Systems and Control Group (SCG)

R&D Unit CIDMA

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Coordinator: Delfim F. M. Torres delfim@ua.pt

Members: 19 Senior Researchers (affiliated with University of Aveiro and Polytechnic Institutes of Coimbra, Leiria, Lisboa, Setúbal, Viana do Castelo, and Viseu) and **5 PhD students**.

Keywords: systems and control, coding theory, calculus of variations, optimal control, fractional systems, Biomathematics.

Summary

The SCG provides a strong integration of high-quality fundamental research with cross-disciplinary advanced applications in the general area of Systems and Control. Specific topics of interest include: behavioral systems and convolutional codes, adaptive control and control of drug administration, calculus of variations, optimal control, fractional calculus, dynamic systems on time scales, and optimal control applied to epidemiological models.

The group's activity has an impressive substantiation of international visibility:

• **Highly Cited and Influential Papers**, **e.g.,**

C. Silva, H. Maurer and D.F.M. Torres, Optimal control of a tuberculosis model with state and control delays, Math. Biosci. Eng. 14 (2017), no. 1, 321-337.

• **External Awards, e.g.,**

The work 'Discrete-time fractional variational problems' by Nuno R. O. Bastos, Rui A. C. Ferreira and Delfim F. M. Torres has been the winner of the 2015 EURASIP Best Paper Award, EUSIPCO 2015, 23rd European Signal Processing Conference, Nice, Côte d'Azur, France, 2015.

• **Participation in European Research Networks and Projects, e.g.,**

2011-2014: Marie Curie Project SADCO - Sensitivity Analysis for Deterministic Controller Design, Networks for Initial Training (ITN)

2013-2016: COST action IC 1104 – Random Network Coding and Designs over GF(q)

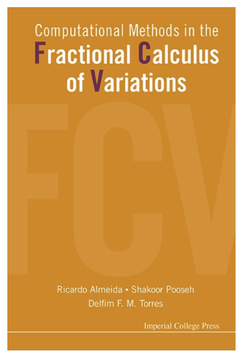
Since 2018, COST action CA16227 – Investigation and Mathematical Analysis of Avant-garde Disease Control via Mosquito Nano-Tech-Repellents

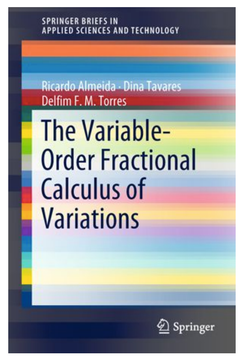
• **Seminal book publications, which are an international reference in their area, e.g.,**

R. Almeida, S. Pooseh and D. F. M. Torres, Computational methods in the fractional calculus of variations, Imperial College Press, London, 2015.

A. B. Malinowska, T. Odzijewicz and D. F. M. Torres, Advanced methods in the fractional calculus of variations, SpringerBriefs in Applied Sciences and Technology, Springer, Cham, 2015.

R. Almeida, D. Tavares and D. F. M. Torres, The variable-order fractional calculus of variations, SpringerBriefs in Applied Sciences and Technology, Springer, Cham, 2019.





• **Editorships in scientific journals, e.g.,**

- Commun. Nonlinear Sci. Numer. Simul. (Elsevier)
- Comput. Appl. Math. (Springer)
- J. Dyn. Games (AIMS)

• **Strong partnership with PALOP, e.g.,**

organization of The Cape Verde International Days on Mathematics 2013, 2015 and 2017.

Coding Theory

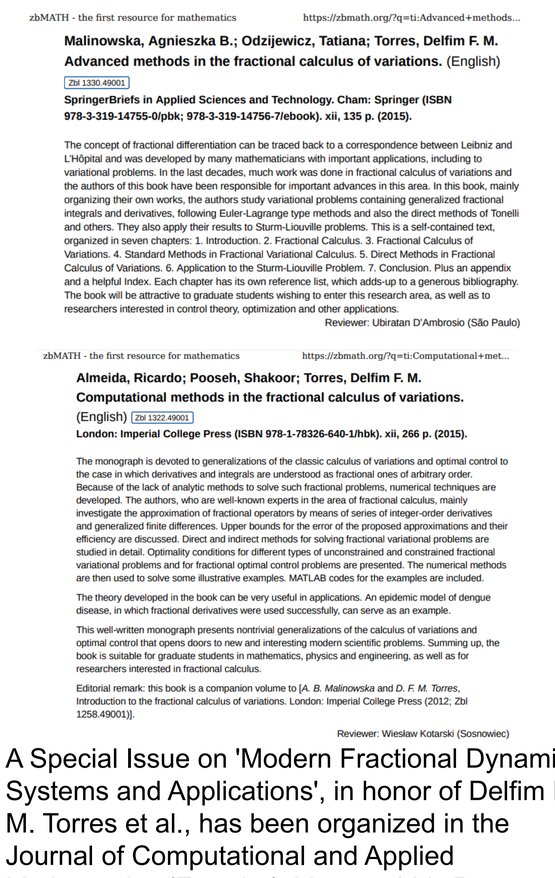
We introduced important notions in the context of 2D (two-dimensional) systems and provided concrete constructions of standard Maximum Distance Separable (MDS) convolutional codes. The results are of practical relevance for sending/storage of data in 2 dimensions. For instance, we investigated the notion of superregular matrix, which is fundamental for the construction of codes with high error-correcting capabilities. Moreover, we generalized the notion of superregularity for building codes with large distances for any given set of parameters. The first general construction of a superregular matrix over finite fields of any characteristic was obtained. See, e.g.,

J.-J. Climent, D. Napp, C. Perea and R. Pinto, Maximum distance separable 2D convolutional codes, IEEE Trans. Inform. Theory 62 (2016), no. 2, 669-680.

