Innovative Intelligent Interaction Systems of Loader Cranes and Their Human Operators

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Abstract. An overview of the research on the design of interaction systems between lifting devices and their human operators equipped with a speech interface in a natural language, is presented, covering also the integration with augmented reality and interactive manipulators with force feedback. An innovative processing scheme, using several functional modules employing developed hybrid methods, for the interaction has been presented. The proposed design is based on an experimental implementation of the interactive speech-based complex system for controlling loader cranes. It features intelligent methods for meaning analysis of spoken natural languages, analysis and evaluation of command effects, assessment of command safety, and supporting decision-making processes.

Keywords: Interactive system · Intelligent control · Intelligent interface · Speech communication · Natural language processing · Neural networks · Innovative Interfaces · Lifting devices

1 The Design of Intelligent Interaction Systems

Substantial efforts have been put toward the development of intelligent and natural interfaces between humans and machines. Recent research has led to making significant improvements in new developments and new patents in the field of knowledge of spoken natural language processing. Recent advances in development of prototypes of speech-based interactive systems are described in articles in [1–4]. Innovative interaction systems feature speech-based interactive communication [5–7], machine vision - vision systems [8], augmented reality [9] as well as interactive controllers [10] providing force feedback.

The presented research involves the development of a system for controlling a loader crane, equipped with vision and sensorial systems, interactive manipulators with force feedback, as well as a system for bi-directional communication through speech and natural language between the operator and the controlled lifting device. The proposed speech communication system is presented in abbreviated form in Fig. 1. The system is considered intelligent, because it is capable of learning from previous commands to reduce human errors. It is very significant for the development of new effective and flexible methods of precise positioning

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of objects and cargo manipulation. The proposed concept specifies integration of a system for natural-language communication with visual and sensorial systems.

The importance of safety in working with lifting devices is absolutely important. The proposed approach to interaction systems has proven crucial and very useful in safety systems. The safety of the interaction system includes analysis of crane stability for various load conditions and trajectories of load translocation [11]. During the operation cycle, the analysis of mobile crane load handling system stability for selected configurations and operating conditions is performed. It is an important task, because a failure to consider stability conditions in dynamics of the real crane arrangement may lead to loss of stability. As the results of the analysis, variations in stability conditions depending on angular position of the turning column with booms and telescopic booms, positions of telescopic booms, values of boom angle of elevation, load-bearing system components masses as well as on crane loading are processed by the safety system. The safety of the interaction system also includes analysis of the support system reactions for the assessment of mobile crane stability [12]. The developed module is used for computing the ground reaction forces of the crane support system in the entire operating range. The verification of the mathematical model was performed using the finite element method. The results of numerical computations were used to analyze the stability of the mobile crane load handling system for selected configurations and operating conditions. The results of the simulation provide changes of the reaction forces in the support system and the envelope of the load path for given load capacities and reach of the crane.

The proposed interactive system (Fig. 2) contains many specialized modules and it is divided into the following subsystems: a subsystem for voice communication between a human operator and the mobile crane, a subsystem for natural language meaning analysis, a subsystem for operator's command effect analysis and evaluation, a subsystem for command safety assessment, a subsystem for command execution, a subsystem of supervision and diagnostics, a subsystem of decision-making and learning, a subsystem of interactive manipulators with force feedback, and a visual and sensorial subsystem. The novelty of the system also consists of inclusion of several adaptive layers in the spoken natural language command interface for human biometric identification, speech recognition, word recognition, sentence syntax and segment analysis, command analysis and recognition, command effect analysis and safety assessment, process supervision and human reaction assessment.

The subsystem of visually aiding loader crane control with augmented reality generates virtual images of augmented reality (including markers, points), and also projects images from the vision system on a monitor setup or inside of 3D-vision goggles. The operator's extended field of view contains a camera system in configurations: parallactic setup - synchronization with the operator's head, and a system of stationary cameras making a virtual camera.

