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Research Statement

I am an interdisciplinary applied mathematician: I have worked with clinicians and measurement scientist. I received my Ph.D. in 2009 under the guidance of Prof Gert van der Heijden at the Centre for Nonlinear Dynamics at University College London. After my Ph.D. I took a post doctoral position at the department of Mechanical Engineering, also at UCL as part of the mathematical-biology research group. The research moved from Hamiltonian dynamical systems to collective behaviour of driven nonlinear oscillators.

This lead to an another post-doctoral position at the Institute of Cancer Research, where I designed a treatment planning platform for transcostal high-intensity focused ultrasound. This optimization of linear partial differential equations on large domains, with constrained on where the acoustic field should be focused, while minimizing damage to surrounding structures. I then obtained a position at the National Physical Laboratory, which is the ***. My role was to support standardisation efforts for. This meant ensuring that the measurement-based simulations.

In general, my primary mathematical focus is the development of analytical and computational methods and models for problems arising in biology, physiology, and engineering; in this context, I have worked on projects related to mathematical biology, surface catalysis, and molecular dynamics.

Whenever possible, I seek analytical or semi-analytical solutions of model problems that reveal fundamental scaling behavior of the system of interest.

I then use those results in the design of numerical algorithms and as a guide to explore more complex behavior in regimes where the idealized model assumptions breakdown.

Computational Topology

Let us cite all the books: [1].

[1] M. Baker, “The book,” Journal **1**, 1–10 (2010)

Ultrasound & Thermal Therapies

The Right Dose In The Right Place

The typical dose model [1]. A research program would focus on

- A foundational tool would be an open-source model for histotripsy [3]. This would be a time-domain finite-volume solver which would solve the with spatially and temporally-varying material properties, including significantly, phase-changes due to both boiling and acoustic cavitation. The nucleation of bubbles would be modelled via a threshold for the peak-negative pressure. The presence of bubbles would present a number of computational challenges, the main being that the bubble dynamics would need to be computed to determine the scatterer co-efficient. The bubble dynamics occur on a finer time scale than the wave equation. Furthermore, dense bubble clouds may require that the interaction between bubbles be taken into account. Preliminary numerical and analytical work has investigated this.
- A measure of dose would be due to the mechanical damage induced by both the acoustic wave and the bubble activity.
- The second measure of biological effect would be to model the expression of heat-shock proteins, via a systems biology approach.
- An approach to correlate bio-effects [2].

Quantitative Ultrasound

Typically image reconstruction and segmenting objects within the image are performed separately. However, in ultrasound, the most basic image formation approach neglects almost all variations in material properties, so produces images with significant artefacts.

Recently a *joint segmentation and reconstruction* approaches have been proposed. These will be ideally suited to ultrasound. An implementation of the Computed Ultrasound Tomography in Echo mode (CUTE) method coupled to the Chan-Vase equation. Such an approach would have immediate impact in ultrasound imaging, thermometry as well as dosimetry. There is some literature in this area, but all approached have used deep-learning methods. The drawback is that these methods typically required labelled segmentation data, and producing this can be a laborious process. Thus the methods are trained on synthetic data, and do not generalise well. The proposed approach would overcome this short-coming while still retaining the ability to include anatomical information via initial guesses for segmentation curves. To maximize impact, validation would have be performed with experimental colleagues.

[1] DM. Sinden, *Something else book* (Me, 2010)

[2] Pauline Coralie Guillemin, David Sinden, Yacine M'Rad, Michael Schwenke, Jennifer Le Guevelou, Johan Uiterwijk, Orane Orane Lorton, Max Scheffler, Pierre-Alexandre Poletti, Jürgen Jenne, Thomas Zilli, and Rares Salomir, "A novel concept of transperineal focused ultrasound transducer for prostate cancer local deep hyperthermia treatments," Cancers **15**, 163 (2022)

[3] Ki Joo Pahk, Pierre Gélat, David Sinden, Dipok Kumar Dhar, and Nader Saffari, "Numerical and experimental study of mechanisms involved in boiling histotripsy," Ultrasound Med. Biol. **43**, 2848–2861 (2017)