Tommaso FERRI – XXXVIII Cycle

DESIGN AND VALIDATION OF A SPECT IMAGING DETECTOR TOWARDS REAL-TIME DOSE MONITORING IN BNCT
Supervisor: Prof. Carlo Ettore Fiorini

Abstract:

This doctoral thesis focuses on the design, implementation, and experimental validation of a gamma-ray detector for real-time single photon emission computed tomography (SPECT) imaging during boron neutron capture therapy (BNCT). The work introduces artificial neural networks (ANNs)-based reconstruction algorithms and their deployment on a field-programmable gate array (FPGA) for low-latency online processing, a first SPECT setup, and a comprehensive experimental validation campaign. BNCT is a highly selective form of hadron therapy that exploits the nuclear reaction between thermal neutrons and 10B, which accumulates in tumour cells through suitable carrier compounds. This reaction yields two particles with high linear energy transfer (LET) that deposit their energy over short distances, thereby confining the biological effect to the targeted tumour volume. Due to this intrinsic selectivity, BNCT is ideal for treating infiltrative or diffuse malignancies and lesions in close proximity to critical organs. Despite its potential, the widespread clinical implementation of BNCT has historically been challenged by several factors. These include the limited availability of neutron sources capable of providing clinically relevant flux, the necessity of highly selective and non-toxic boronated agents, and the absence of reliable systems for real-time dose monitoring. However, recent progress in compact accelerator-based neutron generators has renewed interest in BNCT. A growing number of clinical and preclinical facilities are either in operation or under development worldwide. In this context, there is an urgent need for advanced BNCT-related technologies. In-beam dosimetric imaging systems, such as the one investigated in this study, play a pivotal role in this regard. The main objective of this thesis is to quantify and localise the dose delivered to patients undergoing this therapy. To achieve this, we developed a prototype of a single-module BNCT-SPECT system by integrating the BeNEdiCTE detector, developed within a parallel PhD project, with a dedicated imaging chain comprising a collimator and a reconstruction algorithm based on ANNs. Moreover, this study investigates the feasibility of implementing the ANN-based algorithm on the system's FPGA for real-time information processing. Throughout this work, three successive versions of the reconstruction algorithm are introduced. Initially, the algorithm relies solely on the reconstructed x and y coordinates of interaction. Subsequently, the algorithm is extended to incorporate depth of interaction (DOI) information. A comprehensive experimental campaign was carried out at two neutron facilities: the TRIGA Mark II research reactor at the University of Pavia in Italy and the NUANS accelerator at Nagoya University in Japan. At the former facility, the proposed system enabled the first tomographic reconstruction of two boron-containing vials placed 1 cm apart under neutron irradiation. At the latter facility, vial activity profiles at different boron concentrations were successfully reconstructed under clinically representative neutron field conditions. Taken together, these results provide strong evidence that the

BNCT-SPECT system proposed and developed in this thesis has substantial potential for clinical application in the future.

PhD Committee

Prof. Giacomo Borghi, **Politecnico di Milano**

Prof. Brian Forbes Hutton, **University College London**

Prof. María Magdalena Rafecas López, **Universität zu Lübeck**