Doctoral Dissertation
Doctoral Program in Electrical, Electronics and Telecommunications Engineering
(37th cycle)

Treatment Planning and Real-time Temperature Monitoring in Microwave Cancer Hyperthermia

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Summary

Hyperthermia (HT) has emerged as a promising adjuvant cancer therapy, leveraging controlled heating of tumor tissues to 40-44°C to enhance the efficacy of radiotherapy and chemotherapy. Despite its clinical potential, widespread adoption of HT is hindered by challenges in precise energy delivery, patient-specific optimization and real-time treatment monitoring.

This thesis presents a comprehensive investigation into the treatment planning methods, experimental validation, and real-time temperature monitoring in microwave hyperthermia.

The first contribution concerns the development of reproducible tissue-mimicking phantoms and consequently the development of an experimental testbed to replicate head and neck (H&N) hyperthermia treatments. This was complemented by a digital twin implemented in COMSOL Multiphysics to enable validation and complement experimental measurements. Next, we introduced a joint SAR-based optimization strategy integrating array matching, aimed at improving antenna performance, ensuring efficient tumor targeting, and reducing reflection coefficients while maintaining electronic stability. The influence of blood flow on heat focusing was then analyzed, highlighting the importance of accounting for major vessels in treatment planning.

Building on these foundations, the third and main contribution is a novel real-time 3D temperature reconstruction method, which integrates sparse invasive thermometry with pre-computed libraries of patient-specific simulations. Validated in fully anthropomorphic phantoms (Duke and Ella from the Sim4Life virtual population), and the developed experimental setup, this approach enables minimally invasive, low-cost, and robust temperature monitoring method. Finally, a deterministic Alternating Projections Algorithm (APA) for SAR-based optimization was proposed as an alternative to metaheuristic methods, achieving comparable thermal performance with improved hotspot suppression and reduced power requirements.

Overall, this work provides methodological and computational advances to enhance the safety, accuracy, and clinical feasibility of microwave hyperthermia, contributing toward its broader adoption as an effective adjunct in cancer therapy.