

TITLE: Adaptive AI-Driven Control and Context-Aware Interaction for an Assistive Robotic Arm Supporting Activities of Daily Living

ABSTRACT

People with upper-limb impairments often rely on caregivers for Activities of Daily Living (ADLs). Wheelchair-mounted robotic arms (WMRAs) can reduce this dependence, yet adoption is limited by single-mode control interfaces, lack of context-aware interaction, and insufficient mechanisms for data logging and safety governance. We present an integrated framework that addresses these gaps across three layers: (i) a cost-conscious 6-DOF assistive arm (mR2A) with safety-aware real-time control; (ii) adaptive multimodal interfaces (finger joystick, chin joystick, eye-gaze, and an AssistKey keypad); and (iii) a context-aware speech pipeline capable of interpreting multi-step instructions with clarification dialogues. The control stack is realized via Beckhoff TwinCAT 3 over EtherCAT with Cyclic Synchronous Position updates at 1 kHz for coordinated multi-joint motion and software-enforced safety bounds. A dedicated Data Management Portal (Django MVT) provides role-based access, remote monitoring, and longitudinal analytics.

The thesis aggregates and extends results from couple of manuscripts and ancillary materials. First, a study with ten able-bodied participants compared four control modalities on representative ADLs; all tasks were completed successfully, with clear trade-offs in speed, precision, and ergonomics across modalities. Second, we detail the EtherCAT-based framework, the unification of input channels, and the speech interface that maps free-form utterances into safe robot action plans. Together, these contributions demonstrate that an economical WMRA can deliver industrial-grade real-time performance alongside accessible, user-tailored interactions. We also describe a governance layer for data and safety that supports clinical translation.

Beyond reporting component performance, we synthesize cross-modal findings, outline safety and ethical considerations for context-aware control, and propose a path to clinical evaluation using the ADL task bank developed with clinicians. We argue that adaptivity across control, interaction, and data—rather than any single modality—best supports heterogeneous user abilities and evolving needs. The framework and accompanying materials aim to serve as a reproducible foundation for researchers and clinicians working toward practical, scalable assistive manipulation in daily life.