The subsystem for speech communication is used to perform the following tasks: processing the operator's spoken commands, operator biometric identification, converting voice commands to text and numerical notation, handling

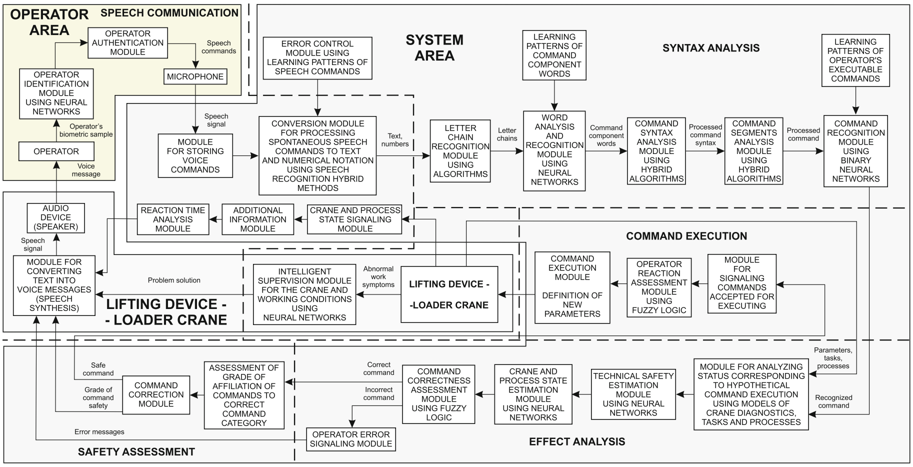

Fig. 1. Intelligent speech communication systems for controlling lifting devices.

errors, analysis of words, recognition of words, analysis of commands' syntax, analysis of commands' segments, recognition of commands, meaning analysis of natural-language messages, as well as converting text into voice messages (speech synthesis [13]). The voice communication subsystem also provides voice feedback to the operator including reporting on the crane's working conditions' safety and expert information for exploitation and controlling. It is also communicated with a subsystem of interactive manipulators with force feedback.

The subsystem of effect analysis and evaluation of the operator's commands is designed for the following tasks: analysis of a state after hypothetical execution of a command, evaluation of technical safety, evaluation of crane systems' and process's states, evaluation of crane working conditions' safety, forecasting of process states' causes, evaluation of commands' correctness, as well as detection of the operator's errors. The commands' safety assessment subsystem is assigned to evaluate the command correctness. The subsystem of the command execution is capable of signaling of process states. The execution of commands involves determination of process's parameters and its manner of execution for the configuration of the crane. The subsystem for supervision and diagnostics implements crane diagnostics, supervision of the controlling process, remote supervision with mobile technologies. It also includes the tasks related to measurements of the crane's working space and collection of geometrical data using photogrammetric techniques. The decision-making and learning subsystem is composed of expert systems, and the intelligent learning kernel integrated with augmented reality. The system is also linked with the interactive manipulators providing force feedback, which include the operator's shoulders' movement interactive scanner for gesture-based manipulation, a shifter with the forces-measuring system, and a multi-axis joystick. It is a connection to a force feedback-based communication channel (crane's working conditions diagnostic information) containing force

