TO THE TEACHING AND SCIENTIFIC COUNCIL OF THE FACULTY OF ENGINEERING

TO THE COUNCIL FOR TECHNICAL AND TECHNOLOGICAL SCIENCES OF THE UNIVERSITY OF KRAGUJEVAC

At the session of the Teaching and Scientific Council of the Faculty of Engineering, University of Kragujevac held on 19.10.2023. (decision number: 01-1/3870-8) and at the session of the Council for Technical and Technological Sciences of the University of Kragujevac held on 22.11.2023. (decision number: IV-04-874/12) we were appointed as members of the Commission for writing the report on the evaluation of scientific basis of the doctoral dissertation proposal entitled:

"NEUROERGONOMIC ASSESSMENT OF MENTAL WORKLOAD IN ADAPTIVE INDUSTRIAL HUMAN-ROBOT COLLABORATION"

and fulfillment of the requirements of the candidate Carlo Caiazzo, Master of Mechanical Engineering for the Design and Production, and the proposed mentor for the preparation of the doctoral dissertation. The doctoral dissertation belongs to the specific scientific field of Industrial engineering. Based on the information at our disposal, we submit the following

REPORT

1. The scientific approach to the problem of the doctoral dissertation proposal and evaluation of the scientific contribution of the outcome of the dissertation

The fifth industrial revolution, or Industry 5.0 (IR5.0), is on the verge of setting humans at the center of the production systems, designing innovative industrial collaborative workplaces. Contrary to the previous four industrial revolutions, in which the aim was to dehumanize the human role in manufacturing activities, this fifth industrial revolution emphasizes how technology should be used for the benefit of individuals, by focusing on the personalized demands and requirements of customers.

Collaborative robots, or cobots, allow to enhance the social sustainability in industries without decreasing the level of productivity. The deployment of these machines opens the door to human-robot collaboration, or HRC, combining the advantages of automation, such as accuracy and repeatability, with the flexibility and cognitive soft-skills of humans.

With the disruption of sensors applied in HRC environments, psychophysiological measures can be used to identify and evaluate the human partner's responses to the interaction with the robot. Research studies suggested different physiological measurements in HRC applications to have indicators of anxiety, stress, and engagement of the operator. In this regard, Neuroergonomics, as the discipline of Neuroscience applied in Ergonomics, allows a better analysis of the workload of the operator performing a task. Cognitive workload represents the volume of mental work required of an employee to accomplish a task.

This dissertation aims to propose a comparative analysis of three laboratory experimental scenarios: standard scenario in which the participant performed the task without any intervention and support; collaborative scenario in which the participant performed the task interacting with the robot (supporting activity) in the workplace; collaborative guided scenario – the participants performed the task in collaboration with the robot and guided by Poka-Yoke aspects taken into account in order to accomplish the activity. The goal of this analysis is to show the different responses of participants while working or not alongside the robot in terms of cognitive ergonomics.

This scientific contribution may be presented as follows.

The conceptualization of the new model for the neuroergonomic Assessment. The evaluation of mental workload is achieved through the combination of subjective (NASA TLX) and re-al-time objective measurements. This last measurement is achieved through the innovative electroencephalogram (EEG) device and the characterization of the cognitive workload through the brainwave power ratio β / α, defined after the pre-processing phase of EEG data. Finally, observational analyses are considered regarding the task performance of the three scenarios. The statistical analyses show how significantly the mental workload variation and a performance, as the number of components assembled correctly by the participants, are achieved in the three scenarios.

The methodology for the neuroergonomic assessment defined by the proposed model. The assessment is performed through the EEG cap, mounted on the participant, collecting the neuronal activity from the scalp. The measurement allowed a real-time, direct, safe, and non-obtrusive acquisition of data while the participant accomplished the task in both scenarios. Regarding the subjective analysis, at the end of the test, for each scenario, the participant answered questions through the NASA TLX to have a subjective response of the state of the participant while performing the task. Further-more, observational measurement was performed to analyze the productivity index in terms of components assembled correctly in the different scenarios. The paper aims to cover the research gap through a combination of metrics (EEG – β / α, NASA TLX, and performance) to evaluate the mental workload and performance of the operator while working with the robot in HRI (human-robot interaction) tasks.

