



OPINION

for dissertation for the scientific degree "Doctor of Sciences"

Author of the dissertation: Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva

Title of the dissertation: HYBRID APPROACHES FOR BUILDING A DIGITAL TWIN OF HEART RATE VARIABILITY

Professional field: 5.2. Electrical engineering, electronics and automation, Scientific specialty: 02.21.01 Elements and devices of automation and computing technology.

Reviewer: Prof. Dr. Valentin Mateev, Technical University – Sofia, Faculty of Electrical Engineering, member of the scientific jury according to order No. 50/20.04.2026 of the Director of the Institute of Electrical Engineering-BAS "St. Matthew" - Sofia

1. Relevance of the dissertation.

The object of research in the dissertation is biomedical systems for building a digital twin model of heart rate variability, based on registration, processing, analysis, simulation and protection of cardiological signals. The heart rate variability model is considered as an integrated dynamic model that reproduces and predicts the state of autonomic cardiac regulation in real time through physiological data, mathematical models and intelligent algorithms. Electrocardiographic, photoplethysmographic signals are used as input data for the digital twin, as they reflect complex regulatory mechanisms associated with physiological stress, fatigue, adaptation and risk deviations in the cardiovascular system.

The relevance of the problem is determined by the growing requirements for modern health, sports and IoT-based systems for continuous monitoring and prediction of physiological states in real time. In the conditions of rapid development of portable sensors, telemedicine and the concept of digital twins, approaches that simultaneously provide high measurement accuracy, noise resistance, interpretable analysis and the ability to simulate future states of cardiac regulation are of particular importance.

2. Degree of knowledge of the state of the problem.

The dissertation is 250 pages long, contains 116 figures, 69 tables, 235 cited sources and contains an introduction, five chapters, a conclusion, and contributions. The problems posed, the research conducted, and the results obtained are described contextually and substantively. The dissertation is based on 25 current scientific publications made in the period 2021 - 2026, which have received wide popularization in open access journals and scientific conferences. The reference for the citations of these articles is indicative, with over 70 such citations described, which are still growing at the moment. Eight of the publications are independent, in the overwhelming majority the author is the first co-author. Based on the content of the dissertation, the publications under the current procedure, the remaining publications, and the author's scientific biography in general, one can definitely establish excellent knowledge of the information-computational and applied parts of the problem and free work with a wide range of modern numerical methods for the purposes of the dissertation.

3. Compliance of the research methodology and the objectives of the dissertation with the contributions achieved.

The main goal of the dissertation is to develop and research an integrated hybrid methodological framework for processing, analysis, modeling and protection of cardiological signals, based on a

combination of classical mathematical and modern AI approaches, supporting the construction of a digital twin of heart rate variability in IoT environments. The selection of methods by novelty, productivity and relevance is undoubtedly successful.

The following main tasks have been defined and implemented in the dissertation:

1. Research and development of methods for effective noise reduction in cardiological signals by combining classical and AI-based approaches.
2. Development of robust hybrid methods and algorithms for detection of characteristic peaks in ECG and PPG signals, applicable in real and noisy conditions.
3. Creation and analysis of new models for simulation of heart rate variability in ECG, PPG signals, based on Gaussian models, chaotic systems and neural networks, with increased physiological reliability, controllability and reproducibility of real cardiological processes.
4. Research and development of methods for protection of cardiologica data through integration of cryptographic and watermarking approaches, ensuring confidentiality, integrity and authenticity of data without compromising their diagnostic value.
5. Development of a methodological framework for distinguishing the physio logical states of rest, fatigue and stress in athletes through a complex analysis of heart rate variability indicators, with a focus on applications in sports cardiomedicine.
6. Research and development of approaches for building a digital twin of heart rate variability, integrating real measurements, simulation models and intelligent analysis, with application in IoT and portable systems for continuous monitoring.
7. Creation of new integral indices for assessing and predicting the functional state of the body, based on heart rate variability indicators, intended for use within the framework of an HRV-based digital twin

I accept the grouping of the scientific and applied scientific contributions of the dissertation work in the following areas:

Scientific contributions

1. A concept for a digital twin of heart rate variability is formulated as a customizable and dynamic framework for modeling, interpretation and prediction of autonomic cardiac regulation.
2. Original methods for analysis and detection in PPG/ECG signals are proposed, including a hybrid AI approach integrating wavelet representation, CNN–LSTM architecture and a temporal attention mechanism for P-peak detection in PPG signals.
3. New simulation models for heart rate variability, PPG and ECG signals are developed, including hybrid and fractal-oriented solutions, including the GMF–Rössler model, combining morphological description and chaotic dynamics.
4. A regionally adaptive principle for cardiological data protection is formulated, in which cryptographic protection and watermarking protection are adapted to the diagnostic significance of different signal segments.

Scientific and applied contributions

5. Methods for adaptive noise suppression, reliable detection and interval extraction from PPG and ECG signals are developed, validated in real-time and energy-constrained conditions.
6. Three integral heart rate variability indices – FDTI, RDTI and PDTI – have been created to assess fatigue, short-term recovery and long-term adaptation, tested on data from athletes under different training regimes.

7. Methods and architectures for secure processing of cardiological data have been developed, including hybrid cryptography, watermarking and mechanisms for traceability and authenticity, as well as a multi-index method for automatic signaling of physiological risk in real time.

Applied contributions contain the realizations of scientific and scientific-applied contributions.

The dissertation proposes a conceptual and interdisciplinary scientific framework that connects the means of mathematical modeling, artificial intelligence, physiology and cybersecurity into a single platform for analyzing cardiological data. The obtained results expand the theoretical foundations of the analysis of heart rate variability and create a methodological basis for the development of intelligent digital twins, personalized monitoring and prognostic health technologies. The obtained results show that there is a correspondence between the set goals and the achieved results in the dissertation.

4. Assessment of dissertation publications.

The dissertation is based on 25 scientific publications, 14 of which in editions with IF and/or SJR (6 with Q1, 2 with Q2, 4 with Q3 and 2 with Q4); 10 were presented at international and national scientific conferences and 1 chapter of a monograph. Eight of the publications are independent, and the rest are in a team of authors. They were made in the period 2021 - 2026, received wide popularization in open access journals and scientific conferences. The reference for the citations of these articles shows over 70 noticed at the time of the start of the procedure. This gives me reason to assess the publications presented in the dissertation as sufficiently representative.

Regarding the national and institute scientometric data for the field of "Technical Sciences" for obtaining the scientific degree "Doctor of Sciences" by group of indicators as follows: A = 50 points; B = 100 points; G = 424 points (respectively G7 = 307.98 points, G8 = 106.66 points, G9 = 10 points); E = 558 points (respectively E12 = 520 points, E14 = 38 points). Total points 1132 points. Since the minimum number of points is 350 points, and the fulfilled number is 1132 points, the regulatory requirements are categorically exceeded.

5. Opinions, recommendations and notes.

My opinion on the presented dissertation work is positive. Notes can be made on the presentation of some of the terminology in the text, which is in English, this also applies to the designations of figures, abbreviations and others. A certain striving to enrich the names in Bulgarian is advisable, even if the terms are not generally accepted, as the dissertation work itself can introduce them and set them as a standard for their use. Also, a comparative assessment of the computational complexity of the methods would be very useful due to the limited resources in wearable biomedical applications.

CONCLUSION

The analysis of the submitted materials shows that the dissertation work of Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva contains research and results that are significant for practice and theory, through which important scientific, scientifically-applied and applied tasks have been solved and relevant significant contributions have been achieved. The requirements of the ZRASRB, the Regulations for its application and the requirements for the development of the academic staff of the Institute of Robotics for the award of the scientific degree "Doctor of Sciences" have been met. This gives me reason to support and confidently recommend to the members of the esteemed Scientific Jury to award Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva the scientific degree "Doctor of Sciences" in the field of

higher education 5. "Technical Sciences", professional direction 5.2. "Electrical Engineering, Electronics and Automation".

09.06.2026

Reviewer:

/Prof. V. Mateev, PhD/