REVIEW
of DOCTORAL DISSERTATION

titled:

"Analysis of biomechanical and bioelectric parameters for the needs of automation of diagnostics and rehabilitation of patients"

by

Anna ROKSELA

The dissertation does not contain the synthetic description and analysis of papers cycle but has been written as monography. However Mrs Anna Roksela as an Coauthor has very good scientific achievement and these papers and book chapters are cited in the dissertation.

Scientific achievement of Mrs. Anna Roksela:

1. J. Leszczak, A. Wolan-Nieroda, M. Drużbicki, A. Poświata, M. Mikulski, **A. Roksela** and A. Guzik. 'Evaluation of Reliability of the Luna EMG Rehabilitation Robot to Assess Proprioception in the Upper Limbs in 102 Healthy Young Adults'. In: Medical Science Monitor: International Medical Journal of Experimental and Clinical Research 30 (2024), e942439. doi: 10.12659/MSM.942439. url: https://doi.org/10.12659/MSM.942439. (MNiSW 70, IF 2.685)

2. Justyna Leszczak, Bogumiła Pniak, Anna Poświata, **Anna Roksela**, Michał Mikulski, Mariusz Drużbicki and Agnieszka Guzik. 'Assessment of external and internal compliance of the Luna EMG robots as a tool for assessing upper limb proprioception in people after stroke'. In: Międzynarodowe Dni Rehabilitacji w Rzeszowie. Poster presented at the Międzynarodowe Dni Rehabilitacji w Rzeszowie, 8-9 February 2024.

3. Patrycja Lewandowska-Sroka, Rafał Stabrawa, Dominika Kozak, Anna Poświata, Barbara Łysoń-Uklańska, Katarzyna Bienias, **Anna Roksela**, Marcin Kliś and Michael Mikulski. 'The Influence of EMG-Triggered Robotic Movement on Walking, Muscle Force and Spasticity after an Ischemic Stroke'. In: Medicina (Kaunas, Lithuania) 57 (Mar. 2021), p. 227. doi: 10.3390/medicina57030227.

4. Łukasz Oleksy, Aleksandra Królikowska, Anna Mika, Pawel Reichert, Monika Kentel,

*Maciej Kentel, Anna Poswiata, **Anna Roksela**, Dominika Kozak, Katarzyna Bienias, Marcel Smoliński, Artur Stolarczyk and Michael Mikulski. 'A Reliability of Active and Passive Knee Joint Position Sense Assessment Using the Luna EMG Rehabilitation Robot'. In: International Journal of Environmental Research and Public Health 19 (Nov. 2022). doi: 10.3390/ijerph192315885.*

*5. **Anna Roksela**, Anna Poswiata, Jarosław Śmieja, Dominika Kozak, Katarzyna Bienias, Jakub Ślaga and Michael Mikulski. 'Evaluation of Neurological Disorders in Isokinetic Dynamometry and Surface Electromyography Activity of Biceps and Triceps Muscles'. In: Sept. 2023, pp. 325–338. isbn: 978-3-031-38429-5. doi: 10.1007/978-3-031-38430-1_25.*

*6. Krystyna Stańczyk, Anna Poświata, **Anna Roksela** and Michał Mikulski. 'Assessment of Muscle Fatigue, Strength and Muscle Activation During Exercises with the Usage of Robot Luna EMG, Among Patients with Multiple Sclerosis'. In: Information Technology in Biomedicine. Ed. by Ewa Pietka, Pawel Badura, Jacek Kawa and Wojciech Wieclawek. Cham: Springer International Publishing, 2019, pp. 117–128. isbn: 978-3-030-23762-2.*

*7. Ewa Zasadzka, Sławomir Tobis, Tomasz Trzmiel, Renata Marchewka, Dominika Kozak**, Anna Roksela**, Anna Pieczyńska and Katarzyna Hojan. 'Application of an EMG-Rehabilitation Robot in Patients with Post-Coronavirus Fatigue Syndrome (COVID-19) - A Feasibility Study'. In: International Journal of Environmental Research and Public Health 19.16 (2022). issn: 1660-4601. doi: 10.3390/ijerph191610398. url: https://www.mdpi.com/1660-4601/19/16/10398.*

Presented below dissertation analysis contain the numbered and marked queries to the PhD Student.

Athor underlined that the motivation behind the research is the pressing need to address these challenges amidst the growing demands on healthcare systems worldwide and the potential of advanced technologies, such as machine learning and robotics, to revolutionize diagnostics and rehabilitation through automation what seems to be very proper heading nowadays.

