



OPINION

by Prof. Dr. Anna Lekova, Institute of Robotics, Bulgarian Academy of Sciences
on a dissertation work for the degree of "Doctor of Science"

Scientific field: Technical Sciences

Professional field: 5.2 Electrical Engineering, Electronics and Automation

Scientific specialty: Elements and Devices of Automation and Computing

Author: Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva, Institute of Robotics,
Bulgarian Academy of Sciences

Title: "HYBRID APPROACHES FOR BUILDING A DIGITAL TWIN OF HEART RATE
VARIABILITY"

1. General Presentation of the Procedure and the Candidate

By Order No. 50/20.04.2026 of the Director of the Institute of Robotics, BAS, I was appointed as a member of the Scientific Jury in a procedure for the award of the scientific degree Doctor of Sciences in Professional Field 5.2 Electrical Engineering, Electronics and Automation, Scientific Specialty: Elements and Devices of Automation and Computing.

The dissertation under review has been developed by Assoc. Prof. Dr. Eng. Galya Georgieva-Tsaneva from the Institute of Robotics, BAS and is in the field of biomedical information technologies. The work addresses the highly relevant and promising scientific area of Heart Rate Variability (HRV) and the challenges associated with the development of a digital twin of HRV.

The dissertation consists of 245 pages and includes an introduction, five chapters, conclusions, a statement of scientific and scientific-applied contributions, a list of publications related to the dissertation topic, citation records, and references. The structure is logically organized and follows the complete development cycle of the digital twin concept - from the processing of cardiological signals, through their modeling and simulation, to data protection and the formulation of a comprehensive methodological framework.

The set of materials submitted by Assoc. Prof. Dr. Galya Georgieva-Tsaneva complies with the Regulations for the Implementation of the Academic Staff Development Act in the Republic of Bulgaria, as well as with the internal regulations of the Institute of Robotics, BAS, and satisfies the requirements for the award of the scientific degree Doctor of Sciences.

2. Relevance of the Research Topic

The dissertation topic is highly relevant and corresponds to some of the most rapidly developing directions in contemporary science and engineering practice, digital twins, artificial intelligence, intelligent biomedical systems, and personalized healthcare.

The increasing use of wearable devices, IoT platforms, telemedicine solutions, and continuous physiological monitoring systems creates a need for advanced methods for the analysis, prediction, and interpretation of cardiological data. In this context, the development of a digital twin of autonomic cardiac regulation represents a significant scientific and practical contribution.

Particularly significant is the comprehensive approach adopted in the dissertation, integrating biomedical signal processing methods, nonlinear and fractal analysis, artificial intelligence algorithms, machine learning techniques, simulation modeling, and cryptographic data protection.

3. Knowledge of the State of the Art

The dissertation clearly demonstrates an in-depth understanding of the current state of research and the challenges within the scientific field. Chapter 1 presents a detailed critical review of existing methods for processing, analyzing, modeling, and protecting cardiological signals.

Both traditional and modern techniques for HRV analysis are discussed, including wavelet-based approaches, deep learning methods, generative models (GAN), cryptographic solutions, and the concept of digital twins in medicine. The analysis goes beyond a descriptive overview and identifies specific research gaps that are subsequently addressed in the dissertation.

4. Research Methodology

The methodology employed is modern, well-structured, and fully aligned with the stated research objectives and tasks.

Particularly impressive is the effective integration of approaches from multiple scientific domains:

- Digital signal processing
- Discrete wavelet transforms
- Fractal and nonlinear analysis
- Machine learning and deep learning
- GAN-based generative models
- Statistical modeling
- Cryptographic algorithms
- Digital twin architectures.

The proposed methods are theoretically justified and experimentally validated using real biomedical datasets and simulation experiments. It should also be emphasized that the results obtained in the individual chapters are systematically built upon, ultimately leading to the formulation of a comprehensive conceptual framework for a digital twin of heart rate variability.

5. Evaluation of the Dissertation and its Contributions

The dissertation represents a completed scientific study with clearly identifiable scientific, scientific-applied, and applied contributions. Of particular importance is the integration of signal processing, modeling, analysis, and information security into a unified digital twin architecture.

