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Concept of a Self-X Sensory System and its first implementation on an XMR-based Angular Decoder Demonstrator

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Summary:
The methodology and case study presented in this article reveals the impact of self-X properties on long-term system reliability. The studies were conducted on the data received from XMR-based angular decoders used as a demonstration setup and Red Pitaya platform used for real-time measurement. A new approach inspired by the biological immune system was explored to detect anomalies and novelties in the field of one-class classification (OCC) XMR sensor properties. The accuracy of the proposed methodology was 96.2 %. Due to the implementation of the self-X (self-healing, self-calibration, self-repairing, etc.) properties, it is possible to increase the efficiency of the physical demonstrator by maintaining satisfactory system performance, despite the defects that occur during the operation.

Keywords: Self-X system, Artificial immune system, Positive selection algorithm, XMR-based angular decoder, Tuning knobs

Background, Motivation, and Objective

Driven by the rapid growth of information technology in manufacturing, industry 4.0 focuses on intelligent monitoring using machine learning and optimization techniques [1].
One of the main goals of industry 4.0 is to predict the anomalous behaviour of the system. Fault diagnosis, early detection of defects, and increased system reliability are essential to lower operational costs [2]. Numerous methodologies are presented in the literature [3-6] to reduce maintenance costs and prevent unplanned downtime in the production chain due to equipment failures.
This research presents a self-X approach based on the extension of condition monitoring of instrumented processes to self-monitoring of the involved sensors, focusing on real-time anomaly detection and elimination. For this goal, inspired by the adaptability and autonomy of living beings, the concept of a holistic and robust system with self-X properties is proposed.

Proposed Methodology

This study aims to create a self-X system that will diagnose and evaluate the operation of controlled equipment while providing its monitoring with subsequent correction of errors and malfunctions. Thus, it will increase the system's reliability and ensure satisfactory performance without human interference due to the existence of the self-X properties. The flowchart of the proposed methodology is presented in Fig. 1.

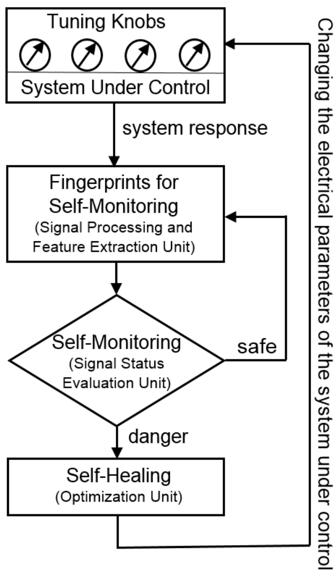

Fig. 1. Self-X mechanisms implementation.

In this approach, the data received from the system under examination is processed with new features extraction. Self-monitoring mechanism, based on the principles of the biological immune system, produces a one-class classification according to signal features, similar to the definition of self and non-self cells in the body of living beings. OCC uses a Positive Selection Algorithm (PSA) [7] based on the NOVAS filtering approach proposed by König [8], where only safe signal features are used as a set of detectors during the training phase. Hence, the often impossible task of comprehensively describing the set of errors is eliminated [8]. The self-healing property is based on changing the parameters of the input signal using the tuning knobs, bringing the output signal into a safe zone.

Results

An XMR-based angular decoder demonstrator with error incubation capability is used as an experimental setup (Fig. 2). The Red Pitaya platform was used as a real-time measuring system. The motor speed was set to 1413.63 rpm, while the sampling rate of the Red Pitaya's ADC was 1907.35 Hz. One period was sampled with 81 samples, the number of samples in the experiment was limited to 16384 samples [9].

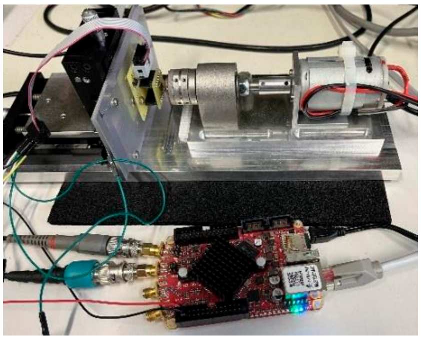

Fig. 2. Demonstrator with error incubation capability.

This experiment is the first step to move from synthesized [10] to real measured data acquired by the Red Pitaya platform. In current studies fault injection is still done simulated on real data acquisition and was labelled as distorted signal, while the measured data were labelled as good samples (Fig. 3). Extracted features from measured and synthesized data are still basic and uncorrelated and will be complemented in the next step to full complexity met, e.g., in [5].

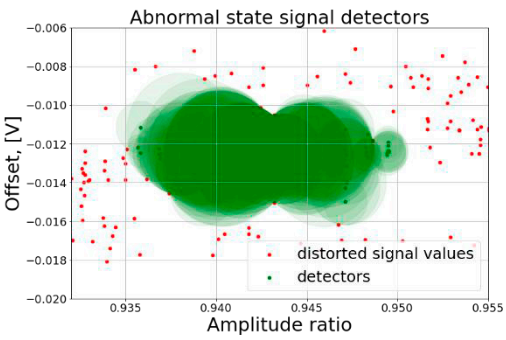

Fig. 3. Set of detectors with different radius.

At the training stage, a set of detectors with different radii [11] are determined (Fig. 3). The allowed minimum radius was 0.0004, while the max and min radii obtained by the training algorithm phase were 0.00353 and 0.00063. When an abnormal value is observed, the self-healing property will be activated. Self-healing (see Fig. 1) can follow in the same footsteps as the extrinsic or intrinsic evolution of electronics pursued in [5], but needs a different cost function. The cost function to minimize in the optimization loop of Fig. 1 in our approach relies on the condition monitoring itself. In previous work, the accuracy of synthesized data was 98.16% [10], while on the real measurement, the accuracy was 96.2%. The accuracy of the actual hardware is slightly lower than the synthesized data but still falls in an acceptable range. Further work will be based on extension for continuous online measurement and adaptation based on the Red Pitaya platform. To advance the experiment studies, it is intended to inject the real-world faults at the mechanical, sensory, and electronics level before acquisition of measurement data.

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