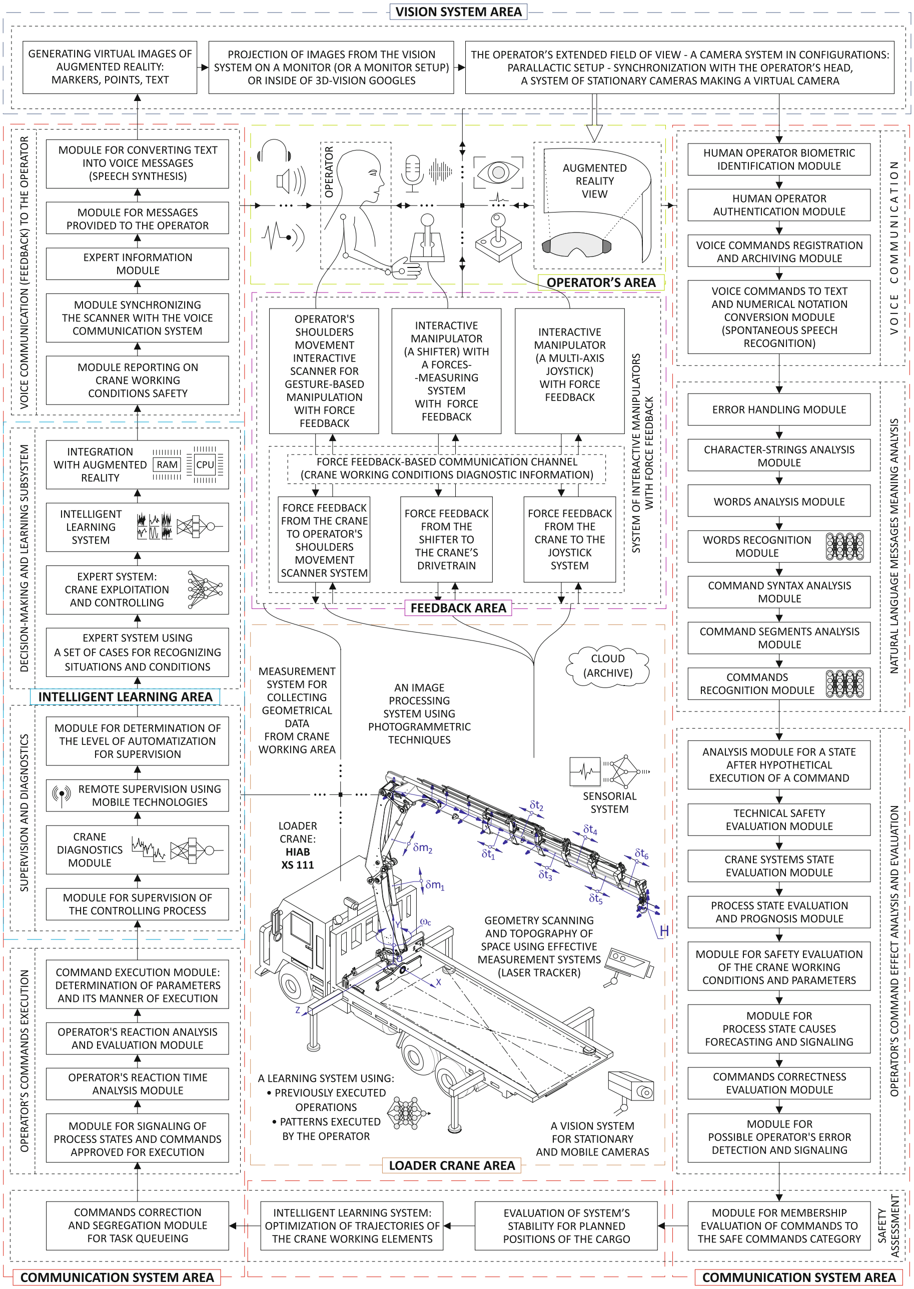

Fig. 2. Designed structure of an innovative system for interaction of the loader crane (Hiab XS 111) with its operator equipped with a speech interface, vision and sensorial systems, and interactive manipulators with force feedback.

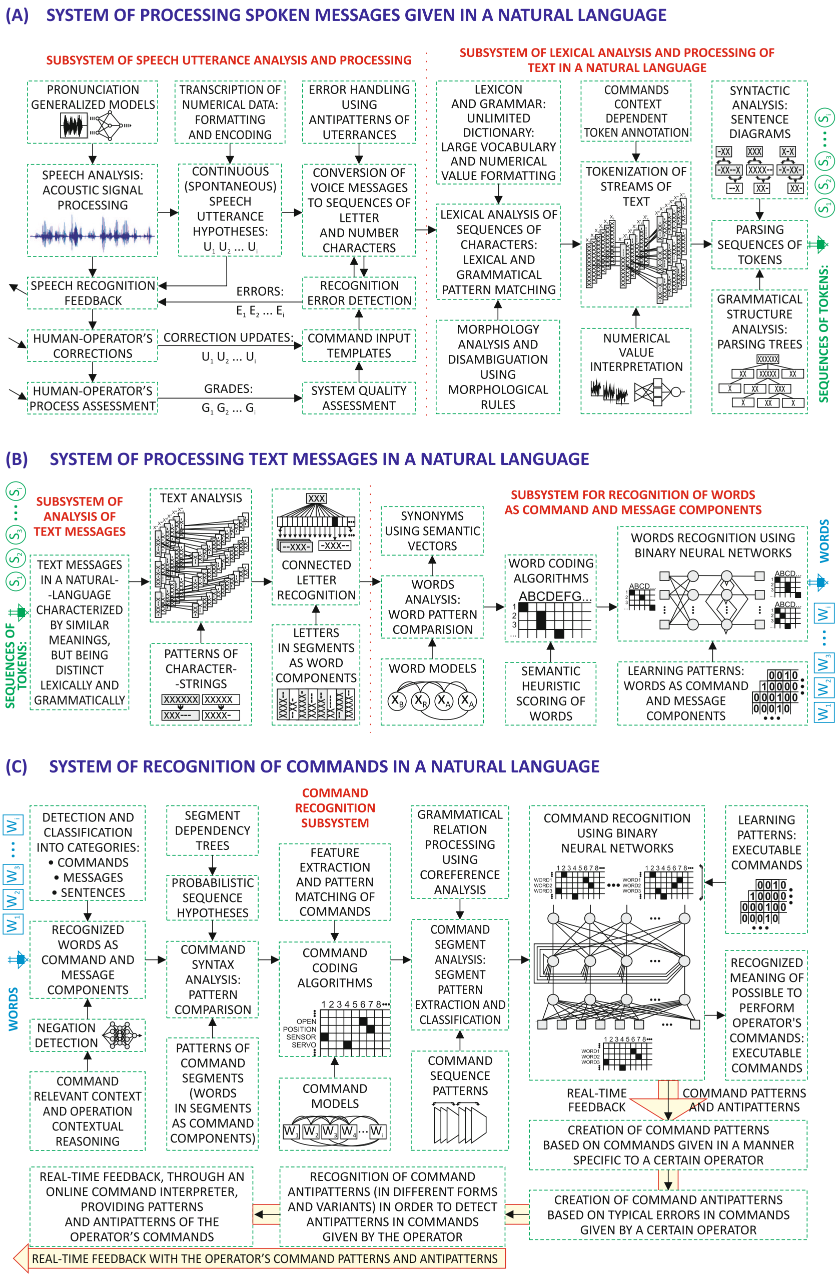

Fig. 3. Recognition of speech commands in a natural language using patterns and antipatterns of commands, consisting of: (A) a system of processing spoken messages given in a natural language, (B) a system of processing text messages in a natural language, (C) a system of recognition of commands in a natural language.

feedback from the crane to the operator's shoulders' movement scanner system, force feedback from the shifter to the crane's drivetrain, as well as force feedback from the crane to the joystick system.

2 Meaning Analysis of Commands and Messages

The concept of the innovative intelligent interaction system includes a subsystem of recognition of speech commands in a natural language using patterns and antipatterns of commands, which is presented in Fig. 3. In the subsystem,