The most significant results include:

- The formulation of an original methodological concept for a digital twin of heart rate variability
- The development of novel multimodal approaches and integrated indices supporting the construction of reliable HRV digital twins in real-world IoT and wearable-system environments
- The development of hybrid cryptographic methods for biomedical data protection
- Novel hybrid methods for noise reduction in PPG signals
- Improved algorithms for the detection of characteristic points in PPG and ECG signals
- New models for the simulation of HRV, PPG, and ECG signals.

6. Assessment of the Publications and Personal Contribution of the Candidate

The submitted publications adequately reflect the principal results of the dissertation. Out of a total of 25 publications, 14 have been published in journals indexed with an Impact Factor or SJR ranking, including 6 papers in Q1 journals, 2 in Q2 journals, 4 in Q3 journals, and 2 in Q4 journals. The remaining 10 publications have been presented at international and national scientific conferences, while one publication is a book chapter.

At the time of submission, the publications related to the dissertation topic had received a total of 71 citations, 52 of which are indexed in Scopus. This demonstrates that the research results have already gained recognition within the scientific community, and broader international impact can reasonably be expected in the future, particularly considering that the dissertation addresses an important gap through the formulation of a novel conceptual framework for a digital twin of HRV.

The publications further indicate that the principal scientific results were obtained with the leading participation of the candidate, who is the first author in 23 of the 25 publications. There is clear evidence of substantial personal contribution both in the formulation of scientific contributions and in the development of the proposed algorithms, models, and architectures.

The publication activity is sufficient in both quantity and quality for the award of the scientific degree Doctor of Sciences and adequately reflects the scientific achievements corresponding to the objectives and tasks defined in the dissertation.

7. Abstract

The dissertation abstract has been prepared in accordance with the applicable requirements and accurately reflects the content of the dissertation. It presents the objectives, research tasks, methods employed, principal results, and scientific and scientific-applied contributions. The text is sufficiently detailed and well structured, allowing a clear and coherent understanding of the conducted research.

8. Critical Remarks and Recommendations

I have no substantive critical remarks regarding the dissertation.

With respect to the claimed scientific-applied contribution (Contribution 2), concerning the development of the integrated indices FDTI, RDTI, and PDTI, the presented experimental validation does not allow fully substantiated generalization and interpretation of the results, since the indices were validated on a limited sample of only 22 athletes. In addition, the demographic characteristics of the participants are insufficiently described, including the absence of information regarding sex distribution, which is particularly important considering well-documented sex-related differences in HRV parameters (Koenig & Thayer, 2016). Consequently, it remains unclear to what extent the proposed indices maintain their sensitivity and specificity across different age groups, sports disciplines, training levels, and sexes. This limitation does not diminish the scientific value of the experimental work, however at the current stage, the FDTI, RDTI, and PDTI indices should be regarded not as fully validated tools for reliable assessment of fatigue, recovery, and prediction, but rather as promising developments requiring further validation in future studies.

Additionally, the Bulgarian terms corresponding to “detection” and “noise reduction” are direct translations from English and are not fully established within the traditional Bulgarian scientific terminology. In academic writing, these terms could more appropriately be replaced by “identification” or “recognition” and by “noise suppression” or “signal preprocessing,” respectively.

CONCLUSION

The dissertation submitted by Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva constitutes a completed, independent, and original scientific study with clearly defined scientific and scientific-applied results that contribute to the advancement of knowledge in biomedical signal processing using artificial intelligence, digital twins in medicine, telemedicine, and the protection of medical data.

The presented results fully satisfy the requirements of the Regulations of the Institute of Robotics at the Bulgarian Academy of Sciences for the implementation of the Academic Staff Development Act in the Republic of Bulgaria. As a member of the Scientific Jury, **I express my strong support for awarding the scientific degree Doctor of Sciences and respectfully recommend that the Scientific Jury confer this degree** upon Assoc. Prof. Dr. Eng. Galya Nikolova Georgieva-Tsaneva in Professional Field 5.2 Electrical Engineering, Electronics and Automation, Scientific Specialty: Elements and Devices of Automation and Computing.

Date: 10.06.2026

Member of the Scientific Jury:

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(Prof. Dr. Anna Lekova)