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Noise-robust estimation in dc motors

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Abstract

DC motors remain widely used in robotics and mechatronic systems due to their simplicity, low cost, and straightforward control implementation. In practical robotic applications, however, estimation and control performance are frequently limited by noisy measurements and operating uncertainties. Typical sensing setups rely on low-cost encoders or Hall sensors for speed
estimation and current measurements affected by quantization, electromagnetic interference, and sampling constraints. In parallel, the mechanical load torque varies with payload changes, friction drift, and external interactions. These factors lead to degraded tracking accuracy, amplified noise in derivative signals, and reduced stability margins when conventional fixed-gain observers and controllers are used.

The objective of this work is to formulate and justify a noise-robust estimation framework for DC motor drives that supports reliable operation under measurement noise and time-varying load torque. The central problem addressed is the online reconstruction of velocity and disturbance/load torque in conditions where direct differentiation of measured signals is unreliable and where plant parameters cannot be assumed constant. The report focuses on estimation approaches that remain implementable in real time on embedded hardware and that can be integrated into standard cascaded motor control structures.

Keywords
DC Motor Drives, Noise-Robust Estimation, Disturbance / Load Torque Estimation, Model-Based Observers.

Шумоустойчивое оценивание в двигателях постоянного тока

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Аннотация
Двигатели постоянного тока по-прежнему широко применяются в робототехнических и мехатронных системах благодаря своей простоте, невысокой стоимости и относительно несложной реализации управления. Однако в реальных робототехнических приложениях качество оценивания и управления часто ограничивается шумными измерениями и эксплуатационными неопределённостями. Типовые системы измерения основаны на недорогих энкодерах или датчиках Холла для оценки скорости, а также на измерении токов, подверженных квантованию, электромагнитным помехам и ограничениям дискретизации. Параллельно механический момент нагрузки изменяется в зависимости от массы полезной нагрузки, изменения трения и внешних взаимодействий. Эти факторы приводят к снижению точности слежения, усилению шума в производных сигналах и

уменьшению запасов устойчивости при использовании традиционных наблюдателей и регуляторов с фиксированными коэффициентами.
Целью данной работы является формулирование и обоснование шумоустойчивой структуры оценивания для приводов на основе двигателей постоянного тока, обеспечивающей надёжную работу в условиях измерительного шума и переменного момента нагрузки. Основная рассматриваемая задача заключается в онлайн-восстановлении скорости и возмущающего/нагрузочного момента в условиях, когда прямое дифференцирование измеряемых сигналов является ненадёжным, а параметры объекта не могут считаться постоянными. В отчёте акцент сделан на методах оценивания, пригодных для реализации в реальном времени на встраиваемых вычислительных платформах и интегрируемых в стандартные каскадные структуры управления электроприводом.

Ключевые слова
Приводы на основе двигателей постоянного тока, шумоустойчивое оценивание, оценка возмущающего/нагрузочного момента, модельные наблюдатели.

Main part

The proposed approach is structured as a sequence of stages aimed at improving estimation quality while preserving real-time implementability on embedded hardware. First, a measurement conditioning pipeline is introduced to improve signal quality without excessive delay. This stage includes outlier suppression and low-latency smoothing suitable for encoder-derived speed signals and current measurements, with parameters selected to preserve transient dynamics during acceleration while reducing jitter during quasi-static motion.
Second, load torque is treated as an unknown disturbance and is estimated online using model-based observer structures. Candidate estimator families considered in the report include disturbance-observer formulations and adaptive observer/identification schemes, which differ in tuning burden and sensitivity to model mismatch. Particular attention is paid to the practical bandwidth–noise trade-off that appears when disturbance reconstruction relies on filtered velocity estimates; this trade-off implies that estimator design cannot be separated from measurement preprocessing.
Third, the estimated disturbance is incorporated into the control loop through compensation, enabling improved robustness to payload variation and friction changes while maintaining tracking performance. The report proposes an optimal solution strategy based on co-design: measurement conditioning and disturbance estimation are tuned jointly to achieve stable, low-latency performance across operating regimes. The research methods discussed emphasize economical and modern approaches that are feasible for real-time implementation, including systematic comparison against baseline estimators and structured validation under representative disturbance scenarios.
To evaluate the effectiveness of the framework, the report defines validation scenarios representative of robotic actuation tasks, including low-speed motion, step changes in load, and variable friction conditions. Performance is assessed using tracking error metrics, steady-state error, transient overshoot, and noise amplification indicators, as well as qualitative robustness criteria under sensor degradation. The evaluation plan also includes comparative analysis against baseline methods such as fixed-gain observer with conventional filtering and alternative estimator families, to demonstrate the conditions under which noise-robust estimation provides measurable improvement.

Conclusions, practical use, and implementation proposals

The expected contribution of this work is a coherent estimation-centric view of DC motor actuation under realistic sensing constraints. By explicitly co-designing measurement conditioning with disturbance/load torque estimation, the report aims to reduce dependence on ad-hoc differentiation and to provide practical guidelines for selecting estimator bandwidth and filtering parameters. The results are intended for practical use in robotic drives operating under payload changes and external disturbances, where improved actuator-side robustness can translate into higher-level trajectory tracking stability.

For implementation and testing, the report proposes experimental verification under controlled conditions with repeatable disturbance profiles and sensor noise levels, followed by validation on a robotic platform where the actuator experiences realistic load variations. The testing procedure includes ablation studies (compensation on/off, different preprocessing settings) and comparison with baseline estimators to support objective conclusions about robustness, latency, and tracking performance.

References

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