学 位 論 文 の 要 旨

論文題目：Research on Application of Artificial Neural Networks and Network Pruning Strategies to Temperature Control Systems
（温度制御システムにおける人工ニューラルネットワークの応用とネットワークプルーニング手法に関する研究）

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Thermal process is usually viewed as a nonlinear, large lag and large inertia system. In general, it takes lots of time, patience and expense to achieve accurate and stable control of the thermal systems. Furthermore, for a multi-input multi-output, there exists strong mutual interference between different heating channels, the generated temperature differences will seriously affect the temperature control effect and the quality of the workpiece. As Industry 4.0 becomes the standard for various processing machines, equipment manufacturers are in urgent of updating their temperature controller for more smart features, making the production processes more efficient. In the past few years, the digital intelligent controller has been widely used in various applications, along with the developed microcomputer processing and a variety of advanced algorithm arises for overcoming the control problems in complicated systems.

The optimized temperature control algorithm is required for effective temperature adjustment to overcome nonlinearity, strong coupling, disturbances, etc. With the development of artificial intelligence technology in the industry, which has the ability to process amounts of data and complex patterns in them, the temperature control during industrial processes can also be moved from traditional control methods based on precise mathematical models or complex optimization algorithms to simpler real-time artificial intelligence-based control, to satisfy more stable and precise control performance, and then to realize higher quality and lower energy costs.

This research is aimed at improving the performance of temperature control in multi-input multi-output systems and effectively compress the pre-trained NN-based temperature model without the obvious control accuracy loss. The following solutions are mainly proposed:

(1) A multi-input multi-output temperature control system not only has the characteristics of nonlinear and large lag, but also has strong coupling and other uncertain factors. Commonly, multiple heaters are used to control the temperature of the controlled object. However, the output of each heater (heating channel) will affect the output of other channels. The temperature difference between different heating channels of the controlled object will negatively affect the

quality of the products in industrial process. The design of the optimization control to such mutually interfering channel temperature of the controlled object is difficult and complicated. To address this problem, a multi-layer neural network control system is proposed for the multi-input multi-output system, which is driven by a reference model. It eliminates the temperature difference between each pair of heating channels for achieving the uniform temperature of different heating channels, while improving the transient and steady-state control performances of coupling channels. The designed NN-based control system can receive real-time data and do self-tuning to give optimal control input to each channel without the need of precise system modeling and additional decoupling links.

(2) Deep network models are usually over-parameterized to provide stronger characterization and optimization capabilities. Even a network model that is not so big also needs a large amount of memory and hardware to perform computation, which results in slow inference speed and limits the deployment of models to embedded devices with small storage capacity and low computational power. Considering our pre-trained NN control models, the network pruning technique is one of the effective model compression methods, which removes some unimportant parameters without affecting the initial model accuracy obviously. Therefore, inspired by the reconstruction error-based pruning method used in CNN models, which is based on minimizing the linear reconstruction error to optimize the network, a layer-wise iterative pruning method is adopted to prune our FNN-based and RNN-based temperature control model, by minimizing the nonlinear reconstruction error between the outputs of the pruned model and unpruned models. This method can effectively eliminate a large number of redundant parameters of the well-trained FNN and RNN temperature control models without a significant loss of accuracy.