Development and Construction of a Parameterizable Condition Classification System for Electromagnetic Proportional Valves using Neuronal Networks

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Abstract

In this paper the development of a compact condition classification system for electromagnetic proportional valves is shown. It allows the generation of training data as well as a fast testing and comparison of different trained neuronal networks. By using quantization and pruning, a neuronal network with drastically reduced complexity has been created, so a FPGA implementation was possible. The developed and implemented network shows a very high classification rate and can distinguish 12 different false reasons of the valves. The system requires the measurement of the supply current only, which allows a simple integration of such a false detection circuitry into existing systems. In the future, the system can be modified easily, e.g. to use and test a hardware based AI accelerator instead of the FPGA implementation.

1 Introduction

Current developments in the field of artificial intelligence (AI) are visible everywhere and promise simplifications as well as efficiency improvements in almost all technical and non-technical areas. Two challenges resulting from this progress are the identification of strategic use cases for the application of this powerful technology and the development of practical interfaces to existing technical systems. In the ideal case, these interfaces with AI can be simply plugged into systems without requiring any changes. This allows to extend existing machines by AI based condition monitoring without bigger modifications.

Different neural network structures can used for realization. All of these require a large amount of data for training and verification, where the two data sets are generated by splitting the original measurement data set into two parts. After successful verification, the neuronal network is tested in the real environment. Ideally, several of these steps can be combined in one system that can be used for several steps: generation of the training data and testing the trained neural network in the real world. In the following, we describe such a system, which is quite small and includes all required components to emulate different usage conditions of the device under test (DUT).

2 System Description

2.1 Use Case

The condition monitoring of electromagnetic proportional valves was chosen as a model application. In order to introduce the functionality of real-time condition monitoring without modifying the design of the system and its components, only the supply current of the proportional valves

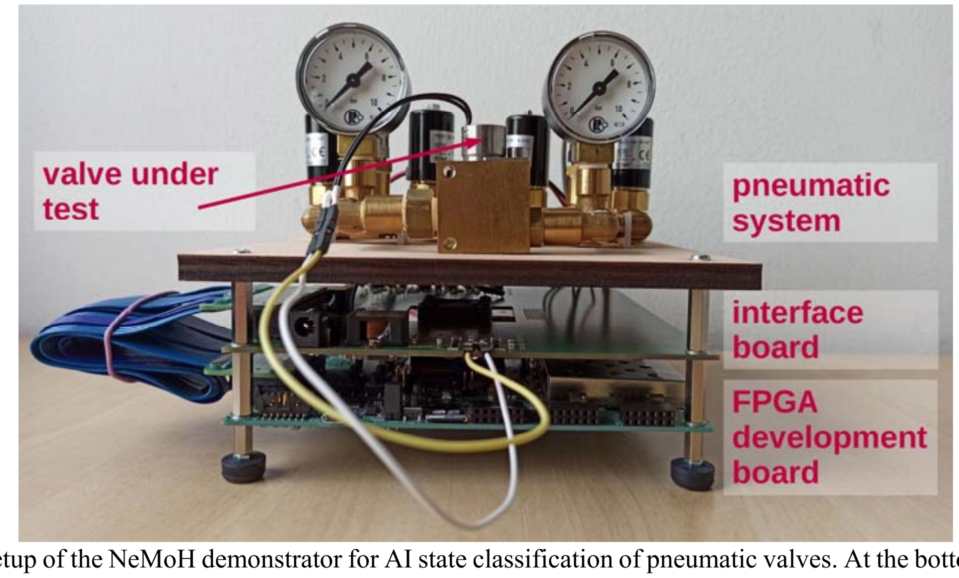

Figure 1: Setup of the NeMoH demonstrator for AI state classification of pneumatic valves. At the bottom, the FGPA development board is seen, the middle level contains the interface board and on top, the pneumatic system is shown which contains the valve under test.

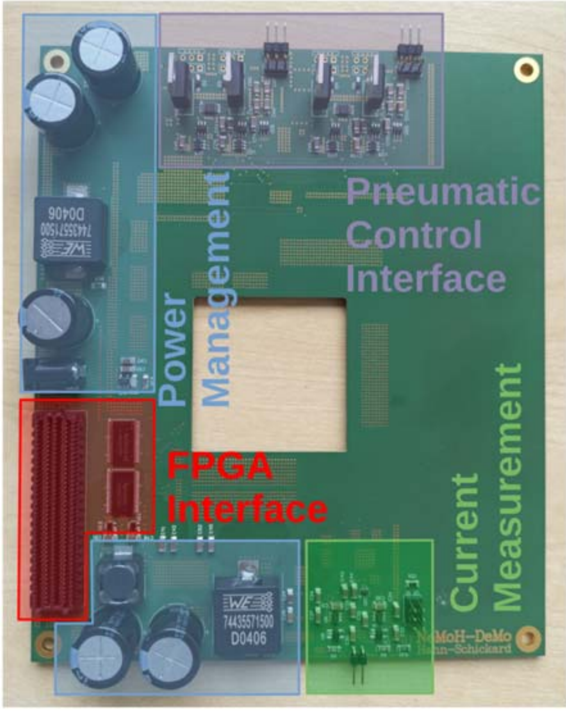

Figure 2: Interface board for signal translation between FPGA, pneumatics and supply current measurement of the valve under test and pneumatic control interface.

and their housing temperature should be monitored and be used as input to the AI module. This "minimally invasive" approach offers the possibility to adapt the classification system for condition monitoring of other electrically operated components without much effort. Furthermore, it allows upgrading existing systems easily with an AI based condition monitoring function.