J.-J. Climent, D. Napp, R. Pinto and R. Simões, Series concatenation of 2D convolutional codes by means of input-state-output representations, Internat. J. Control 91 (2018), no. 12, 2682-2691.

Fractional Dynamic Systems and Applications

We proved necessary optimality conditions and developed numerical methods for fractional-order optimal control problems. The proposed numerical procedures are based on approximation formulas or on discretization techniques. The SCG published four books dedicated to Fractional Variational Problems, two of them published by Imperial College Press (in 2012 and 2015) and the other two by Springer (in 2015 and 2019). These four books are a reference in the area of Fractional Calculus of Variations.



zbMATH - the first resource for mathematics https://zbmath.org/?q=ti:Advanced+methods...

Malinowska, Agnieszka B.; Odzijewicz, Tatiana; Torres, Delfim F. M.
Advanced methods in the fractional calculus of variations. (English)

Zbl 1330.49001

SpringerBriefs in Applied Sciences and Technology. Cham: Springer (ISBN 978-3-319-14755-0/pbk; 978-3-319-14756-7/ebook). xii, 135 p. (2015).

The concept of fractional differentiation can be traced back to a correspondence between Leibniz and L'Hôpital and was developed by many mathematicians with important applications, including to variational problems. In the last decades, much work was done in fractional calculus of variations and the authors of this book have been responsible for important advances in this area. In this book, mainly organizing their own works, the authors study variational problems containing generalized fractional integrals and derivatives, following Euler-Lagrange type methods and also the direct methods of Tonelli and others. They also apply their results to Sturm-Liouville problems. This is a self-contained text, organized in seven chapters: 1. Introduction. 2. Fractional Calculus. 3. Fractional Calculus of Variations. 4. Standard Methods in Fractional Variational Calculus. 5. Direct Methods in Fractional Calculus of Variations. 6. Application to the Sturm-Liouville Problem. 7. Conclusion. Plus an appendix and a helpful Index. Each chapter has its own reference list, which adds-up to a generous bibliography. The book will be attractive to graduate students wishing to enter this research area, as well as to researchers interested in control theory, optimization and other applications.

Reviewer: Ubiratan D'Ambrosio (São Paulo)

zbMATH - the first resource for mathematics https://zbmath.org/?q=ti:Computational+met...

Almeida, Ricardo; Pooseh, Shakoor; Torres, Delfim F. M.
Computational methods in the fractional calculus of variations.
(English) Zbl 1322.49001
London: Imperial College Press (ISBN 978-1-78326-640-1/hbk). xii, 266 p. (2015).

The monograph is devoted to generalizations of the classic calculus of variations and optimal control to the case in which derivatives and integrals are understood as fractional ones of arbitrary order. Because of the lack of analytic methods to solve such fractional problems, numerical techniques are developed. The authors, who are well-known experts in the area of fractional calculus, mainly investigate the approximation of fractional operators by means of series of integer-order derivatives and generalized finite differences. Upper bounds for the error of the proposed approximations and their efficiency are discussed. Direct and indirect methods for solving fractional variational problems are studied in detail. Optimality conditions for different types of unconstrained and constrained fractional variational problems and for fractional optimal control problems are presented. The numerical methods are then used to solve some illustrative examples. MATLAB codes for the examples are included.

The theory developed in the book can be very useful in applications. An epidemic model of dengue disease, in which fractional derivatives were used successfully, can serve as an example.

This well-written monograph presents nontrivial generalizations of the calculus of variations and optimal control that opens doors to new and interesting modern scientific problems. Summing up, the book is suitable for graduate students in mathematics, physics and engineering, as well as for researchers interested in fractional calculus.

Editorial remark: this book is a companion volume to [*A. B. Malinowska* and *D. F. M. Torres*, Introduction to the fractional calculus of variations. London: Imperial College Press (2012; Zbl 1258.49001)].

Reviewer: Wiesław Kotarski (Sosnowiec)

A Special Issue on 'Modern Fractional Dynamic Systems and Applications', in honor of Delfim F. M. Torres et al., has been organized in the Journal of Computational and Applied Mathematics (Elsevier), Volume 339, Pages 1-430, September 2018, Edited by Amar Debbouche, Carlos Lizama, and Xiao-Jun Yang.

Mathematical Modeling and Optimal Control

We developed, among others, mathematical models for HIV/AIDS, TB-HIV/AIDS co-infection, dengue, and cholera, with and without time delays, and investigated necessary and sufficient optimality conditions for their control, when applied to L1 and L2 cost functionals. The results were validated with case studies and real data.

We proposed optimal control strategies to minimize the cost of interventions when fighting against the diseases. They depend on the parameters of the model and reduce effectively the number of active infectious and/or latent individuals. We proved that the time that the optimal controls are at the upper bound increase with the transmission coefficient. Numerical results show the usefulness of the obtained optimization strategies. See, e.g.,

C. J. Silva and D. F. M. Torres,
Optimal control for a tuberculosis model with reinfection and post-exposure interventions,
Math. Biosci. 244 (2013), no. 2, 154–164.

H.S. Rodrigues, M.T.T. Monteiro and D.F.M. Torres, Vaccination models and optimal control strategies to dengue, Math. Biosci. 247 (2014), 1-12.

The research carried out by the SCG is substantiated by the collaboration with several external partners.

The attractiveness of the SCG for young researchers and PhD students is high, as witnessed by the number of visitors or collaborative supervision activities.

32 PhD high-quality theses were completed under the guidance of SCG members in the period 2013-2017, e.g., the PhD student Monika Dryl has received The Bernd Aulbach Prize for Students 2014, to honor the significant quality of her doctoral research.

SCG Funding 2013-2017

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13 K€ from International sources

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