

Capacitive Grid Sensing on Everyday Objects: A Scalable Interface for Clinical Motor and Cognitive Monitoring

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Abstract— Capacitive sensor arrays, embedded in everyday objects, offer a novel method for capturing fine-grained hand-object interactions in naturalistic settings. This study introduces a modular sensing pipeline that uses flexible capacitive grids to monitor grip and touch behavior, with the aim of extracting clinically relevant motor and cognitive features—especially for individuals with neurological conditions such as Multiple Sclerosis. We outline key signal features including grip stability, contact area, micro-adjustments, and inferred force proxies, and propose their mapping to clinical outcomes such as fatigue, tremor, lesion lateralization, and cognitive load. Prototype implementations on household objects confirm the feasibility of this approach, with promising implications for long-term, real-world monitoring [1], [2], [3].

I. INTRODUCTION

TRADITIONAL assessment of motor and cognitive impairments in neurorehabilitation relies heavily on lab-based instrumentation or subjective scales. Capacitive sensing offers a low-cost, scalable alternative for capturing real-world interaction data [4]. By embedding capacitive grids in everyday objects, we aim to bridge the gap between structured assessments and natural behavior, enabling continuous monitoring of subtle functional changes.

The goal is to create a closed-loop computational model that dynamically learns, predicts, and adapts grip and grasp behavior using real-time or longitudinal input from capacitive sensor grids embedded in everyday objects [5].

II. MATERIAL AND METHODS

A. Conceptual Overview

We developed a modular sensing pipeline comprising flexible capacitive grids, microcontroller-based acquisition, and a digital interface for signal processing and annotation [2], [6]. Objects such as bottles, table surfaces, and remotes were equipped with thin-film capacitive arrays. Signals were recorded during both scripted and naturalistic tasks. An application that has been largely neglected is the use of the precise spatiotemporal output of capacitive sensing in patients

with sensorimotor impairments (e.g., MS), where even minor grip fluctuations can be clinically significant [7]

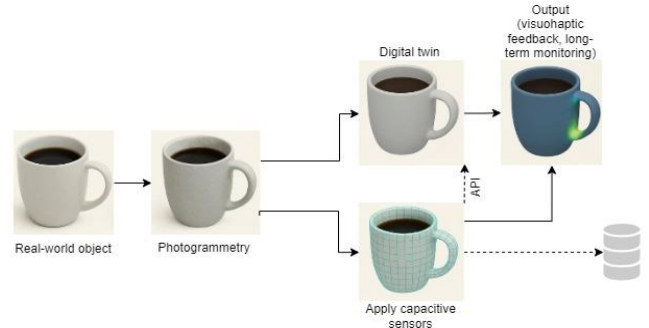


Fig. 1. Schematic depiction of the proposed data pipeline: A real-world object is digitized through photogrammetry. Onto the real-world object’s surface, a capacitive sensor mesh is applied that informs the digital twin of the object via API. The recorded interaction may then be mapped on the digital twin as feedback or be stored for long-term monitoring.

B. Mapping grip parameters to their neurophysiological basis

To associate sensor outputs with clinical outcomes, we identified a set of signal features extracted from capacitive grid data—each reflecting specific aspects of motor control. Grip stability, calculated as the standard deviation of contact area and force proxy over time, is crucial for identifying motor instabilities such as tremor, dystonia, or general coordination loss, all of which are common in conditions like Multiple Sclerosis (MS) and Parkinson’s disease [7]. Fluctuations in these measures over task duration can indicate the onset of fatigue or neuromuscular compensation. Similarly, the micro-adjustment rate—quantifying short-duration regripping events—can reflect discomfort, dyskinesias, or motor system overcorrections, especially when repetitive or context-inappropriate movements are observed [4].

Reaction latency, defined as the time interval between a visual or auditory cue and initial capacitive activation, serves as a sensitive marker for cognitive-motor slowing. This latency is particularly informative in neurodegenerative conditions where attention, planning, and motor initiation are impaired, such as in MS or early Alzheimer’s [3]. When paired with force proxy measurements, which use capacitance amplitude as an indirect marker for grip strength, a more comprehensive profile of motor output can be constructed. For example, a correct grip configuration with low amplitude may indicate motor weakness rather than poor coordination [5].

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Contact area variability adds an orthogonal dimension by highlighting inconsistencies in surface engagement, which can be linked to sensorimotor planning errors or loss of tactile feedback. This is especially relevant in demyelinating disorders or post-stroke populations. Grip type deviation, determined by comparing observed grip configurations to normative patterns using classification models, reveals adaptive or pathological strategies employed by the user. Deviations may result from spasticity, compensation, or motor neglect.

Another informative metric is bilateral asymmetry, which assesses differences between dominant and non-dominant hand interactions. This is particularly useful in identifying lateralized lesions—such as hemispheric or spinal cord lesions—that impair one side more than the other [5]. Lastly, pausing or hesitation time, derived from dwell-time anomalies or irregular inter-contact intervals, serves as a proxy for executive dysfunction or elevated working memory load. When contextualized over task stages, such as during initial engagement versus task switching, these features can highlight momentary cognitive lapses or sustained attentional deficits [6].

These parameters not only enrich the interpretability of raw capacitive data but also support the integration of sensor outputs with clinical scales. By aligning them with established neurophysiological markers, we establish a mapping framework that supports both diagnosis and longitudinal monitoring across neurological conditions.

TABLE I: APPROXIMATE MAPPING BETWEEN SIGNAL FEATURES AND INDICATION-SENSITIVE PARAMETERS

a)

Model Parameter	Description	Neurophysiological Basis / Evidence
Grip Stability Index	Std. deviation in contact area and force proxy across time	Instability reflects tremor, dystonia, or coordination loss
Micro-Adjustment Rate	Frequency of short-duration shifts in contact pattern	Linked to fatigue, discomfort, or dyskinetic corrections
Reaction Latency	Time between cue onset and initial grid contact	Sensitive to cognitive-motor slowing in MS and related conditions
Force Proxy (Amplitude)	Relative capacitance value as indirect pressure marker	MS-related weakness may manifest in reduced amplitude, despite correct grip posture
Contact Area Variability	Variation in activated surface across trials or within tasks	Reflects sensorimotor inconsistency and motor planning errors
Grip Type Deviation	Divergence from normative grip configurations (classification error)	Atypical patterns indicate compensation or motor impairment
Bilateral Asymmetry	Difference in interaction metrics between	Lateralized lesions (e.g., spinal cord or hemispheric MS lesions) produce

Model Parameter	Description	Neurophysiological Basis / Evidence
	dominant/non-dominant hand	asymmetrical use
Pausing/Hesitation Time	Inter-contact intervals and dwell-time anomalies	Associated with working memory load, task uncertainty, or executive dysfunction

III. DISCUSSION

Unlike traditional assessments, capacitive grid sensing allows real-time mapping of grip and touch metrics onto interpretable clinical features [4], [6]. Its integration into everyday objects facilitates naturalistic monitoring without impeding daily routines. The approach is well-suited for in-home or community-based rehabilitation, especially when paired with visual feedback or telemedicine solutions.

IV. CONCLUSION

This work lays the groundwork for low-burden, real-world neurobehavioral tracking via ubiquitous, embedded capacitive systems. Ongoing efforts focus on extending deployment to additional populations and refining feature-extraction models for broader clinical use [3], [5].

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