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Modelling and Control of Electrode Deformation in Battery Manufacturing Stacking Processes

The growing reliance on lithium-ion batteries across electric mobility, grid-scale energy storage, and portable electronics has intensified the need for high-quality manufacturing. The electrode stacking process, in which flexible anode, separator, and cathode foils are sequentially layered, is a critical yet vulnerable step in battery production. Owing to their thinness and flexibility, these foils deform under mechanical loads, adhesive interactions, gripping actions, and self-weight, producing misalignment, wrinkling, and stretching that compromise battery durability, safety, and efficiency. This project addresses this gap by developing an integrated modelling and control framework for electrode deformation during stacking.

The central research question is how electrode deformation can be accurately modelled and actively controlled using a discretized thin-plate deformation framework combined with online feedback and model-based control. To this end, a dynamic deflection model is formulated on the basis of thin-plate equations and discretized in space, with temporal integration performed using the Crank–Nicolson method for numerical stability. The model captures the mechanical response of electrodes under physical influences including gravity, gripping force, and adhesion, enabling realistic prediction of deformation throughout the stacking sequence.

Building on this model, several closed-loop control methods are formulated to mitigate electrode deflection. The implemented strategies include PID control, linear state feedback (including the linear quadratic regulator, LQR), and iterative learning control (ILC), which improves performance by learning from control errors observed in previous stacking cycles. These approaches are systematically evaluated for their capacity to counteract dynamic deformation, reject external disturbances, and ensure repeatable performance across stacking cycles.

For validation, the Python-based simulation outputs are compared against finite element analysis in ANSYS, confirming both the accuracy of the reduced-order model and the effectiveness of the proposed controllers. The results demonstrate that the developed reduced-order model can accurately predict electrode deformation and that the proposed control methods can effectively reduce deflection and improve repeatability during stacking. These findings provide a basis for future experimental validation on a real physical electrode-stacking system under actual manufacturing conditions. Further studies could examine how variations in electrode material, thickness, and gripping conditions affect the controller performance. And how automatic controllers tuning can be preformed in such cases.