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Using the RedPitaya Platform in Automated Eddy Current Testing

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Abstract
This study highlights the use of the RedPitaya platform for developing prototypes of automated eddy current testing systems. The platform's flexibility, robustness, and affordability make it an ideal tool for such development. The versatility of RedPitaya allows for the integration of various programming environments like MATLAB, Python, and LabVIEW, efficient data processing, feature extraction, and decision-making algorithms. However, the lack of input commutators limits the use of matrix probes. The study suggests RedPitaya-based eddy current systems can serve dual roles, performing specific inspection tasks and facilitating research into new data processing methods and algorithms. Despite some limitations, RedPitaya offers promising opportunities for the evolution of eddy current testing systems.

Keywords: automated eddy current testing, RedPitaya, system prototyping

1. Introduction

Modern trends in the development of automated eddy current testing (ECT) require the use of new technologies and signal processing methodologies to improve its efficiency. One of the key trends is the improvement of eddy current probes and devices. For example, the use of matrix sensors makes it possible to measure eddy current fields over large areas of the inspected objects, increasing the probability of detecting defects [1-8]. Periodically, researchers return to the use of pulsed eddy current inspection technology, explore its new capabilities, and use it in automated eddy current NDT systems [9-10].

The use of pattern recognition, machine learning, and artificial intelligence methods in ECT is becoming increasingly common. These methods make it possible to automate the analysis of eddy current testing data and the process of making diagnostic decisions [11].

Developers of ECT tools pay special attention to feature extraction and feature selection technologies. They allow identifying the key information characteristics of eddy current signals, which facilitates defect recognition. Machine learning algorithms can detect complex patterns in the data that correspond to certain defects and that may be missed in traditional analysis [12-15].

The development of automated ECT has its challenges. One of the most important of these is the development of reliable and flexible software that can effectively solve a set of tasks of data processing, information feature extraction, and real-time diagnostic decision-making. The development of such software requires a deep understanding of the physical principles of ECT, knowledge of information and measurement technologies, digital signal processing and modelling methods, and machine learning algorithms.

These challenges have a direct impact on the design, development, and use of eddy current NDT systems. To increase efficiency, systems must be able to process large amounts of data and provide high processing speeds. In addition, to support the automation of the production process, systems must be able to perform measurement and control operations without direct human intervention and integrate with other systems.

Implementing this ideology of ECT systems requires the use of powerful hardware and software. The RedPitaya platform has significant potential for solving automated ECT tasks. Its unique capabilities are due to the successful combination of powerful computing resources and software flexibility. Below are several examples of RedPitaya platform use in various fields of research and technology that illustrate its wide range of capabilities.

Paper [16] describes the development and implementation of a blocking amplifier on the open source RedPitaya platform. The development process was carried out in the Xilinx Vivado environment using the VHDL programming language. The use of embedded blocks based on the principle of smart blocks in accordance with the Xilinx paradigm allowed us to create a modular system. Such an amplifier makes it possible to distinguish information signals against the background of significant noise.

Article [18] describes the process of developing the open source software package PyRPL. This package is designed to perform experiments in quantum optics. The user interface and all high-level programs are developed in Python. Part of the PyRPL software implements various digital signal processing modules, which confirms the flexibility and wide range of capabilities of the RedPitaya platform.

Article [19] demonstrates the development of software for a capacitive biosensor. The software was created in the LabView environment, which allowed developers to easily integrate RedPitaya and other components into a single system. This environment allowed the use of a high level of abstraction, which simplifies the programming and testing process. The software created as part of this work allows for the measurement of bioimpedance parameters. The measurement results are processed to detect specific DNA sequences, confirming RedPitaya's ability to perform complex tasks in the field of biomedical engineering.

In the context of Industrial Revolution 4.0, automated eddy current NDT systems have great potential for further development. Possible directions include increasing the level of automation, using the latest data processing technologies, and integrating with cloud services for remote monitoring and inspection. [20-21]

The purpose of the report is to analyse the possibility of the RedPitaya platform for use in automated ECT systems.

2. Overview of the RedPitaya platform

The RedPitaya is a powerful computing platform and an excellent choice for automated eddy current NDT systems. However, there are other platforms such as LabJack, BeagleBone, Raspberry Pi and others that can also be used in this context. So what are the advantages of RedPitaya over other platforms? To answer this question, we have performed a comparative analysis of RedPitaya with other similar platforms. Their main characteristics are shown in Table 1.

