Abstract

Neurodegenerative diseases such as Alzheimer’s disease and Parkinson’s disease represent a major and growing global health challenge. Both conditions are progressive and currently incurable, with symptoms that evolve over a long prodromal phase. Despite their different clinical manifestations, they share a common need for early detection: identifying pathological changes at an initial stage can significantly improve patients’ quality of life, enable timely therapeutic interventions, support caregivers, and reduce the socio-economic burden on healthcare systems. However, existing diagnostic techniques are often invasive, expensive, or unsuitable for large-scale screening, limiting their applicability in early-stage. In this context, microwave-based techniques have recently attracted attention as non-invasive, low-cost, and portable alternatives for neurological assessment. Operating through the interaction between electromagnetic waves and biological tissues, these methods are sensitive to variations in dielectric properties associated with physiological and pathological changes. Such characteristics make microwave technologies particularly appealing for population-level screening. The first part of this thesis focuses on Alzheimer’s disease (AD) and investigates the feasibility of microwave sensing for its early detection and staging. The proposed approach is motivated by emerging evidence that abnormal concentrations of protein biomarkers in the early phases of AD induce measurable changes in the electromagnetic properties of cerebrospinal fluid (CSF). A conformal six-element antenna array, positioned on the upper portion of the head and operating in the 500 MHz to 6.5 GHz frequency range, was designed to measure variations in the scattering parameters resulting from intracranial CSF permittivity changes. Diagnostic information was extracted using a multi-layer perceptron neural network. The classification strategy consisted of a two-step process, comprising a binary classification to determine disease presence and a multi-class classification to assess disease severity. The system was trained and validated through controlled experiments conducted on an anthropomorphic, multi-tissue head phantom, specifically designed for this application. The results demonstrate that reliable classification can be achieved using amplitude-only data, supporting the feasibility of the proposed method. The second part of the thesis addresses Parkinson’s disease, that is characterized by neurodegenerative processes affecting the substantia nigra, a deep brain structure, which in its early stages may lead to dielectric asymmetries between the two brain hemispheres. In this work, the potential of differential microwave imaging to detect small permittivity contrasts associated with the illness was investigated through a controlled phantom study. A simplified two-dimensional head phantom was developed using a 3D-printed cylindrical container filled with water, incorporating a Teflon tube to represent the substantia nigra. The tube was filled with hot water, whose gradual cooling was used to emulate controlled dielectric variations. A four-antenna differential imaging system was employed, with image reconstruction performed using the multi-frequency bi-focusing algorithm. The results demonstrate the ability of the system to detect dielectric contrasts corresponding to temperature variations as small as 0.4 °C, equivalent to approximately 0.17 % in relative permittivity. Although the exact dielectric alterations associated with Parkinson’s disease are not yet fully characterized, these findings confirm the high sensitivity of the proposed approach and support the potential of differential microwave imaging as a promising tool for future investigations into Parkinson’s disease detection. Overall, this thesis demonstrates the feasibility and sensitivity of microwave-based sensing and imaging techniques for the early investigation of neurodegenerative diseases, highlighting their potential role as complementary, non-invasive tools for large-scale screening and preliminary diagnosis of Alzheimer’s and Parkinson’s disease.