Tallinn University of Technology
Department of Cybernetics, School of Science

Research Report 330/23

Annual Report 2022 on Nonlinear Dynamics and Biophysics

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Tallinn, 2023

Contents

1. Introduction

This Report continues the series of Annual Reports on nonlinear dynamics started in 1999 within the Institute of Cybernetics. After the restructuring of the Tallinn University of Technology, the studies on nonlinear waves are carried on in the Department of Cybernetics, the School of Science. What follows, is the description of the results of the subgroup of biophysical modelling in the Laboratory of Solid Mechanics in 2022. The attention is focused on dynamical processes and waves in nerve fibres which means working at the interface of physics, mathematics and physiology.

2. Research results

Waves in nerve fibres

1. K. Tamm, T. Peets, J. Engelbrecht. Mechanical waves in myelinated axons. Biomechanics and Modeling in Mechanobiology, **21**, 1285-1297 (2022).
DOI:10.1007/s10237-022-01591-4
arXiv: 2112.11116 [physics.bio-ph]
The propagation of an action potential in nerves is accompanied by mechanical and thermal effects. Several mathematical models explain the deformation of the unmyelinated axon wall (a mechanical wave). In this paper, the deformation of the myelinated axon wall is studied. The mathematical model is inspired by the mechanics of microstructured materials with multiple scales. The model involves a Boussinesq-type equation together with a modification that describes the process in the myelin sheath. The dispersion analysis of such a model explains the behaviours of group and phase velocities. In addition, it is shown how dissipative effects may influence the process. Numerical calculations demonstrate the changes in velocities and wave profiles in the myelinated axon wall.

2. J. Engelbrecht, K. Tamm, T. Peets. Physics shapes signals in nerves. The European Physical Journal Plus, **137**, 6, 696 (2022).
DOI: 10.1140/epjp/s13360-022-02883-5
In this short review, the importance of physics in understanding the signal propagation in nerve fibres is discussed. The main carrier of information is the action potential, but it is accompanied by mechanical and thermal effects. A possible model governing the ensemble of waves takes the basic laws of physics into account and describes the interactions between the dynamical effects. Such a model needs a corresponding mathematical formulation and, in this way, the interdisciplinarity combining electrophysiology, physics, and mathematics helps to understand the complex process of signal propagation in nerves measured experimentally.

3. J. Engelbrecht, K. Tamm, T. Peets. Signals in nerves from the philosophical viewpoint. Proceedings of the Estonian Academy of Sciences, **71**, 4, 369-375 (2022).
DOI: 10.3176/proc.2022.4.07
philsci-archive.pitt.edu/id/eprint/18135
The signals in nerves include electrical, mechanical and thermal components and are characterised by the complexity of processes. The modelling of these signals is analysed from the viewpoint of DeLanda who has demonstrated the possibility to expose the philosophical theories of Deleuze by using the notions from nonlinear dynamics. It is demonstrated that the mathematical modelling of processes in nerves by the authors of this paper follows the general ideas of multiplicity and causal interactions described by DeLanda.

Submitted research papers
1.J. Engelbrecht, K. Tamm, T. Peets. From modelling to understanding: the signals in axons. Horizons in Neuroscience Research (Nova).
The modelling of biological systems means actually the modelling of complexity. In this chapter, our inquiry is focused on signals in axons. The complexity of the axonal structure and processes accompanying the electrical signals need functional integration of many disciplines for the full description of signalling in axons. The modelling involves not only biology or more definitely electrophysiology, but it also involves physics including thermodynamics and theory of continua, the mathematics used for deriving the governing equations of processes, and also a philosophy for embedding the results into the general understanding. Consequently, one must deal with interdisciplinary studies. The ideas of modelling, paying attention to the structure of an axon and the possible physical mechanisms responsible for a signal generation as an ensemble of several effects, are analysed step-by-step. The concrete integrated general models are presented. It is shown how the knowledge from physics, chemistry, mathematics, and philosophy has helped to build up a mathematical model that helps understand the process of formation and propagation of action potential with accompanying effects. The possible modifications of models are also briefly discussed.