The analysis of the relationship between EEG Mental Workload, Nasa TLX and Performance. The performance in terms of mental workload and productivity, as the number of components assembled correctly, is shown through the EEG – Mental Workload plot, NASA TLX questionnaire, and observational measurements (checklist).

Connection with previous research

Industrial collaborative robots, or cobots, allow to enhance the social sustainability and well-being of operators in industries, performing industrial tasks alongside operators in a fenceless shared environment [1]. The deployment of these machines opens the door to innovative interactive applications between the human and the operator, named human-robot interaction (HRI), combining the advantages of automation, such as accuracy and repeatability, with the flexibility and cognitive soft skills of humans [2,3]. In this regard, to combine the different perks of humans and robot, research studies have shown different degrees of HRI [4]. On the base of these, safety principles are crucial in HRI applications [5-9].

Different authors set up HRI scenarios of assembly tasks to deal with ergonomic aspects [10]. Some research studies applied individual surveys and questionnaires to evaluate the improvement of the well-being of the operator in HRI [11,12]. Regarding the performance of the operator in HRI tasks, some authors pointed out that hu-man-robot interactive tasks did not improve the level of performance, in terms of productivity, of the task [13]. In other research studies, authors suggested different physiological measurements in HRI applications as indicators of the well-being state of the operator using the deployment of physiological sensors [14-17]. Yet, these indicators did not concern the neuronal aspects of the operator's mental workload in HRI.

Different methodologies are adopted to analyze the mental workload [18]. In HRI activities, questionnaires are of pivotal importance to analyze the mental state of the operator [74]. NASA TLX questionnaires are still the most deployed in the research field to assess the cognitive workload of the operator after having performed a task [19]. Other studies analyzed empirical methodologies to analyze the operator's performance through surveys and error analysis of participants to evaluate the impact of the cognitive state of the operator while working with the robot in HRI activities [20]. However, subjective interpretations are affected by bias in the analysis of mental workload.

Thus, in combination with these interpretations, physiological measurements are deployed to analyze the mental workload in HRI [21]. Different frameworks have been developed to evaluate the mental state of the operator. Authors [22] defined the amount of cognitive workload through the heart-rate variability in physical activity, using a stopwatch. However, the analysis did not show significant results in terms of mental fatigue. Other authors defined the level of mental fatigue using eye-tracking [23]. The results showed an acceptable sensibility of the measurements in terms of task load, though the mental workload through the gaze behavior was not significantly different. In these studies, the presence of artifacts is crucial to discriminating the level of mental workload. However, the cognitive analysis lacks direct measurements regarding the neuronal activity of the brain.

In this regard, the electroencephalogram (EEG) provides an online, objective, re-al-time, and quantitative direct measure of neuronal activity. Through EEG pre-processing phase, it is possible to remove those artifacts that could affect the acquisition of the signals [24]. Furthermore, EEG found a vast application in different fields [25]. Authors highlighted the application of EEG in smart factories to evaluate mental stress [26]. From the analysis and pre-processing of EEG signals, re-search studies analyzed the real-time human brainwaves responses [27]. In the lit-erature review, different power ratios of the brainwaves were considered to assess the mental state of the human in a relaxation (Alpha waves) or stress/engagement (Beta waves) phase. [28]. In this research paper, the ratio β / α is considered for the analysis of the mental workload.

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2. Explanation of the subject, method, and goal that convincingly indicate that the proposed topic is important for the development of science.