All of these platforms differ in key features and capabilities, including computing power, number of input/output ports, connectivity, signal processing quality, vendor support, and user community activity. RedPitaya has a significant advantage in real-time signal processing and FPGA support. However, other platforms may have advantages in other areas.

In regards to cost, the RedPitaya may be more expensive than a Raspberry Pi, but cheaper than some LabJack models. However, given potential expansion or maintenance costs, the total cost can vary significantly.

Analog Devices ADALM-PLUTO (PlutoSDR). This platform is designed to build a digital radio (SDR) containing high-quality ADCs and DACs. PlutoSDR is especially useful for working with radio signals.

Table 1. Main technical characteristics of a number of platforms for the implementation of measurement and control tools

Platform	Processing performance	ADC	DAC	Communication interfaces	Memory
RedPitaya 125-14	Xilinx Zynq-7010 (ARM Cortex-A9)	2x 14-bit, 125 MSPS, ±1V	2x 14-bit, до 125 MSPS, ±1V	Ethernet, USB, HDMI, GPIO	512MB DDR3 256MB
LabJack T7-Pro	1 GHz ARM Cortex-A9	24-bit, 50 kSPS, ±10V	14-bit, до 128 kSPS, ±10V	Ethernet, USB, Modbus TCP, SPI, I2C, GPIO	16MB RAM 4MB
Analog Devices ADALM-PLUTO	ARM Cortex-A9 (Zynq-7010)	12-bit, 61.44 MSPS, ±1V	12-bit, 61.44 MSPS, ±1V	USB, Ethernet, GPIO	512MB RAM 4GB
Texas Instruments Delfino F28377S LaunchPad	TMS320F28377S (ARM Cortex-M3)	12-bit, 1 MSPS, ±3.3V	12-bit, 1 MSPS, ±3.3V	USB, JTAG, SCI, SPI, I2C, GPIO	1MB RAM 2MB
Microchip PIC32MZ EF Development Board	PIC32MZ2048EF (MIPS M14K)	12-bit, 1 MSPS, ±3.3V	12-bit, 1 MSPS, ±3.3V	USB, Ethernet, CAN, SPI, I2C, GPIO	512KB RAM 2MB
Raspberry Pi 4 Model B 8GB + ADC-DAC Pi Zero	Broadcom BCM2711 (ARM Cortex-A72)	12-bit, 100 kSPS, ±2.048V	12-bit, 100 kSPS, 0-2.048V	USB, Ethernet, HDMI, GPIO	8GB LPDDR4-3200 MicroSD Card

Texas Instruments Delfino F28377S LaunchPad. This microcontroller platform has built-in ADCs and DACs and is used in a wide range of systems, including automated NDT systems.

Microchip PIC32MZ EF Development Board. This board contains a 12-bit ADC and can be used to develop NDT systems.

Raspberry Pi.Although the standard Raspberry Pi board does not have built-in ADCs or DACs, it can be easily extended with additional modules (e.g. HATs or Hardware Attached on Top) that have these functions.

The RedPitaya is therefore a high-performance platform that is ideally suited to the requirements of automated eddy current NDT systems. In addition, this platform supports various programming environments (Matlab, C/C++, SciLab, Labview, Python), which allows scientists and engineers to choose the most convenient tool for their projects.

The developer has already created a number of measurement tools that are part of the standard Red Pitaya package, including an oscilloscope, signal generator, spectrum analyser, LRC meter, logic analyser, and Bode analyzer [21].

The core of Red Pitaya's architecture is the Xilinx Zynq-7010 chip, which is a system-on-chip (SoC). It consists of two complementary subsystems: a processor subsystem responsible for data processing and a programmable logic subsystem that provides high flexibility in configuring the chip's functionality (Fig. 1). This architecture makes it possible to effectively perform various tasks using a combination of these two subsystems.

The central advantage of RedPitaya is the possibility of flexible configuration and programming, which allows scientists to adapt the platform to specific research requirements.

These advantages make RedPitaya an attractive platform for developing flexible software systems for automated ECT systems, implementing complex information processing algorithms, including feature extraction, decision making, and data mining.