The primary goal of the study was to lay down the methodological foundation for an automated expert platform aimed at supporting, enhancing, and automating the diagnostic and rehabilitation processes. Utilizing machine learning and robotic technologies, the research develops a feedback mechanism that integrates electromyography (EMG), torque, and limb position data. This integration facilitates a more objective, efficient, and personalized approach to patient care.

1/ Such studies may have the application in personalized medicine.

Presented for review dissertation focuses on the analysis of upper limb movements, specifically elbow flexion and extension, involving the biceps and triceps muscles during isokinetic muscle force assessments, as well as tests for spasticity and muscle stiffness.
There were also explored the application of EMG biofeedback for pelvic floor muscles within a telerehabilitation framework and investigated EMG-triggered movement for knee rehabilitation using a rehabilitation robot.

It is important that the research validates its hypotheses through extensive evaluations, comparing control and stroke groups for muscle force tests, assessing muscle spasticity in healthy and stroke survivors, and exploring the effectiveness of telemedicine in urinary incontinence rehabilitation and EMG-triggered movement therapy for knee rehabilitation post-stroke. These researches focus on utilizing electromyography (EMG), torque, and positional data to derive biomechanical and bioelectrical parameters. By applying machine learning algorithms, the research aims to objectively evaluate and distinguish between healthy subjects and those with conditions, and to tailor rehabilitation exercises based on a feedback loop mechanism.

2/ It should be underlined that the results presented in the dissertation contain project studies that were founded by The National Centre for Research and Development (NCBR). One of them was titled "Development of innovative methods of automatic diagnostic and rehabilitation using robots and bioelectric measurements" POIR.01.01.01-00-2077/15, in which Mrs. Anna Roksela was contributed as a Product Engineer, and was responsible for development of the Luna EMG rehabilitation robot. The other one was titled: "Development of an innovative rehabilitation splint for the lower limbs for neurological and orthopaedic patients using electromyography and electrostimulation" POIR.01.01.01-00-0855/20, in which Mrs. Anna Roksela was contributed as a Research and Development Project Manager and Biomedical Engineer. Moreover Mrs. Anna Roksela took significant part in the project of "Development of an innovative robot for automated hand neurorehabilitation and occupational therapy using electromyography" POIR.01.01.01-00-1859/20, where she was Biomedical Engineer. She is also Coauthor of the patents.

The dissertation has been divided into few parts. The first introduction, where Author in two chapters very clearly described motivation and the scope. The next one is background and related work where there are also two wide chapters titled biomechanical and bioelectrical

parameters in diagnostic and rehabilitation and automatization in diagnostic and rehabilitation.

Next chapter contains information about methods and materials that were used in the studies provided by Author. They were titled: system design and implementation and general concept and research equipment.

This chapter outlines the system design and implementation framework developed for the analysis of biomechanical and bioelectric parameters, aimed at enhancing the automation of diagnostics and rehabilitation processes for patients. The integration of advanced sensing technologies (an electromyograph, a dynamometer, and a goniometer), data analysis methods, and machine learning algorithms forms the cornerstone of this innovative system, enabling precise and real-time monitoring and assessment of patient conditions.

In this part there are few subchapters descripted methodology and used rehabilitation equipment. There are computer unit and software, Luna EMG, Stella BIO.

3/   Very interested and useful chapter in this part of the work is titled: practical implementation in healthcare. This section details the specialized hardware and software components selected for data acquisition, processing, and analysis, ensuring the highest standards of precision, reliability, and scalability in the study of patient diagnostics and rehabilitation, what is very important due to studies and measurements performed in presented work.

Another chapter is A**utomatization of diagnostics and selected rehabilitation procedures which is divided into:**
- Automatization of diagnostics of stroke patients - Muscle stiffness and spasticity
- Automatization of diagnostics and rehabilitation of urinary incontinence patients
- Automatization of rehabilitation - EMG-triggered movement exercises

Author ticked that the pilot study of part of the results was presented during a poster session at the European Congress of NeuroRehabilitation 2019 in Budapest. It is position 108 from the Literature and Mrs. Roksela is the first Author.

Anna Roksela, Anna Poswiata, Jarosław Śmieja, Dominika Kozak, Katarzyna Bienias,
Jakub Ślaga and Michael Mikulski. 'Evaluation of Neurological Disorders in Isokinetic Dynamometry and Surface Electromyography Activity of Biceps and Triceps Muscles'. In: Sept. 2023, pp. 325–338. isbn: 978-3-031-38429-5. doi: 10.1007/978-3-031-38430-1_25.