2. T. Peets, K. Tamm, J. Engelbrecht. On concepts of mathematical physics for modelling signals in axons. The European Physical Journal E.
In this short paper, the results of the paper by Drab et al. are described in the framework of wave mechanics and mathematical physics based on common understandings. The attention is focused on properties of Boussinesq-type equations, solitons, and peakons. These concepts are supported by several experimental observations.

Conferences and abstracts

1. T. Peets, K. Tamm, J. Engelbrecht. Mechanical waves in myelinated biomembrane, The 11th European Solid Mechanics Conference ESMC11, Galway, 4-8 July 2022.
2. K. Tamm, T. Peets, J. Engelbrecht. Modelling of mechanical waves in a myelinated axon. The 11th European Solid Mechanics Conference ESMC11, Galway, 4-8 July 2022.
3. J. Engelbrecht, K. Tamm, T. Peets. Modelling of complex signals in nerves. World Conference on Basic Sciences and Sustainable Development, Belgrade, Serbia, 20-22 September, 2022.

Seminars and outreach activities

1. T. Peets. Science popularisation lecture. Tallinn Secondary School of Science, Tallinn, 05.04.2022
2. K. Tamm, T. Peets, J. Engelbrecht. Modelling of mechanical waves in a myelinated axon. Seminar in the Institute of Cybernetics, Tallinn, 05.05.2022
3. J. Engelbrecht, K. Tamm, T. Peets. Modelling of complex signals in nerves. Seminar in the Institute of Thermomechanics, Czech Academy of Sciences, Prague, 08.11. 2022.
4. K. Tamm, T. Peets, J. Engelbrecht. Modelling of complex signals in nerves. Seminar in the University of Dortmund, Department of Physics, Dortmund, 22.11.2022.

Research Reports

1. J. Engelbrecht, K. Tamm, T. Peets. Annual Report 2021 on Nonlinear Dynamics and Biophysics. RR Mech 328/22, Tallinn University of Technology, School of Science, Department of Cybernetics.
2. J. Engelbrecht, K. Tamm, T. Peets. Overview of modification ideas on modelling of signals in nerves. Research Report 329/22, Tallinn University of Technology, School of Science, Department of Cybernetics.

General publications

1. J. Engelbrecht. Piirid mitmest vaatenurgast. Akadeemia, 2022, 1, 120-133.
2. J. Engelbrecht. Foreword Ülo Lepik 100. Proc. Estonian Acad. Sci., 2022, 71, 1, 1-2.
3. J. Engelbrecht. Eesti Teaduste Akadeemia rahvusvahelisel areenil aastatel 1991-2021. Eesti Teaduste Akadeemia sõnas ja pildis 2021. Tallinn, Eesti Teaduste Akadeemia, 2022, 51-55. The Estonian Academy of Sciences in the international arena in 1991-2021
4. J. Engelbrecht. XVII Balti vaimse koostöö konverents. Ibid, lk 98 The 17th Baltic Conference on Intellectual Cooperation
5. J. Engelbrecht, I. Šlaus. Academies of Sciences in the contemporary world. Trames, 2022, 26 (76/71), 2, 219-227.
6. J. Engelbrecht. Tuleviku modelleerimine *Kasvu piiride* ainetel. Akadeemia, 2022, 9, 1675-1687.

General publications in preparation

1. G. Jacobs, I. Šlaus, J. Engelbrecht, A. Zucconi (eds). Leadership in Thought: Catalytic Strategies for Concious Social Transformation (prepared for Cambridge Scholars Publishing), 326 pp.