2.2 System Setup

To be able to easily transfer the intended edge AI into an energy-efficient, miniaturized embedded system or a dedicated ASIC at a later stage, an FPGA development board was chosen as the basic platform for implementing the neural network(s) (Figure 1, bottom PCB). To monitor the valves under test, an interface board was implemented (Figure 1, middle level and Figure 2). It measures the valve's supply current and housing temperature and passes this data to the FPGA for processing. Additionally this PCB contains elements for power management and the electrical pneumatic control interface elements.

Later on, this board might be redesigned to fit to new requirements or to test a dedicated AI ASIC additionally. This gives the possibility to use a specialized ASIC instead of the FPGA implementation easily.

On top of this stack the valve under test and the required pneumatic control elements, are placed. The valve under test is inserted into a special holding element, which allows a fast exchange of the valve without any tool. Next to the valve a conduct free IR thermometer is placed to measure its housing temperature during the test series.

To set the input and output pressures applied to the valve being monitored, a pneumatic control loop was developed whose code was implemented in the FPGA's programmable logic. In addition, the interface board (Figure 2) generates out of these control values the current signals required for operating the pneumatic components. With the help of a Graphical User Interface (GUI) developed in Qt (Figure 3), all system parameters can be set. Automated recordings of data series can be programmed to characterize the valves under test. This part runs on the processing system of the FPGA development board uses the ARM based processor and runs "PetaLinux", a Linux based operating system.

This test setup allows a simple and fast generation of a huge amount of training data for the neuronal network under different test conditions like the input and output pressures. After training the neuronal network and integrating it onto the FPGA, the system can be used to verify its functionality easily.

3 Results

Twelve specimens of the same valve model were measured in different functional states, generating transient data series as examples of intact models and models with different fault types. Based on these, a suitable AI model for state classification was developed. The chosen neural network structure is shown in Figure 4. After the network was

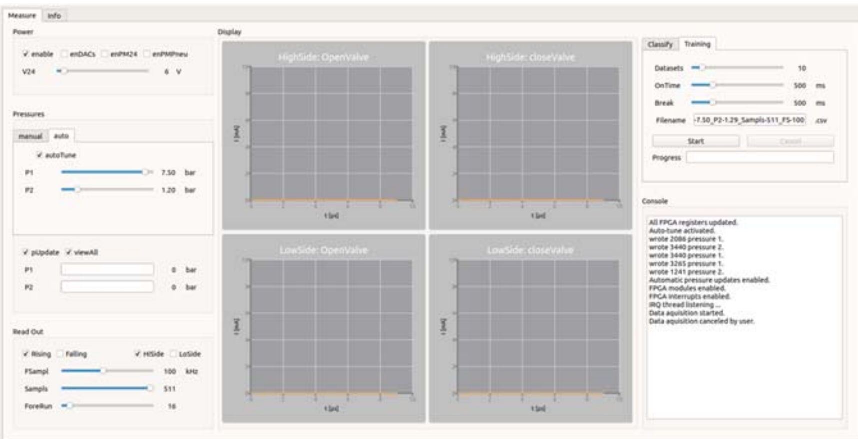

Figure 3: Screenshot of the GUI used to control the system and display recorded data series and classification results.

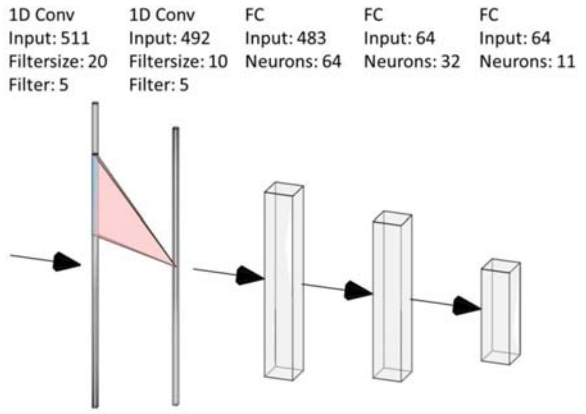

Figure 4: Structure of the neural network used for classification and implemented in the FPGA. The network size was reduced by quantization and pruning for implementation.

trained with the transient data series, it could be compressed by over 90% via reduction of the variables bit width (quantization, [1]) and elimination of network nodes of minor relevance (pruning, [2]) without significantly losing classification quality. In this state, it was synthesized and implemented in the programmable logic of the FPGA. The resulting system achieves a very high classification accuracy of 99% in classifying the inrush current of an unknown valve as "intact" or "faulty" and 90% in determining the fault present when measured once.

4 Summary

The development and construction of a parameterizable condition classification system for electromagnetic proportional valves using neural networks has been presented. The system allows to generate series of measurement data for different valves, different operation conditions and different failure types easily.

Additionally it allows the integration of a trained neuronal network used to classify the valve under test and determine its functional state precisely. Up to 12 different fault types can be distinguished automatically. It provides the possibility for fast testing and comparison of different types of neuronal networks within this use case scenario.

In the future this system can be simply modified by small modifications in hardware and software to include AI algorithms or complete new hardware, like newly developed hardware accelerators for neuronal networks. By this it provides an extendable platform for a simple and fast testing different neuronal networks within this system and allows to easily compare these.

5 Acknowledgement

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6 Literature

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