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ADAPTIVE ROBUST PREDICTIVE CONTROL FOR HYPERSONIC VEHICLES USING RECURRENT FUNCTIONAL LINK ARTIFICIAL NEURAL NETWORK

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Abstract. *A novel adaptive predictive control methodology is presented for air-breathing hypersonic vehicles (AHVs) subjected to unknown dynamical disturbances and uncertainties. The control architecture is comprised of a continuous-time nonlinear generalized predictive controller, a recurrent functional link artificial neural network (RFLANN) control adjustment, and an adaptive robust control item. The RFLANN proposed by this paper, is a simple recurrent NN without hidden layers. Due to its strong ability of learning dynamic information and small computing cost, the RFLANN is utilized to approximate external disturbances and parameter uncertainties during hypersonic flight. The weights of the RFLANN are first online tuned by a derived adaptive law based on Lyapunov stability theorem and the offline training is not necessary. By the stability analysis of the closed-loop control system, it is proven that all errors are uniformly ultimately bounded. Finally, simulation results show better performance of the controller for the AHV attitudes tracking than the methods compared, moreover, the robustness to disturbances and uncertainties are successfully accomplished.*

Keywords: Adaptive control, Predictive control, Recurrent functional link artificial neural network, Hypersonic vehicle

1. **Introduction.** Air-breathing hypersonic vehicles (AHVs) offer the great potential for feasible access to space and high speed civil transportation. Their control law design is very challenging because of the plant inherent nonlinearity, parameter uncertainties and the sensitivity to external disturbances. Moreover, the wide range of flight speed, the rapid change of mass distribution, and the lack of a broad flight dynamic database remarkably add dynamical uncertainties to the control problems of AHVs. Some researchers proposed different control methods to improve AHVs' control performance under parameter uncertainties. In [1], Xu designed an adaptive sliding controller with robustness. Fiorentini [2] adopted a robust nonlinear sequential loop closure approach. Lee [3] presented a dynamic inversion control law with μ analysis to improve the robustness. These traditional control methods assume that the uncertainty bounds are known, and thus they are not appropriate to resolve control problems arising out of large dynamical uncertainties in flight.

Recently, the approximation-based technique using feedforward neural networks (FNNs) has attracted increasing attention. This method does not need the assumption about known uncertainty bounds, so it is suitable for handling uncertainties in fight [4,5]. However, FNNs belong to a static mapping method. They may be a good analytic tool to the relation existing in long term. For the approximation of dynamical and fast time-varying functions, recurrent neural networks (RNNs) have stronger capability than FNNs [6,7].