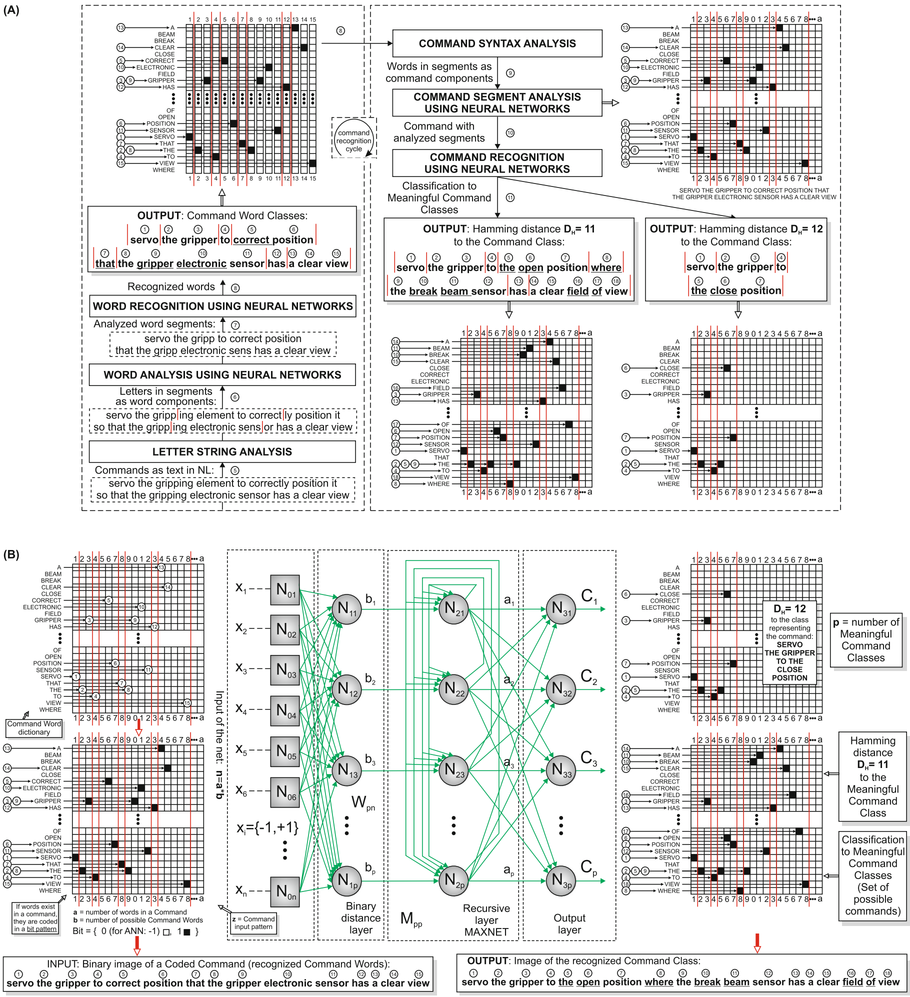

Fig. 4. (A) Block diagram of a meaning analysis cycle of an exemplary command, (B) Illustrative example of recognition of commands using binary neural networks.

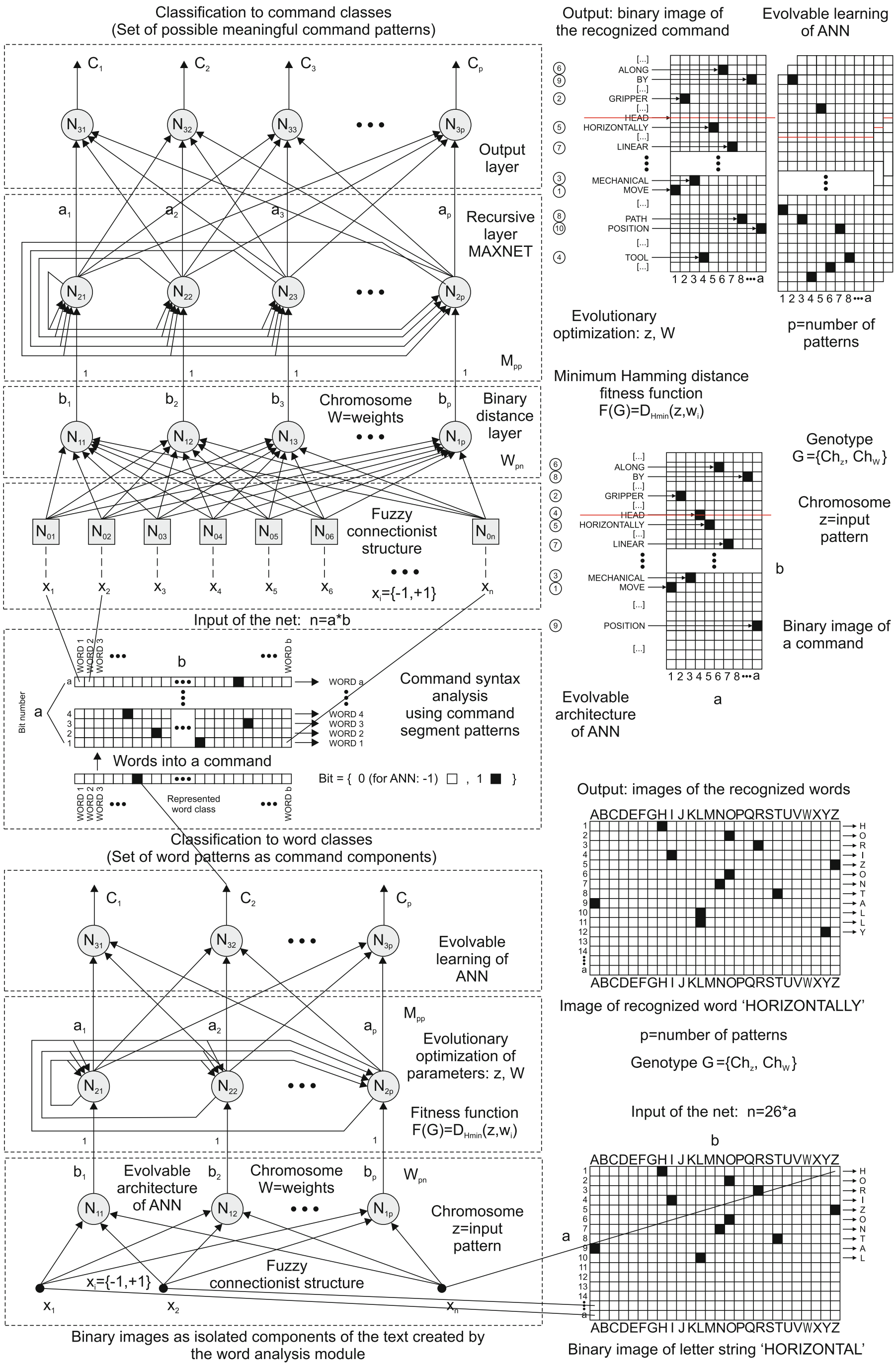

Fig. 5. Evolvable fuzzy neural networks for word and command recognition.

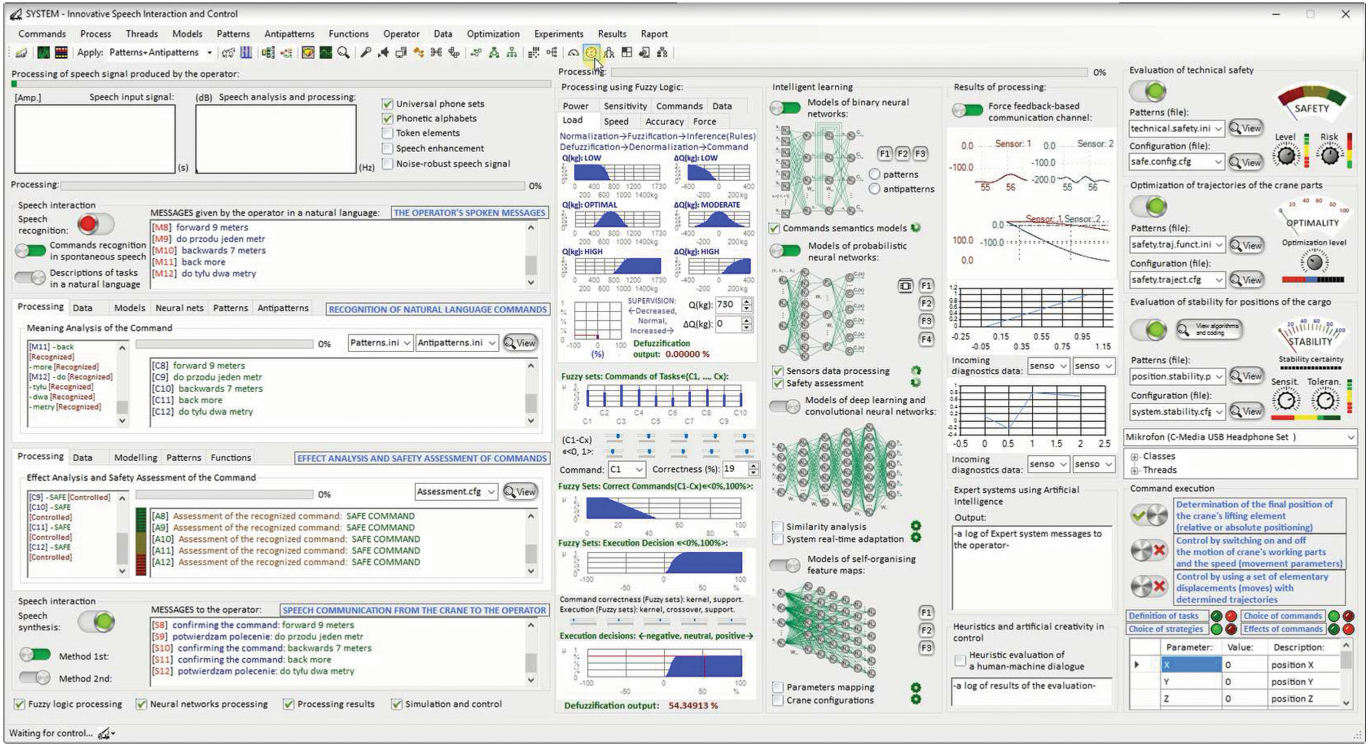

Fig. 6. The implementation of the innovative intelligent interaction system allowing different configurations and settings.