The study aimed to establish a protocol for assessing joint stiffness, employing a robotic device to measure torque in the elbow joint during continuous passive motion of a patient's limb. The evaluation involved two distinct groups, each comprising ten individuals: one group consisted of neurological patients who had experienced an ischemic stroke, and the other group was made up of healthy individuals with no movement impairments related to central nervous system disorders.

4/   It is extremely important chapter (subchapters) in the work as well as from practical/medical point of view and rehabilitation development what was one of the main goals in which Mrs. Anna Roksela's dissertation and also provided by her all studies.

The last chapter is the conclusion and future work where Author summarized performed and described results and its practical implementation.

One can read in this part that the primary goal of this research was to lay the foundational methodological principles for an automated expert platform that aims to augment, improve, and automate the processes of diagnosis and rehabilitation.

The distinctive contribution of the author primarily lies in the analysis of bioelectrical and biomechanical parameters based on muscle activity (EMG), torque, and position measurement and the application of machine learning for objective assessments: differentiating between healthy and patients, and tailoring exercises to suit the patient's capacity based on the feedback loop. This integration enables more objective, efficient, and personalized approach to patient care. The focus of the studies was primarily on upper limb movements, emphasizing elbow flexion and extension, and examining the roles of the biceps and triceps muscles in isokinetic muscle force assessments, as well as in evaluating spasticity and muscle stiffness.

Another investigation summarized in the conclusion delved into the application of EMG biofeedback for pelvic floor muscles within the scope of telerehabilitation, utilizing a protocol conducted remotely. The research was conducted on the rehabilitation of knee movement, triggered by EMG, focusing on the rectus femoris and biceps femoris muscles through the use of a rehabilitation robot. The chosen bioelectrical and biomechanical parameters were validated for their effectiveness and objectivity in diagnostic and therapeutic processes through robot-assisted procedures.

The findings from the adopted methodology indicate the feasibility of creating a cohesive system for the initiation and oversight of rehabilitation processes (automation). Before commencing exercises, individuals undergoing rehabilitation can undergo diagnostic

evaluations. The muscle movements can be scrutinized to ensure adherence to the prescribed exercise protocols (utilizing the feedback loop). This approach effectively addressed the outlined scientific problem by demonstrating the practicality and applicability of these parameters in enhancing patient care.

Author in presented dissertation as well as in the studies performed within the provided research confirmed that:
- EMG signals complemented by torque and limb position, generated by patients during machine-assisted diagnostic procedures, allow to objectively assess the patient's condition,
- EMG, complemented by torque and position measurements, when applicable, provide a complete set of signals facilitating biofeedback-based effective rehabilitation, also in telemedicine solutions.

5/ Performed studies and obtained results can be treated as a beginning of implementation the measured biosygnals and theirs integration what enables more objective, efficient, and personalized approach to patient care, so the personalized medicine. It can be/should be implemented not only in diagnostic and rehabilitation but I am sure in other medicine specializations.

6/ One question to Mrs. Anna Roksela:
Can You find the possibility of use the thermal imaging in automatic diagnostic procedures or evaluation the therapy effects in machine-assisted procedures? Can You give an idea how to use thermal imaging in rehabilitation process that uses Luna EMG?

Reviewer completely agree that this dissertation not only addresses a significant gap in the existing literature but also lays the groundwork for future innovations in the field of robotic-assisted healthcare and automatization. And the methodologies and findings presented herein have the potential to significantly impact the way we approach diagnosis and rehabilitation, leading to more personalized, efficient, and effective patient care.

<u>Moreover the Reviewer emphasize that the whole project described in the dissertation as well as provides studies by Mrs. Ann Roksela is very important and valuable from the medical and practical point of view. Most of the results are</u>

continuously implemented by the Egzotech Company into the rehabilitation marked not only in Poland but all over the world.
Taking into consideration the practical meaning of the doctoral thesis, science achievements, participation in grants and in patents Reviewer contributes to distinction of the doctoral thesis.

Przedstawiona do recenzji rozprawa doktorska spełnia warunki określone w art. 187 ustawy z dnia 20 lipca 2018 r. – prawo o szkolnictwie wyższym i nauce (j.t. Dz U. z 2023 r. poz. 742, z późn. zm.), dlatego wnoszę do Rady Dyscypliny Inżynieria Biomedyczna Politechniki Śląskiej o dopuszczenie Doktorantki pani mgr Anny Roksela do dalszych etapów przewodu doktorskiego.

Prof. Dr n. fiz. Hab. n. med. Armand Cholewka

z-ca Dyrektora Instytutu Inżynierii Biomedycznej UŚ
Kierownik Grupy Badawczej Inżynieria Biomedyczna
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