteration regardless of the dimension of the optimization problem [57].

- We have presented a new method for thresholding the coefficients in the wavelet transform domain based on the robust local polynomial regression technique using iterative reweighting. The proposed method combines the main advantages of multiresolution analysis and robust fitting [52]. The technique ensures efficient denoising at low resolution levels. Besides, it provides simultaneously high density impulse noise removal in contrast to other adaptive shrinkage procedures [54].
- We have developed an adaptive wavelet-based noise-removal method for our previously presented mobile robot remote sensing data processing system by which the built experimental robot is able to move accurately in its in-door laboratory environment [84].
- Starting of the results of our previous investigations related to the family of "Fixed Point Transformations", we have proposed a new control strategy based on the combination of the "adaptive" and "optimal" control by proposing time-sharing in the SGFPT method. Further, new improvements have been introduced on SGFPT technique by introducing "Stretched Sigmoid Functions". The efficiency of the presented control solution has been applied in the adaptive control of an under actuated mechanical system [86]. Also, a new type of function has been proposed that enables more precise positioning in the vicinity of the solution of the control task [88]. Applicability of this method has been confirmed by the adaptive control of the Kapitza's pendulum system. Additionally, the possible ways of the combination of the wavelet theory and the SGFPT-type control design have been discussed in paper [88]. It has been shown that the SGFPT method applied for regulating propofol administration through wavelet-based anesthetic value is far promising [87].
- We have investigated the applicability of fuzzy logic in the SGFPT control method [89] [82]. We have found, that the applicability of fuzzy approximation in this new method is highly efficient and allows performance enhancement [82], [110].
- We have proposed to combine Robust Fixed Point Transformation (RFPT) with some modification of the classical methods, such as the Modified Adaptive Inverse Dynamic Controller. The technique proved to be simple and requires low computational need. The results of numerical simulations have shown, that the new tuning rule of the method outperforms the previous ones and ensures high performance of the controller [108].
- Additionally a possible combination of the improved fixed point transformation – based method and soft-computing techniques has been presented in [110]. It has been shown that the proposed method results in improved performance of the controller in the case of nonlinear dynamic systems also in the presence of external disturbances.
- We have introduced new improvements on wavelet-based noise reduction [55] and a new approach regarding intelligent point cloud processing by the combination of fuzzy information measure and wavelets [83]. This latter paper was awarded by "Best student paper" award.
- Our results about NNs trained with the simultaneous perturbation stochastic approximation (SPSA) algorithm have been published in [85].
- We have analyzed the effect of the novel application of the reactive search optimization (RSO) methodology (including the integration of machine learning techniques and optimization methods) in robot learning processes, automation of algorithm selection and parameter tuning [90], [112].
- One of the young researchers of the group prepared and successfully (100%) presented her PhD Thesis in the field of non-conventional control and data representation [109].

Robot-room:

- We have turned the ISpace room into a new intelligent robot space (Integrated Intelligent Laboratory Assistant) actively supporting human activities [16].
- We have proposed a visual command-recognition system for the ISpace. To improve its performance, the fuzzy-RBF colors introduced for skin extraction has been proposed to build in [44], [41].
- We have shown that the generalized filter of multi-class clustering can advantageously be used also in hand posture and gesture identification [41].
- We have introduced a fully automated decision-making system with potential of combination of learning from big data and optimization which can be applied to complex and dynamic systems. The approach is at the boundary between machine learning and optimization [60].
- We have published a paper with a survey about the ways intelligent robots can offer to improve the comfort and quality of life and to ensure safe and independent living for humans. We have also presented and analyzed two of our smart home applications [79].
- We have proposed an anytime voice controlled Ambient Assisted Living (AAL) system [28]. We have also implemented the application and tuned it for a severely disabled woman living with multiple sclerosis [63].
- We have presented in [53] an anytime fuzzy supervisory expert system for online anytime signal processing and applied it in an intelligent auto-healing module. As result, precise reconstruction of slowly varying signals can be guaranteed even in case of data loss.
- We have developed a robot tracker application for vision-based control in iSpace. The idea is to find a Nexus robot on camera images and to construct estimated 3D models (the pose and position of the robot) based on them [120].