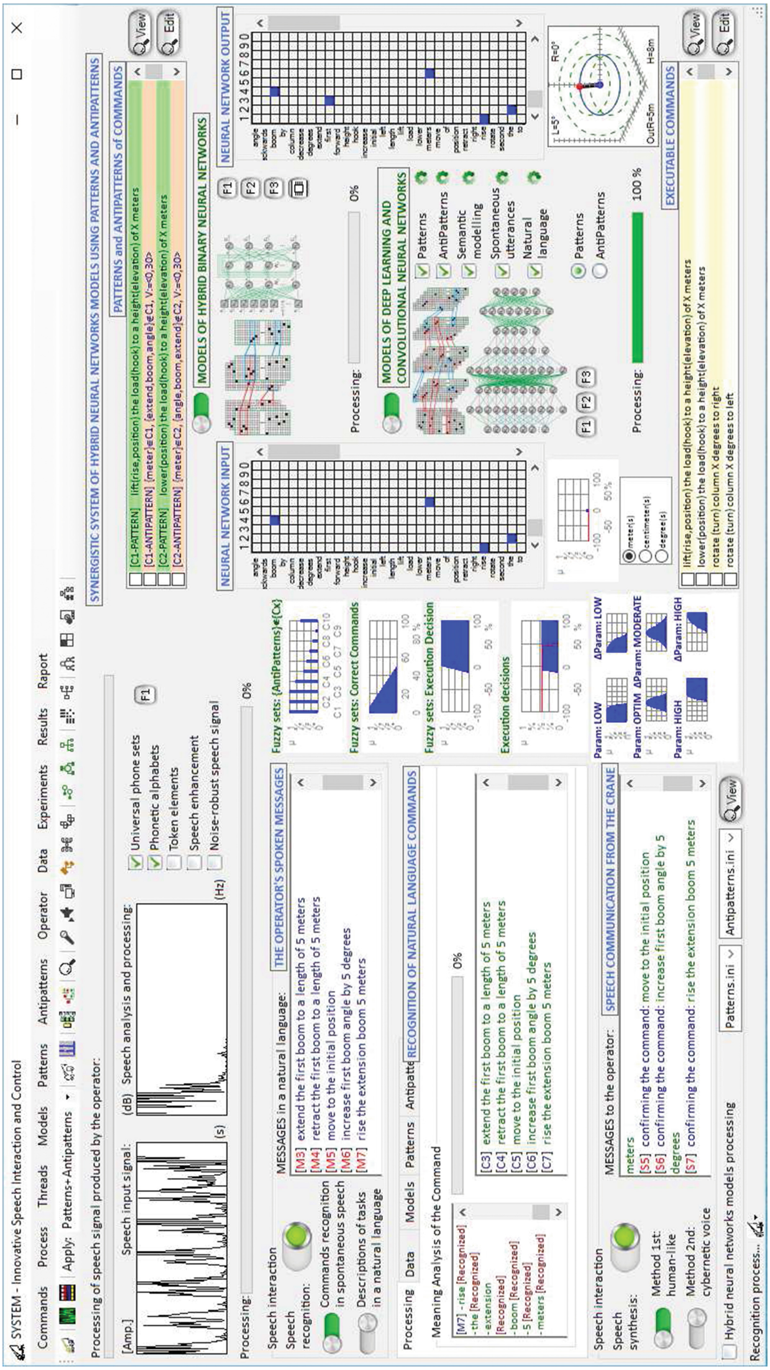

Fig. 7. The implementation of the innovative intelligent interaction system using patterns and antipatterns.

the speech signal is converted to text and numerical values by the continuous speech recognition module [14,15]. After a successful utterance recognition, a text command in a natural language is further processed.

Individual words treated as isolated components of the text are subsequently processed with the modules for lexical analysis, tokenization and parsing [16–18]. After the text analysis, the letters grouped in segments are processed by the word analysis module. In the next stage, the analyzed word segments are inputs of the neural network for recognizing words. The network uses a training file containing also words and is trained to recognize words as command components, with words represented by output neurons.

In the meaning analysis process of text commands (Fig. 4A) in a natural language, the meaning analysis of words as command or message components is performed [19]. The recognized words are transferred to the command syntax analysis module which uses command segment patterns.

It analyses commands and identifies them as segments with regards to meaning, and also codes commands as vectors. They are sent to the command segment analysis module using encoded command segment patterns. The commands become inputs of the command recognition module using neural networks. The module uses a 3-layer Hamming network to classify the command and find its meaning (Fig. 4B). The neural network of this module uses a training file with possible meaningful commands.

The proposed method for meaning analysis of words, commands and messages uses binary neural networks (Fig. 4A, B) for natural language understanding. The motivation behind using this type of neural networks for meaning analysis [19] is that they offer an advantage of simple binarization of words, commands and sentences, as well as very fast training and run-time response. The cycle of exemplary command meaning analysis is presented in Fig. 4A. The proposed concept of processing of words and messages enables a variety of analyses of the spoken commands in a natural language. The developed methods for word and command recognition feature evolvable fuzzy neural networks (Fig. 5).

The experimental implementation of the innovative intelligent interaction system between a loader crane and its human operator using spoken natural languages is presented in Figs. 6 and 7. The complex system also features processing data using patterns and antipatterns of commands.

3 Conclusions and Perspectives

The designed interaction system is equipped with the most modern artificial intelligence-based technologies: voice communication, vision systems, augmented reality and interactive manipulators with force feedback. Modern control and supervision systems allow to efficiently and securely transfer, and precisely place materials, products and fragile cargo. The proposed design of the innovative AR speech interface for controlling lifting devices has been based on hybrid neural network architectures. The design can be considered as an attempt to create a new standard of the intelligent system for execution, control, supervision and optimization of effective and flexible cargo manipulation processes using communication by speech and natural language.

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