<u>The subject, objectives, and hypotheses of this dissertation include</u>

The methodology applied in this research paper shows the feasibility and validation of EEG measurement with subjective measurement (NASA TLX), and observational measures (checklist) in HRI tasks. The application of EEG has been rapidly increased due to its compatibility, efficiency, and practicability in various contexts. Specifically, manual assembly tasks, such as wire harnessing activities, are still the bottle-neck of industrial processes. This has brought to the analysis and study of HRI solutions to let the operators work alongside robots. Thus, the study of the mental workload in HRI is pivotal. However, the method to apply wireless, real-time, objective measurements such as EEG in industrial HRI tasks to define the mental workload in terms of brainwave activity is still at the beginning.

Some authors have presented a strategy to measure mental workload in smart factories. However, the efficacy of these studies did not show an effective difference between a scenario without the robot and with the robot. Other studies presented the analysis of mental workload only through subjective measurements. This study proposes an effective methodology where the results highlight a lower level of mental workload and stress (EEG and NASA TLX) and a higher level of performance in terms of components assembled correctly (checklist), in contrast with other studies. Furthermore, the motivation of our research study is to define an effective evaluation of mental workload through a neuroergonomic assessment through the analysis of mental workload with the application of different measurements. The study was conducted in two different scenarios, with the same number of participants to evaluate the mental workload of participants working with and without the robot. Other studies evaluated the cobot contribution in HRI tasks with different groups of participants or with the same group but with different types of tasks with the cobot [25,67]. In this study, to respect the comparison and maintain the cobot as the only discriminant between the two scenarios, it was reasonable to have the same participants.

The proposed research will test the following hypotheses:

H1 - The implementation of collaborative robot solutions can reduce the level of mental workload (MWL) during work activities.
H2 - Reducing the level of mental workload improves the efficiency, effectiveness and quality of work activities.
H3 - It is possible to define mental workload through objective sensorial devices and measurement.
H4 - The use and implementation of collaborative robots has subjective positive impact on workers during work activities.

Research methods

- In this dissertation, mental workload will be analyzed using the EEG neuroergonomic cap.
- The evaluation of mental workload will be then defined through an analytical equation regarding the brainwaves power ratio between Beta (stress/engagement index) and Alpha (relaxation indicator).
- Further analysis of the mental workload is defined through the subjective measurement such as the NASA TLX questionnaire to determine the performance in terms of Mental, Physical and Temporal Demand, Frustration, Fluency, and Success of the task.
- Further analysis of the performance will be defined through an observational measurement to analyze the task performance in terms of components assembled correctly over time.
- The comparative analysis will focus on three types of experiments: standard scenario in which the participant performed the task without any intervention and support; collaborative scenario in which the participant performed the task interacting with the robot (supporting activity) in the workplace; collaborative guided scenario – the participants performed the task in collaboration with the robot and guided by Poka-Yoke aspects taken into account in order to accomplish the activity.
- The relevance of the results will be analyzed through statistical analyses to evaluate the efficiency, quality, and effectiveness of the performance in terms of mental workload and productivity throughout the three types of experiments.

All the experiments were conducted in the modular industrial assembly workstation, designed at the laboratory of the Faculty of Engineering, University of Kragujevac, Serbia.

Outline the content of the doctoral dissertation

The dissertation will include the following chapters:

1. Introduction
2. Literature review
3. Design of experiments

4. Neuroergonomic assessment and EEG pre-processing
5. Subjective and observational measurements
6. Discussion and implication of the work
7. Conclusion
8. Literature

The first chapter will deal with the analysis of the relevant literature that will be used in the paper.

Sustainability is one of the pivotal aspects of Industry 5.0, or I5.0. Sustainable companies consider environmental, social, and economic aspects to guarantee a higher level of productivity, quality, and efficiency of the company. In this regard, sustainable products are the result of processes in which environmental impacts are reduced and safety and ergonomics principles are respected for the welfare of employees.

Occupational Health and Safety (OHS), wellbeing and satisfaction are the core of sustainability processes in manufacturing to improve safety, physical and mental health of operators. Therefore, manufacturing companies should consider the human element as a relevant resource and a valuable part by improving work conditions and developing human-centered production systems. A possible and concrete solution to improve social sustainability without neglecting the production efficiency is represented by human-robot collaboration (HRC), as demonstrated by the increasing scientific literature on such a topic.

Human-Robot Collaboration (or HRC) is the utmost application of collaborative interaction between human and robot in the industrial workplaces. It guarantees either a proper assistance or interaction of the machine co-working with the operator in those activities that are stressful, repetitive, and complex, in which the physical and mental workload might be exacerbated. The success of HRC is in part due to the ground-breaking application of collaborative robots or co-bots. These devices are more intuitive than their ancestors and allow a closer interaction with the operator, in a fenceless environment.

With the application of cobots, the human role has been changed by the disruption of automation technology in the real-world manufacturing scenarios. Assembly tasks are more and more monitored by the agent to possible system failures. In this regard, ergonomic assessment is of paramount importance for an HRC activity.

Neuroergonomics, as the application of neuroscience to ergonomics, allows a deeper acknowledgement of the operator's mental workload (MWL). The analysis of MWL is defined through indirect and direct observational methods. These last methods are possible through unobtrusive and portable devices such as EEG that paves the way to a new methodology of objective ergonomic assessment, monitoring, and evaluation of parameters in the field of HRC.

The paper highlights the application of EEG devices in a comparative analysis of a manual assembly task in a laboratory environment between three cases.

The second chapter will deal with the analysis of relevant literature that will be used in the doctoral dissertation emphasizing the importance of the following areas: (1) the advantages of Human-Robot Collaboration (HRC) tasks in manufacturing activities (2) Design and optimization of HRC in laboratory activities (3) The effect of mental workload of operators in a HRC activity. The literature analysis will follow the outline content of the dissertation.

Collaborative robots, or cobots, allow to enhance the social sustainability in industries without decreasing the level of productivity. The deployment of these machines opens the door to human-robot collaboration, or HRC, combining the advantages of automation, such as accuracy and repeatability, with the flexibility and cognitive soft-skills of humans.

Manufacturing assembly tasks are rivaling to be one of the most interesting and promising applications in collaborative scenarios as they almost account for half of the average workload in the actual production process. Recently, research studies designed different case scenarios of assembly tasks represented in laboratory scenarios with the application of HRC activities. In this regard, safety and ergonomics principles are of pivotal importance for the design of these collaborative activities. With the disruption of sensors applied in HRC environments, psychophysiological measures can be used to identify and evaluate the human partner's responses to the interaction with the robot. Research studies suggested different physiological measurements in HRC applications to have indicators of anxiety, stress, and engagement of the operator. In this regard, Neuroergonomics, as the discipline of Neuroscience applied in Ergonomics, allows a better analysis of the workload of the operator performing a task. Cognitive workload represents the volume of mental work required of an employee to accomplish a task. Research studies explain in detail how important the mental workload is in the design of workplaces for assembly tasks. The design of HRC workstations must involve the combination of human and robot qualities, without overlooking the performance indicators, to enhance the level of operator's workload. The proper level of workload is the key to enhance productivity and efficiency of the job task. Lower levels of mental workload might be synonym of the out-of-the-loop state of the operator when performing a task. On the other hand, higher levels of mental workload might be the consequence of frustration and cognitive fatigue of the operator executing the task.

Different methodologies are adopted to analyze the mental workload. Among these methodologies, the electroencephalogram (EEG) provides an online, objective, continuous measure of mental workload. Furthermore, EEG found a vast application in different fields. However, The EEG deployment in HRC manufacturing activities is still in its infancy.

Furthermore, a qualitative analysis, using questionnaires, is useful to assess the user experience while working with the robot. Although many studies suggest that cobots reduce an operator's mental workload, there are other studies showing that cobots increase workload. The conflicting pattern of findings indicates that there is still a need to explore workload in HRC tasks. In fact, the evaluation of workload in HRC is a crucial point when investigating satisfaction and performance, which is the general aim of the presented research.

In **the third chapter**, the research methodology is explained.

The experiments were set up in the modular industrial assembly workstation designed for neuroergonomic experiments based at the laboratory of the Faculty of Engineering, University of Kragujevac, Serbia (FINK) in collaboration with Mbraintrain company, Belgrade, Serbia.

The tests consisted of sequential manual assembly tasks. Three scenarios are set up for the experiments: in the first scenario the participant accomplished the task without any interference in the assembly area; in the second scenario, the robot just carries sequentially the components to the assembly providing them to the operator; and in the third scenario robot carries sequentially the components completely prepared to the assembly providing them to the operator. The goal was to conduct a comparative analysis of the mental workload by the EEG real-time acquisition in these three different scenarios. The three experimental scenarios were set in different periods of the year with a time span of minimum 4 months each to reduce the error-bias in the comparative neuroergonomic analysis. Moreover, to reduce the noise due to internal factors that might influence the workload, experiments started in the morning hours of the day, conducted in an isolated environment and at room temperature.

The fourth chapter describes the design of EEG neuroergonomic assessment in a HRC task in the modular assembly workstation. The proposed design allowed to implement the collaborative robot in the workstation without affecting other systems and allowed to conduct an EEG evaluation in laboratory manual assembly activities. The analysis of EEG data is to evaluate the mental workload. The mental workload parameter as the power ratio between Beta Waves (stress/Engagement index) and Alpha Waves (relaxation index) allows to evaluate the mental workload of the participants in the three scenarios.

In **the fifth chapter**, the analyses of subjective and observational measurements are presented. NASA TLX is a certified multidimensional subjective questionnaire used to measure the cognitive workload of participant performing a task. For the purpose of this research study, it is used to correlate the objective analysis coming from the EEG neuroergonomic assessment to further evaluate mental workload. The combination of objective and subjective measurements is necessary to assess the cognitive response of the operator performing the task in the three scenarios. Furthermore, observational measurements through a checklist are deployed to analyze the level of efficiency, effectiveness, and quality of the tasks through the three scenarios.

In **the sixth chapter**, the analysis of the research results is discussed. The scientific approach is considered, describing how the mental workload of the operator is affected by the cobot activity and how this parameter, from the EEG objective and NASA TLX subjective analyses, is correlated with the productivity and efficiency index of the task from the observational measurements.

In **the seventh chapter**, the conclusions from the conducted research are presented. Also, the limitations of the proposed model and future research are analyzed.

In **the eight chapter**, the references used in the dissertation are given.

3. Explanation of the dissertation topic, which enables the conclusion that it is an original idea or an original method of analyzing the problem

Based on the application of the doctoral thesis, the formed Commission brings together the fact that there is a justified need for the development of neuroergonomic assessment in human-robot collaborative applications in manufacturing activities.

The dissertation will bring conceptualization of the new model for neuroergonomic assessments which represents a significant scientific contribution. The methodology will follow the proposed model with the analysis of the relationship between mental workload and task performance in terms of productivity. This will enable better decision-making processes for the optimization of business activities and achieving business continuity.

The proposed topic, along with the research objectives, is sufficiently focused on making scientific contributions in the dissertation field.

The Commission concludes that the proposed topic of the doctoral dissertation with an explanation of the subject and objectives of the work, scientific goals, scientific contributions, and expected results, resulting from the previous independent research and detailed analysis of available scientific papers, is an original idea in a scientific and professional sense.

4. Compliance with the research subject's definition, basic terms, proposed hypothesis, data sources, and analysis methods with scientific criteria while adhering to scientific principles in the preparation of the doctoral dissertation's final version

Candidate Carlo Caiazzo, Master of Mechanical Engineering for the Design and Production, will include in his dissertation all the elements of the scientific-research way of working, respecting the basic criteria of science, scientific goals, and methods of analysis, implementing existing and developing original ideas of scientific research.

The subject of research is aligned with the proposed hypotheses and research methods. The proposed scientific and professional literature is appropriate and contemporary.

In the submitted dissertation application, the candidate used the appropriate terminology and the field of engineering management. The definition of the research subject is harmonized with the basic questions, proposed hypotheses, and research methods.

Given that the research objectives stemmed from the perceived need to improve organizational resilience and its enhancement in complex industrial enterprises in an uncertain environment, the obtained results would represent an original contribution to the research field.

5. Review of the candidate's scientific research work

a) Short biography of the candidate

Carlo Caiazzo is born on April 11, 1995, in Naples, Italy. He has completed a Bachelor Science degree in Mechanical Engineering (ECTS 180) at the University of Naples Federico II, Italy. After that, he completed a master's degree in Mechanical Engineering for the Design and Production (ECTS 180) with a focus on analysis of the materials' viscoelastic behavior through Machine Learning Regression analyses at University of Naples Federico II, Italy.

As part of the European Marie Sklodowska-Curie project, CISC (Collaborative Intelligence for Safety Critical Systems - Grant Number 955901), he took place in the following studies abroad:

- Secondment at IMR (Irish Manufacturing Research) in Mullingar, Ireland
- Secondment at PILZ in Dublin, Ireland

From March to September 2021, he pursued an internship toward a start-up, spin-off from the University of Naples Federico II, Italy.

Since 2021, he has been enrolled as a Ph.D. student at the Faculty of Engineering at the University of Kragujevac. He has passed all exams required by the curriculum with an average grade of 10.0 and is working on a dissertation.

b) Scientific research work

Carlo Caiazzo has published a total of nine papers as an author or co-author in scientific journals and at scientific conferences.

• List of published papers

For journals (M22):

1. Petrovic, M., Vukicevic, A.M., Djapan, M., Peulic, A., Jovicic, M., Mijailovic, N., Milovanovic, P., Grajic, M., Savkovic, M., **Caiazzo, C.**, Isailovic, V., Macuzic, I., Jovanovic, K. (2022) Experimental Analysis of Handcart Pushing and Pulling Safety in an Industrial Environment by Using IoT Force and EMG Sensors: Relationship with Operators' Psychological Status and Pain Syndromes. Sensors, 22, 7467. https://doi.org/10.3390/s22197467
2. Savkovic, M., **Caiazzo, C.**, Djapan, M., Vukicevic, A.M., Pušica, M., Macuzic, I. (2022) Development of Modular and Adaptive Laboratory Set-Up for Neuroergonomic and Human-Robot Interaction. Research Frontiers in Neurorobotics, Vol. 16, https://doi.org/10.3389/fnbot.2022.863637

For conferences (M33):

1. **Caiazzo, C.,** Nestić, S., Savković, M. (2023). A Systematic Classification of Key Performance Indicators in Human-Robot Collaboration. In: Mihić, M., Jednak, S., Savić, G. (eds) Sustainable Business Management and Digital Transformation: Challenges and Opportunities in the Post-COVID Era. SymOrg 2022. Lecture Notes in Networks and Systems, vol 562. Springer, Cham. https://doi.org/10.1007/978-3-031-18645-5_30
2. **Caiazzo, C.,** Savković, M., Djapan, M., Macuzic, I. (2022). Framework of modular industrial workstations for neuroergonomics experiments in a collaborative environment. Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022), Edited by Maria Chiara Leva,

Edoardo Patelli, Luca Podofillini, and Simon Wilson https://doi.org/10.3850/978-981-18-5183-4_J01-07-285-cd

3. **Caiazzo, C.,** Djordjevic, A., Savković, M., Djapan, M., Vukicevic, A. Architecture of human-robot collaboration in manufacturing industries. The 19th International Conference "Man and Working Environment" Occupational and Environmental Safety engineering and Management, pp. 307-314, November 24-25th 2022, Niš, Serbia. https://scidar.kg.ac.rs/handle/123456789/18387
4. Savković, M., Mijailović, N., **Caiazzo, C.,** Djapan, M. Advanced physical ergonomics and neuroergonomics research on an assembly workstation. The 19th International Conference "Man and Working Environment" Occupational and Environmental Safety engineering and Management, pp. 351-358, November 24-25th, 2022, Niš, Serbia. https://scidar.kg.ac.rs/handle/123456789/18500
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6. **Caiazzo, C.,** Savkovic, M., Pusica, M., Nikolic, N., Milojevic, Dj., Djapan, M. Framework of a Neuroergonomic Assessment in Human-Robot Collaboration. Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023). Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio, pp. 2814-2820, doi: 10.3850/978-981-18-8071-1_P214-cd
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A proposal for a mentor with his references proving the fulfillment of the conditions for mentoring

The committee proposes that the mentor of this doctoral dissertation be Marko Djapan, PhD, associate professor at the Faculty of Engineering, University of Kragujevac. Marko Djapan, PhD has published over 60 scientific research papers in journals on the SCI list, domestic journals and international conferences which the five scientific papers are closely related to the topic.

References that prove the fulfillment of the requirements for mentoring:

1. Savkovic Marija, Carlo Caiazzo, **Marko Djapan**, Arso M. Vukicevic, Miloš Pušica and Ivan Macuzic. Development of Modular and Adaptive Laboratory Set-Up for Neuroergonomic and Human-Robot Interaction Research. Frontiers in Neurorobotics 16:863637, ISSN 1662-5218, https://doi.org/10.3389/fnbot.2022.863637, 2022. (M22)
2. Petrovic Milos, Arso M. Vukicevic, **Marko Djapan**, Aleksandar Peulić, Milos Jovicic, Nikola Mijailovic, Petar Milovanović, Mirko Grajic, Marija Savkovic, Carlo Caiazzo, Velibor Isailovic, Ivan Macuzic and Kosta Jovanović. Experimental Analysis of Handcart Pushing and Pulling Safety in an Industrial Environment by Using IoT Force and EMG Sensors: Relationship with Operators' Psychological Status and Pain Syndromes. Sensors, Vol.22, No.16, pp. 7467, ISSN 1424-8220, https://doi.org/10.3390/s22197467, 2022. (M22)
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Based on everything mentioned in the preceding sections of this report, the Commission makes the following

CONCLUSION AND PROPOSAL

Carlo Caiazzo, Master of Industrial Engineering for the Design and Production, met all of the requirements for approval of the doctoral dissertation preparation.

The proposal doctoral dissertation is original and scientifically based. The proposed methodology for preparing the doctoral dissertation is in accordance with scientific principles. The expected results of the doctoral dissertation should represent an original scientific contribution to the scientific field of **Industrial Engineering and Engineering management** (specific scientific field: Industrial engineering) and industry as well.

The Commission proposes to the Teaching and Scientific Council of the Faculty of Engineering, University of Kragujevac, and the Council for Technical and Technological Sciences of the University of Kragujevac to accept the proposed topic for the doctoral dissertation entitled:

"NEUROERGONOMIC ASSESSMENT OF

MENTAL WORKLOAD IN ADAPTIVE INDUSTRIAL HUMAN-ROBOT COLLABORATION"

and to approve its preparation for the candidate **Carlo Caiazzo, Master of Industrial Engineering for the Design and Production**. The Commission suggests that the mentor of the proposed doctoral dissertation would be **Marko Djapan, PhD, Associate Professor** at the Faculty of Engineering, University of Kragujevac.

In Kragujevac and Niš,
Date: November 2023

THE COMMISSION

Ivan Mačužić, PhD, Full Professor - President of the Commission
Faculty of Engineering, University of Kragujevac,
The specific scientific field: Industrial engineering

Marko Djapan, PhD, Associate Professor – member
Faculty of Engineering, University of Kragujevac,
The specific scientific field: Industrial engineering

Evica Jovanović, PhD, Full Professor - member
Faculty of Occupational Safety, University of Niš
The specific scientific field: System research in safety and risk