# REVIEW

of the dissertation work for the acquisition of an educational and scientific degree "Doctor"

of Eng. Adelina Georgieva Kremenska, MSc

by Prof. Dr. Maya Ivanova Dimitrova – Institute of Robotics, Bulgarian Academy of Sciences, (IR-BAS), Section: Interactive Robotics and Control Systems (IRCS)

Dissertation Topic: **Designing a Brain-Machine Interface to Various Devices and Services in the Internet of Things**

Professional Direction: 5.2 Electrical Engineering, Electronics and Automation; Scientific Specialty: Application of the Principles and Methods of Cybernetics in Different Areas of Science

Eng. Adelina Georgieva Kremenska, MSc, graduated from Technical University – Sofia, majoring in "Telecommunications", EQD "Bachelor" in 2015 and EQD "Master" in the same specialty in 2017. She is enrolled in part-time doctoral studies from 01.01.2020 at IR-BAS. There is an order of the Director of the Institute of Robotics, BAS for closing the doctoral studies with the right of defense No. 46/31.05.2024. Currently, she works as an "Engineer" (half-time) at the "Interactive Robotics and Control Systems - IRCS" section of the Institute of Robotics of the Bulgarian Academy of Sciences –Sofia.

**1. General description of the dissertation work and the materials attached to it**

The dissertation has a volume of 134 pages, contains 34 figures, 5 tables and consists of an introduction, 4 chapters, a conclusion and directions for future research. The literature used includes 102 publications of classic and contemporary research, as well as open source software products. In general, the bibliography is sufficient and adequate to the tasks set in the dissertation work.

**2. Relevance of the problem**

Designing a brain-machine interface to various devices and services in the "Internet of Things" is an extremely important current direction of research in modern electronics and robotics for the purposes of improving the living environment of people with disabilities, as well as for controlling various electronic devices in hostile environments such as space, for example. A prototype of such a brain-machine interface, based on the Open BCI brainwave recording device, connected to, in its role as a "thing", the "internet of things", which would be accessible and implementable by non-programmers, has been created, programmed and tested in this dissertation. The dissertation is both timely and complete to be the basis for development of similar devices in the future, which determines its importance.

**3. Knowledge of the state of the problem**

The doctoral candidate Eng. Adelina Kremenska knows very well the state of the problem under consideration. She has compiled a bibliography of 102 titles in English. The balance of sources is evident, both in the field of application programming with various open source languages, and significant sources in the field of neuroinformatics, which is important in the context of the particular study.

The dissertation consists of an introduction, four chapters, a conclusion and directions for future research. In the first chapter an overview analysis is made of the software technologies for brain-machine interface design, as well as the tools for connecting and communicating with people and objects in the "Internet of Things". From this point of view the aim and tasks of the dissertation are formulated, namely:

The **aim of the dissertation** is to propose a *new principle* of program implementation and a *fuzzy signal processing model* through open source software, by *synthesizing* a device that translates brain signals, registered in a different frequency range and spatial localization in the human cerebral cortex, corresponding to a state of attentional *concentration*, in a device for control of a robotic arm.

To achieve this goal, 4 main tasks are formulated:

1) Critical analysis of a certain range of modern scientific developments dedicated to the topic of the dissertation. Systematization of the existing software products in order to select the most suitable ones for implementation;

2) Design and development of an innovative model for registering, transmitting, analyzing and processing EEG signals in order to convert them into commands for controlling devices and services in the "Internet of Things";

3) Research, design and development of original methods and algorithms for recording, interpreting and classifying EEG signals in order to design and integrate an EEG-based brain-machine interface in the "Internet of Things". Design and development of open source software that can be applied to various EEG devices to transmit electroencephalographic data, characteristics and metrics, over the Internet without programming skills;

4) Experimental studies of the developed software for verification of the designed and developed brain-machine interfaces, based on EEG recording, to connect to various devices and services in the "Internet of Things". Development of a methodology and protocol for experimental studies of mental concentration to correctly interpret people's intention encoded in brain signals. Statistical analysis of the recorded EEG signals.

**4. Approach and solution to the problem**

Doctoral candidate Adelina Kremenska has adopted a realistic methodical approach to achieve the goal. On the basis of the literary sources and on the basis of her own analyses she has adopted a conceptual approach for solving the set of tasks, which is systematic and adaptable to the new challenges, facing the brain-machine interfaces of the future.

In the second chapter, an innovative model for transmission, analysis and processing of EEG signals and their conversion into commands for controlling devices and services in the "Internet of Things" is developed. In the third chapter open source software is designed and developed that can be applied to various EEG devices with the ability to transmit electroencephalographic data, characteristics and metrics over the Internet. In the fourth chapter the developed software is tested through an experimental study with volunteers after the approval of the proposed methodology by an ethics committee.