Eto-robotics:

In this field, we planned to deal with new mood models based on the ‘styles’ of movements and gestures of the persons. To be able to extract the movements and gestures, we proposed to follow the face and hand movements. For this, first of all, we focused on the background independent determination of the human skin areas. We also concentrated on the improvement of the sensory capabilities of the Intelligent Space system.

- We have introduced a hybrid color filter that is based on clustering and fuzzy-RBF (Radial Base Function) network architecture for the recognition and localization of human skin regions. The color filter is able to perform nearly real-time when processing the pictures of a camera (of the Intelligent Laboratory) with 640x480 resolutions. For the image processing application, the distinction of only two classes is sufficient (the examined pixel is either a part of a human skin region or not). For that case, two clustering methods have been designed and implemented for the training of the filter network [44].
- We have developed classifiers for fast and robust human skin area detection. We have proposed a hybrid fuzzy-RBF network architecture based color filter [76].
- In order to enhance the performance and speed of the detector, the participants have developed a new fuzzy decision tree (FDT) architecture optimized for fast evaluation [74].

- A new multi-dimensional fuzzy hypermatrix-based filter has been proposed in [73] which proved to be very efficient in color filtering [78].
- We have developed a shape extraction and identification method in order to detect human hand postures. The system is using a Fuzzy Hyper Matrix-based classifier (which has also been developed in the frame of this project) to find human skin regions in the pictures of cameras. Our results have been published in a journal paper [98] and two conference papers [101], [97].
- We have introduced a new shape extraction system [100].
- We have also developed a Sequential Fuzzy Indexing Table classifier [99], [119]. The SFIT is implemented through the sequential combination of 2D matrices.

2. MULTI-FUNCTION SUPERVISION AND RISK ANALYSIS SYSTEMS

Today it is becoming increasingly important to establish a fitting quality of life including adequate living condition of ill/disabled persons and safe sport activity. Smart home applications and Ambient Assisted Living Systems are typical examples that offer a safe and reliable environment for independent and active life. Soft computing techniques are very useful tools in the treatment of the problems arising in such applications, because they can handle the uncertainty, imprecision, and subjectivity of both the data and in the evaluation processes.

During the project period, we achieved the following results:

Risk analysis systems:

In this field, we concentrated on the improvement and extension of our previously developed fuzzy logic-based sport activity risk calculation model and extended it to patient monitoring systems. We also addressed patient-specificity requirements.

- A neuro-fuzzy risk calculation model based on the researchers' former validated hierarchical multilevel risk calculation model has been developed and validated [1].
- To increase the reliability of the risk calculation, we have proposed a user-specific membership function tuning method for the input parameters [15].
- To reduce the evaluation time several new techniques (rule interconnection using disjunction with fuzzy operators) have been incorporated into the system [3], [2].
- A novel anytime model based on the HOSVD method has been proposed and analyzed. With this, the execution time can be decreased by approximately 40 percent [12], [36].
- A new offline pre-processing procedure has been developed to calculate the new membership function values belonging to the crisp inputs in the HOSVD method [11].
- We have proposed a possible theoretical method for the risk evaluation of the physiological processes where there are a lot of input factors with many interactions among them [13].
- For simplifying the sport activity risk calculation model [10], the conventional Mamdani-type inference has been modified and converted into a Mamdani-like structure with discretized output [39]. Due to the reduction of the operational needs, this novel inference procedure can be used in systems that require optimization [14], adaptive techniques, or to be used in real-time, while the advantages of the original Mamdani model are retained. The operator-dependency of the derivative model and its applicability is proven mathematically furthermore through simulation by the authors [39]. It has been also demonstrated which operators can be used to obtain an equivalent simplified evaluation structure and which cannot [32].

- The other proposed direction of simplification applies reduction. We have proposed HOSVD-based fuzzy rule base reduction [10] and the application of an anytime model [36] to optimize the operation of the system [13].
- To make the evaluation more patient-specific, a database schema has been designed, which can be used to create a flexible risk assessment framework [33]. The input parameters of the system can vary depending on the chosen sport type, personal characteristics and medical recommendations and the membership functions can also be tuned, taking into account the same parameters [70]. The changes in the patient's health state can be traced long term by storing the measured values during the monitoring and based on it personal statistics can be used as a pre-processing method, which is used to decide whether the situation is normal or not [37] or to tune the original membership functions by aggregating it with the membership function obtained from the statistics [40], [38], [68].
- A flexible risk assessment framework has been built with a high degree of adaptive capacity. A generalized, modular system structure has been implemented, which is joined with a database to specify the parameters of the configurable subsystems [70].
- In case when also previous measurements are available then the changes in the patient's health state can be traced long term and the evaluation can be improved. From the measurements under the same condition (e.g. resting HR, sampling rate, etc.) a histogram can be created representing the usual values of the patient during the monitoring and fitted to it a fuzzy membership function can be created [69]. This can be used to decide whether the situation is dangerous or not, and depending on this judgement the full or the reduced evaluation is performed [35], [67]. It can also be used to modify the input membership function itself by shifting it toward the appropriate direction [68].
- We have developed a fuzzy logic-based risk assessment framework, which can be adapted to various requirements, depending on circumstances. In the system, the number and type of risk factors can be varied and their membership functions can be tuned according to the individual factors' characteristics [95].
- We have calculated the HOSVD reduction error in hierarchical fuzzy systems using Mamdani-type inference and defined a general formula including the propagated error from the previous levels of the hierarchy. Furthermore, a greedy algorithm has been prepared for reduction optimization [96].
- One of the young researchers of the group prepared and successfully (100%) presented her PhD Thesis in this topic [34].

3. PASSIVE AND ACTIVE SIGNAL AND IMAGE PROCESSING MODELS AND ALGORITHMS OF COLOR PERCEPTION

Measurement and signal processing systems are involved in almost all kinds of activities, where control problems, system identification problems, classification, information enhancement, industrial technologies, etc., are to be solved. With the continued growth of multimedia and communication systems, the instrumentation and measurement fields have seen a steady increase in the focus on image data. In these fields, developing tools and techniques plays a very relevant role however it is not a trivial task.

We planned to focus on passive and active signal and image processing, measurement, and filtering models and algorithms suitable for the correction/improvement of color perception properties. Our main focus is on the improvement of color perception of color deficient persons, and on models and methods for improving the quality of color representation.

The achieved results are as follows:

Color perception:

In this field, we have been basically concentrated on the mathematical model of color vision, the automatic measuring and transformation (maximization) of information in different color spaces, and on the improvement of visualization and color sensing.

- A new, sensitive color vision measuring instrument has been developed and implemented partially under the support of this project [8].
- In [80], the authors presented a fuzzy based low complexity, simple information measure by which the information amount of the different intensity ranges can automatically be determined. This measure can be used to tune the transformation between the HDR and visualized intensity domains. By this, the near points in the color space can be abducted improving the color sensing and making easier the color differentiation.
- We have summarized and improved our previous results in automatic measuring and transformation of non-visible color and intensity ranges to a visible domain in the fields of HDR imaging [103] and image quality improvement and visual sensing [104].
- We have proposed an artificial lighting based spectral power distribution (SPD) filtering technique which may ensure the optimal or quasi optimal assignment of the spectral distribution helping to enhance the colors and details in scenes [105].
- We have further developed the Intelligent Space (iSpace) application in the Intelligent Laboratory of the Institute of Mechatronics and Vehicle Engineering Institute of Óbuda University. The ISpace application is now able to control the LED lighting system according to the command of the human user.
- The stabilization of the luminosity of the Lab. can be supported through controlling the shading curtain state and the brilliancy of the artificial lighting (by which we can help to improve the color sensing abilities). Our results are published in [94]. In this paper, authors have presented the complex control principle and circuits' designs of the curtain moving and artificial light regulation.

Classification:

- We introduced a new, reduced complexity training method for different neural network models used in classification. Our results related to circular fuzzy NNs and RBF NNs are published in [5], [20], and [77], respectively.
- The hybrid color filter reported in [44] has been generalized for multi-class problems. We designed and implemented two additional clustering methods [41].
- We have generalized the hybrid, fuzzy-RBF network architecture based color filter [76] for multi-class cases [72], [71].
- We have developed a fuzzy hypermatrix-based architecture (FHM), built on the principle of pre-calculating and storing fuzzy values, but reducing the necessary evaluation steps by storing the values in multi-dimensional hypermatrices [73].
- We have shown that the layered structure SFIT classifier [119]. can drastically decrease the memory need for large but sparse problem spaces [102].
- We have introduced new classification methods for variable length data classification. The techniques are an extension of the the previously developed Sequential Fuzzy Indexing Tables [119]. They use new types of matrices in order to mark the ending of each value combination, thus allowing the system to process data where the length of the data points is not constant [106], [122]. The structure of the classifier can also be used for quick data retrieval and data mining problems [117].

- One of the young researchers will submit his PhD Thesis in this topic in 2018 [123].

4. COMMAND DETECTION, COMMAND PROCESSING, COMMAND INTERPRETATION, AND COMMAND EXECUTION

With the spreading of intelligent machines, man-machine communication has become an important research area. Today, intelligent robots co-operating with humans usually have to be able to store, retrieve, and update information about their environment, interpret and execute commands, offer existing and gain/learn new services. In these processes, the efficient knowledge representation and storage are also of key importance. The size of the databases, the accessibility to the stored knowledge, the possibilities of building in new or refining the possessed information together with the flexibility of the information update have a direct effect on the speed and effectiveness of the cooperation asking for efficient data and knowledge structures.

Our achieved main results are the followings:

- The collaborators introduced a new, graph based, effective knowledge representation form for ISpace based man-machine communication [21].
- We summarized our results related to the graph based knowledge representation form for ISpace based man-machine communication in a book chapter [46].
- We developed a reliable and quick speech recognition method for our anytime voice controlled Ambient Assisted Living (AAL) system [28] using a new iterative anytime speech recognition algorithm [61].
- We have improved the speech recognition system to be able to adapt to the slow but continuous deterioration of the speech quality of the user [62].
- We have introduced a new anytime binding technique, the so called late binding. Here, the binding decision is delayed and is done parallel with the processing. The technique has been applied for speech recognition in the AAL systems [45].
- To improve the anytime voice controlled Ambient Assisted Living (AAL) system, we have developed an improved adaptive speech recognition framework for dysarthric patients [91] and extended it with a new distance metric for speech commands identification [92], [115].
- One of the young researchers will submit her PhD Thesis in this topic in 2018 [121].

5. FURTHER RELATED RESULTS

During our research we had to deal with different modeling, diagnostics, signal and image processing, classification, control, etc. tasks, which in many of the cases pointed out of the concrete field. In the following, some of our related results are enumerated:

- Diagnostics: We have investigated the advantages and new possibilities of applying soft computing based methods in diagnostics [23].
- Cognitive maps: Starting of the research work done in risk calculation, we have introduced a new model and applied it in another field. We have developed a new Fuzzy Cognitive Map based algorithm for the calculation of the values of the interrelation levels between the factors in a system for student grade evaluation. Furthermore, using the calculated edge weights between the factors and differences of the stored and filtered dates for students from the Neptun education IT system, a learning algorithm has been presented, with the learning cycles and states related for

successive known semesters. By this, continuing the learning process, we can predict and forecast the factors and states for the forthcoming semesters with unknown factor values [31].

- Cognitive maps: There are numerous trading systems in use today that are focused on profiling the customers, so they can adapt to their expectations. A system has been built up on similar principles. Its primary goal is to examine how the events effect each other, so it can create a list related to the search. Soft computing methods are used to create the profile. The first profile is created from the user's nature and habits which changes (evolves) after further activities. The events' attitude towards each other are examined using the Frank operator. Finally, the connection of the available information is represented, using a cognitive map [66], [93].
- Behavior Modeling: Behavior Modeling is an attentive task in the complex product modeling. It is difficult to monitor different behaviors of a product in the physical environment because of different descriptions. In the RFLP (Requirement Functional Logical Physical) structure, behavior modeling is accomplished in Function and Logical level. There are several ways to monitor the behavior of a product. We have made an effort to monitor the behavior of a product system by proposing the Requirement, Function and Logical Block corresponds to RFLP structure and improves the behavior of a product using soft computing technologies. In this context, Mamdani FIS (Fuzzy Inference System) and Adaptive Neuro FIS are used [107].
- Healthcare ontological models: The research presents an approach towards modeling a classical expert system using an ontology-based solution. The aim has been to have an extensible setup, where multiple reasoning methods can be used to provide the desired outcome. The case study is a hierarchical rule-based system for the evaluation of reference ECG signals called the Minnesota Code. It describes an approach to represent it as an ontology that provides support for various reasoning methods [65].
- Adaptive Fuzzy Control Applications in Healthcare Processes: In hemodialysis machines peristaltic pumps are responsible for the transfer of fluids. These pumps can only deliver the solutions with significant error, due to deviation of the pump head and deviation of the production. Previous works focused on system identification and fluid flow control by a PID controller. In the frame of this project, we have replaced the PID controller with an adaptive fuzzy controller. Furthermore, the use of integral component for error signal rejection has been examined as input to the fuzzy logic system. The proposed system proved to be advantageous compared to the existing other approaches [27].
- Fuzzy Control Applications in Healthcare Processes: Hemodialysis machines have an important role in the support and maintenance of life functions, wherein the strict control of peristaltic pumps is a serious need. The research targets to present soft computing control methods, which can be applied for this control. Furthermore, the performances of these controllers are compared with a classical PID controller. An adaptive fuzzy-logic and adaptive neuro-fuzzy inference systems have been designed to fulfill the control criteria. The sought controller should be fast, has to eliminate the residual error and it is insensitive in speak of disturbance. Finally, experiences on a real system with the designed controller are detailed [59].
- Fuzzy modeling in health care processes: The spreading of machine intelligence and the increased computational facilities have opened new possibilities in orthodontics. By combining the methods of computer vision, 3D imaging, and new modeling techniques, new, increased health prevention, aesthetic, and comfortability expectations can be fulfilled with a decreased burden of harmful radiation load and invasive interventions. In the field, we have presented a fuzzy logic supported 3D

modeling based designing technique by which the 3D movements of the teeth (including the roots) can be designed, followed, and kept under control during the whole rehabilitation process. The presented technique makes possible the continuous monitoring of the root's movements without excessive radiation during the long orthodontic treatment [118].

- Filtering: We have developed a non-iterative robust-Gaussian filter-operator for surface roughness parameters. The filter is based on a modified bilateral filtering method with an initial approximation for the roughness measurement [47].
- Error propagation: In real time systems the result should be available in time and due to the reduction sometimes we have to find the balance between the accuracy and evaluation time. In the case of non-exact reduction, the error calculation is essential. In a hierarchical system structure the error propagation is also an important issue, since in these cases the higher level inputs can contain an error from the previous level(s). The author examined a hierarchical system, where the Higher Order Singular Value Decomposition (HOSVD) is used in the subsystems separately to reduce the computational complexity during the Mamdani-type inference. We have defined a formula to calculate the propagated error. This formula takes into account the shape of the membership functions in the fuzzy evaluation, its error bound can be calculated in different ways and it takes into account the case when not all the inputs contain a propagated error [116].

6. EDUCATIONAL ACTIVITIES

- The principal investigator of the project has been invited to give several IEEE distinguished lecturer and plenary talks, and PhD seminars about anytime techniques [4], [43], soft computing based image processing [17], intelligent robots [18], and human-robot communication [19].
- We have investigated the educational possibilities offered by our new ISpace Laboratory [22]. We have presented an educational frame and showed the possibilities offered by the ISpace Laboratory and its robot park in the Mechatronics BSc and MSc Programs [30].
- We have included several BSc and MSc students into the research especially in the fields of mobile robots and robot manipulation. Some of their results: [26] has been honored by 1st prize at the Scientific Students' Associations Conference (TDK) of Óbuda University;. our students analyzed the Roboguide 3D simulation system, which proved to be a good candidate for testing and optimizing programs before implementation and real applications [64]; in [94], authors have presented the complex control principle and circuits' designs of the moving of the shading curtain of the ISpace Lab. and artificial light regulation (by which we can help to improve the color sensing abilities); the students with our help have designed and implemented a new tele manipulation system using an Owi 535 manipulator with 5 DoF [58]; our students have developed an autonomous robot agent which is able to find objects with a specific color and mark them as target positions of the robot's autonomous navigation system [48]; we have proposed a new Radio Frequency Identification System (RFID) network which allows the tracking of objects [81].

Summary and future work

We have published our results at international forums in 11 book chapter (in English), 23 journal papers (in English, 11 having impact factor, sum of impact factor: 15,805), 68 conference papers (67 in English), 13 talks or seminars (12 in English), 1 Scientific Student's Work, 2 presented PhD Theses. Further, 2 PhD Theses works will be submitted in 2018. Currently, we have 49 citations on our works.
Partly as continuation of our research work, we plan to submit a new research proposal under the leadership of the principal investigator.

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