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Tracking Control of Non-differentiable Sandwiched Dynamic Systems: Case Study on Gear Transmission Servo Systems

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***Abstract*—In the practical systems, many systems can be described as non-differentiable sandwiched dynamic systems, which implies a non-differentiable nonlinearity is sandwiched between two cascaded subsystems. Such a system imposes great challenging on the controller designs, because it is not possible to directly handle the non-differentiable unknown nonlinearity, and new approaches must be developed. As a case study, this paper will focus on the tracking control of gear transmission servo systems where a dead zone is sandwiched. It is well known that the dead-zone in gear transmission servo systems adversely affects system performance. The systems, characterized by unknown parameters including dead-zone parameters, become non-differentiable sandwiched fourth-order non-lower-triangular dynamic systems. Furthermore, such systems are frequently subject to uncertainties and external disturbances, potentially hindering convergence and leading to state divergence, thereby exacerbating the complexity of controller designs. A so-called block control framework is proposed by combining disturbance feedforward compensation control technique with extended state observer and dynamic surface control technique based on the results of the system identification. It is rigorously proved that the tracking error will converge to a bounded neighborhood of the origin, additionally, the ultimate bound can be made arbitrarily small by adjusting parameters. Finally, experiment results validate the efficacy of the proposed strategy.**

***Index Terms*—Dead-zone nonlinearity, system identification, non-differentiable nonlinearity, tracking control, disturbance rejection, gear transmission servo systems.**

I. Controller Design and Experiment Results

BASED on the analysis of existing literature, designing controllers for non-differentiable sandwiched dead-zone dynamic systems to achieve satisfactory tracking performance and anti-disturbance capabilities have yet to be explored. Motivated by this, a case study in this paper, an effective solution for the tracking control of gear transmission servo systems with unknown parameters is provided. Fig. 1 depicts the simplified schematic diagram of the actual gear transmission servo system, which is the sandwiched system structure block diagram with non-differentiable dead-zone between two dynamic subsystems. The main contribution of this paper lies in directly handling non-differential components during controller design, aimed at compensating for sandwiched non-smooth dead-zone nonlinearity and obtaining satisfactory tracking accuracy and anti-disturbance capabilities. First, a more accurate system model is achieved by identifying unknown system parameters, including dead-zone nonlinearity, enabling the construction of non-differentiable components. Based on the obtained model, by combining disturbance feedforward compensation control technique with extended state observer and dynamic surface control technique, a block control framework is proposed. The proposed strategy not only handles the dead-zone nonlinearity, but also guarantees the control accuracy of the system with disturbances. Finally, the experimental results demonstrate the proposed strategy's effectiveness in achieving satisfactory tracking accuracy and anti-disturbance performance by employing the gear transmission servo platform. The partial experimental results are illustrated in Fig. 2, showing the tracking error is maintained within a narrow range.

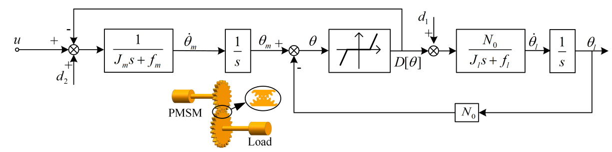

Fig. 1: Sandwiched system structure block diagram with non-differentiable nonlinearity between two dynamic subsystems.

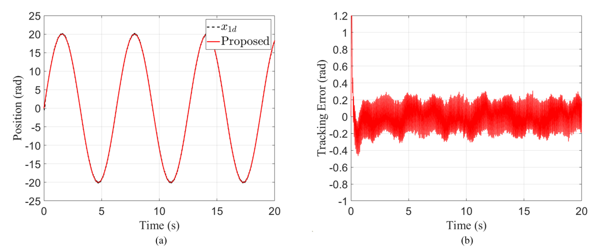

Fig. 2: Output position θ_l (rad) and tracking error when the desired position is $x_{1d}(t) = 20\sin(t)$ (rad).

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