Postulating an activation threshold by fuzzy logic corrects, to some extent, the possibility of "false alarm" from the recorded data, which is an additional advantage of the proposed approach.

I evaluate the approaches, adopted by the author, and the applied solutions as correct to achieve the goal and the formulated tasks in the dissertation, which is also confirmed by the achieved results.

**5. Credibility of the obtained results**

The dissertation was developed in a volume of 134 pages of main text, incl. illustrations, bibliography and 3 appendices. Modern tools were used to solve the tasks, including software programming, fuzzy logic, mathematical statistics, ANOVA, post hoc Tuckey, etc.

I consider the research presented in the dissertation, namely: methods of engineering analysis and synthesis, developed models, algorithms and obtained data, to be reliable and sufficient for the requested educational and scientific degree "doctor".

**6. Main Contributions**

The contributions in the dissertation have a serious scientific and scientific-applied value.

***Scientific contribution:***

1. A new conceptual model for "brain-to-object communication in the Internet of Things" is proposed, which uses intelligent and user-friendly technologies to record and interpret brain waves. Original methods and algorithms for recording, interpreting and

classifying EEG signals have been investigated, designed and developed in order to *synthesize* an EEG-based brain-machine interface in the "Internet of Things".

***Scientific-applied contributions:***

2. The main functional requirements are formulated for systems for transmission, analysis and processing of EEG signals in the brain-machine interface and their conversion into commands for controlling devices and services in the Internet of Things without the need for programming skills.

3. A system architecture for a brain-machine interface based on electroencephalographic signals for communication with devices and services in the "Internet of Things" was designed and developed in order to verify the proposed model. The system is designed to work in real time by using innovative platforms and libraries, supporting flexibility and adaptability to different devices and services in the "Internet of Things".

4. Open source software was designed and developed to be applicable to various EEG devices with the ability to transmit electroencephalographic data, characteristics and metrics over the Internet. The process of publishing to the "npm" software registry is described of the designed and developed new custom nodes added to the Node-RED development toolkit library (GitHub) - "openBCI-streaming", "openBCI-Data" and "openBCI-EEGmetrics" - allowing users to register, interpret and qualify data from different EEG devices.

5. The proposed software is experimentally verified with an OpenBCI brain-machine interface device for controlling a robotic arm in the "Internet of Things". A procedure and a research protocol for the experimental verification of the method of registration of brain signals correlating with the level of mental concentration during the performance of a mental task have been proposed, which have been approved by an ethics committee. The data, obtained from the experiments, were statistically analyzed and summarized. It was determined which electrodes and with what bandwidth power are essential in states of attention and concentration. An average threshold of the "attention" metric was empirically established and proposed for inclusion as an interval in the BrainFlow library (brainflow.org).

**7. Publications on the topic of the dissertation**

Three out-of-print publications related to the dissertation are presented, two of which are at international conferences, indexed in Scopus, in which the doctoral candidate is the first author, as well as a journal article, indexed in WoS. One has already attracted independent citations. This exceeds the requirements and is more than sufficient to defend the submitted dissertation.

**8. Using the obtained results in practice**

From the acknowledgments expressed in the publications it can be seen that the results of the dissertation have been included in a number of research projects, among which one funded by the Scientific Research Fund, one Competence Center and one project under the Erasmus + program, which is an important indicator of the use and dissemination of the obtained results in the dissertation.

**9. Personal impressions**

I know Eng. Adelina Kremenska as a colleague in the IRCS section of the Institute of Robotics, BAS. We have no common research or publications. I definitely believe that Eng. A. Kremenska, MSc possesses the necessary qualities and has proven her rigour, motivation and creativity in the realization of scientific research both independently and in a team.

**10. Critical notes and recommendations on the dissertation**

My main critical remarks are related to the style of presentation of the conducted scientific research in Bulgarian. It is innovative for the country and would promote the topic better if many of the abbreviations used were replaced by equivalent expressions in Bulgarian. This does not affect the completion and quality of the dissertation, which is structured and presented in full compliance with the requirements.

**11. Conclusion**

My overall assessment of the presented dissertation is positive. It is complete in volume and content. The doctoral candidate, Eng. Adelina Kremenska, has collected the necessary credits in fulfilling the minimum national requirements, as indicated in the Law on the Development of the Academic Staff in the Republic of Bulgaria (DASRB), the Rules of BAS and the Internal Rules of the Institute of Robotics, BAS.

Based on my familiarization with the presented dissertation and the contributions contained in it, I believe that the presented material of the dissertation fully meets the requirements of the Law on the DASRB and the Regulations on the Terms and Conditions for the Acquisition of Scientific Degrees of the Bulgarian Academy of Sciences. All requirements for obtaining the educational and scientific degree "Doctor" have been met.

Sofia, 02.10.2024 Signature: