Quantum Biosensing of Neurotransmitters for Real-Time Neural Activity Mapping

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***Abstract*—Recent advances in quantum technologies have opened transformative pathways for neural sensing, enabling unprecedented sensitivity in the detection of biochemical processes underlying brain function. This paper explores quantum biosensing approaches for real-time mapping of neurotransmitter dynamics, focusing on how quantum-enabled sensors can overcome the spatial, temporal, and chemical specificity limitations of conventional neuroimaging and electrochemical techniques. By leveraging quantum phenomena such as spin coherence, superposition, and quantum entanglement, emerging biosensors demonstrate the capacity to detect minute magnetic and electric field variations associated with neurotransmitter release at the synaptic scale. The integration of these sensors with biocompatible platforms enables minimally invasive, high-resolution monitoring of neural activity, offering new insights into fast neurochemical signaling and network-level brain dynamics. This work reviews the principles of quantum biosensing applied to neurotransmitter detection, examines current experimental implementations, and discusses their implications for neuroscience research, neurological disease diagnostics, and brain–machine interfaces. The paper argues that quantum biosensing represents a paradigm shift toward chemically precise, real-time neural activity mapping, with significant potential to reshape both fundamental neuroscience and translational neurotechnology.**

Deciphering the mechanisms underlying neural activity remains one of the most complex challenges in contemporary science. While significant progress has been made in mapping electrical signaling within the brain, neural function cannot be fully understood without accounting for the neurochemical processes that modulate synaptic transmission and network dynamics [10]. Neurotransmitters, including glutamate, γ-aminobutyric acid (GABA), dopamine, serotonin, and acetylcholine, act as the primary chemical mediators of neuronal communication, shaping perception, cognition, emotion, and behavior [8]. Their release, diffusion, and reuptake occur on millisecond timescales and at nanometer spatial resolutions, rendering their real-time observation exceptionally difficult with existing technologies.

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Traditional neuroimaging and neurochemical sensing methods have each contributed valuable insights yet remain constrained by inherent trade-offs. Functional magnetic resonance imaging (fMRI) provides whole-brain coverage but measures indirect metabolic correlates of neural activity with limited temporal resolution [3]. Electroencephalography (EEG) and magnetoencephalography (MEG) capture

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