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BRIDGING MIND AND MACHINE IN SPACE: QUANTUM NEUROTECH FOR HUMAN-ROBOT COLLABORATION

Abstract

As human spaceflight advances toward deep-space exploration, the integration of brain-machine interfaces (BMI) with robotic systems presents new opportunities for enhancing astronaut efficiency, safety, and adaptability. Optically Pumped Magnetometer-based Magnetoencephalography (OPM-MEG), a quantum neurotechnology, offers a real-time, non-invasive approach to monitoring brain activity and interfacing with intelligent systems in space environments.

This paper explores the potential of OPM-MEG as a novel brain-machine interface (BMI) for human-robotic partnerships in space exploration. Unlike traditional MEG systems that rely on superconducting quantum interference devices (SQUIDs), which require cryogenic cooling and immobile setups, OPM-MEG is lightweight, wearable, and motion-tolerant, making it ideally suited for spaceflight applications. By continuously tracking cognitive states, attention levels, and neural workload, OPM-MEG can optimize astronaut-robot interactions, improving mission-critical decision-making and reducing cognitive fatigue.

Key applications include: 1. Brain-Controlled Robotic Assistants – OPM-MEG could enable hands-free operation of robotic arms, rovers, or habitat construction bots, providing an intuitive interface for astronauts in microgravity. 2. Cognitive Load and Stress Monitoring – Real-time neural data could help adaptive AI systems dynamically adjust robotic workflows based on astronaut cognitive strain. 3. Enhancing Human-AI-Robot Symbiosis – By continuously analyzing brain signals, OPM-MEG can facilitate personalized interactions with robotic assistants, ensuring seamless human-machine collaboration in complex mission environments.

The adaptation of quantum neurotechnology to spaceflight will require optimizing sensor stability, mitigating electromagnetic interference, and developing AI-driven neuroadaptive systems for robotic control. However, the potential for OPM-MEG to enhance astronaut performance, safety, and autonomy in deep-space missions makes it a promising frontier for future human-robot partnerships.

This paper presents technique insights, design considerations, and future research directions for implementing brain-driven robotic control in space, contributing to the evolution of intelligent astronaut-assistive systems.