3. Activities

Teaching

K. Tamm - Courses in Tallinn University of Technology:
BSc level: Analytical Mechanics (YFX0591)

T. Peets - Courses in Tallinn University of Technology:
BSc level: Writing Academic Papers and Thesis (YFX0540), Mechanics (YFX0552)
MSc level: Mathematical Modelling and Nonlinear Dynamics (YFX1520),
Seminar of Applied Mechanics (YFX1530)

Reviewing

T. Peets: review for Acta Biomaterialia
K. Tamm: reviews for Journal of the Royal Society Interface; iScience (Cell Press); one master thesis review at Tallinn University of Technology

Membership in Editorial Boards:

Applied and Computational Mechanics (Czech Republic): J. Engelbrecht
Proc. Estonian Acad Sci.: J. Engelbrecht
Applied Mechanics (Kiev): J. Engelbrecht
J.Theor. and Appl. Mech. (Warsaw): J. Engelbrecht
Trames (Estonia): J. Engelbrecht
Akadeemia (Estonia): J. Engelbrecht

Professional organizations

Euromech: J. Engelbrecht, K. Tamm, T. Peets
ISIMM: J. Engelbrecht
Nordic Association for Computational Mechanics: T. Peets (member of the Executive Committee)
Estonian Academy of Sciences: J. Engelbrecht (Adviser)
WAAS – World Academy of Art and Science: J. Engelbrecht (Fellow)
Estonian National Committee for Mechanics: T. Peets (secretary), J. Engelbrecht (member)

4. Grants and cooperation

4.1 Estonian grants
K. Tamm, funded by PRG1227 (ETAg)
T. Peets, funded by PRG1227 (ETAg)
J. Engelbrecht (consultant), funded by PRG1227 (ETAg)

5. Varia: publications reflecting previous work

On book J. Engelbrecht „Juhuslikud jalutuskäigud teadusmetsas“ (Random Walks in Science Woods), Postimehe Kirjastus, Tallinn, 2021:
1. T. Tiivel. Lugesin üht raamatut. Horisont, 1/2022, lk 60.
2. R. Ubar. Korvitäis mõtteid teadusmetsast. Akadeemia, 2022, No 3, 540-546.

On book J. Engelbrecht, K. Tamm, T. Peets "Modelling Complex Signals in Nerves", Springer, Cham, 2021:
1. M. Kumar, zbMath, 2022, Zbl 1475.92003
This book is wholly devoted to foundational methods, concepts in mathematical biophysics and modelling of signals in nerves are divided into ten chapters. In addition to Part I, Part II, and Part III, which cover advanced topics involving complexity, waves, dynamical processes in nerve axons, and modelling of dynamical physiological processes, appendices cover the numerical scheme. Examples are provided Python and MATLAB scripts for numerical integration of proposed model equation, acquainting readers with this important tool in mathematical biophysics and allowing them to play with the explained methods or apply them quickly to their data. This book is self-contained and an excellent collection of earlier publications of the authors. Overall, in the opinion of the reviewer, this is a very well-written textbook. The idea of the book is quite good. The author explains and analyses different approaches comparatively so that readers can see how they are similar and how they differ. The book is a must-read not only for undergraduate students but also for researchers and practitioners.

5. Conclusions

The research on modification of the model (described in a book by Springer in 2021) is continued with the main attention to the modelling of the myelin sheath.

Concerning the previous results:
- papers by J. Engelbrecht have more than 15900 “reads” in Research Gate;
- the book "Microstructured Materials: Inverse Problems" (Springer, 2011) - has ca 7400 chapter downloads;
- the book "Questions About Elastic Waves"(Springer, 2015) - has ca 7700 chapter downloads;
- the book "Modelling of Complex Signals in Nerves" (Springer, 2021) has ca 2000 chapter downloads,
- the book "Applied Wave Mathematics II" (Springer 2019) has ca 8200 chapter downloads and the chapter "Mathematics of nerve signals" - over 500 downloads.

The recent results are widely known according to SciVal lists on topics by authors over the world (in brackets the place in the list):
- Action Potentials; Liquid Membranes; Nerve:
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