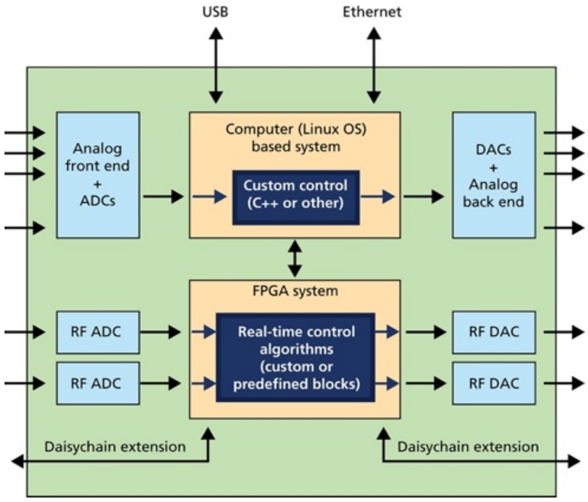

Fig. 1. The Xilinx Zynq7010 chip in Red Pitaya

Below are more complete technical specifications of the RedPitaya board.

- FPGA: The Red Pitaya features a Xilinx Zynq-7010 FPGA (programmable logic integrated circuit) that can be used for digital signal processing, real-time monitoring, and other applications.
- ADC and DAC: The Red Pitaya has two 14-bit analogue-to-digital converters and two 14-bit digital-to-analogue converters, enabling high-resolution sampling and signal generation.
- Peripherals: Red Pitaya has multiple communication options including Ethernet, USB, and Wi-Fi. This makes it easy to integrate the platform into existing information and telecommunication networks and systems.
- Software support: Red Pitaya supports multiple programming environments, including MATLAB, Python, C/C++, and LabVIEW. This allows you to easily develop and implement your own applications.
- Size and power: Red Pitaya has a compact size of 11 cm x 7 cm, which makes it easy to integrate into a variety of devices and systems. The platform is also very powerful, with a quad-core ARM Cortex-A9 processor clocked at 667 MHz and 512 MB of RAM.
- Open source: Red Pitaya is an open source platform. This means that its hardware and software are freely available and allows you to customise and modify the platform to meet your specific needs.

The Red Pitaya OS operating system is pre-installed on an external MicroSD card, so no programming tool is required to configure the software codes. The boards can be programmed via an Ethernet port thanks to the interface in the Zynq-7000 chip. This solution allows you to connect to the platform immediately without installing additional drivers. The boards allow you to use most of the chip pins in external circuits.

- FPGA: Red Pitaya has a Xilinx Zynq-7010 FPGA (programmable logic integrated circuit) that can be used for digital signal processing, real-time control and other applications.
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2.1 Software flexibility

In the context of a software development system, “flexibility” often means the ability of the system to adapt to changing requirements and conditions of use without the need for significant modifications to the code. In this sense, RedPitaya proves to be an extremely useful platform. It enables the development of flexible software that can be tailored to the specific requirements of NDT eddy current testing. With a wide range of built-in tools and support for various programming languages, RedPitaya allows developers to respond quickly and efficiently to new challenges and needs in automated NDT.

2.2 Feature extraction

Feature Extraction is a critical step in signal processing and ECT data analysis. This process involves identifying and extracting useful information from ECT signals for further analysis and decision-making. The concept of building such an automated ECT system is shown in Fig. 2.

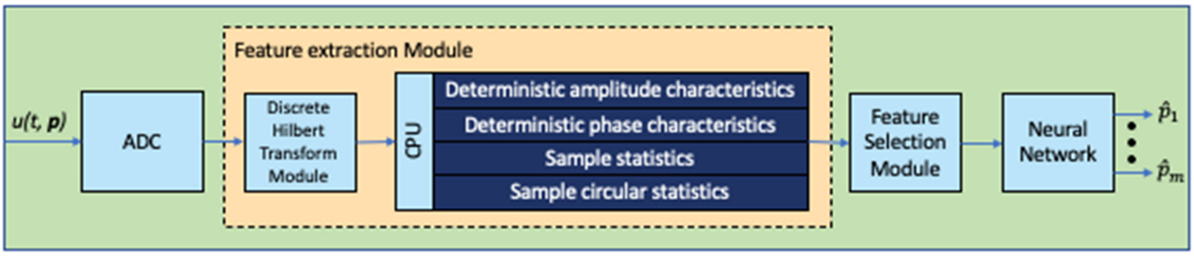

Fig. 2. The concept of ECT system

During the scanning of the controlled object by the eddy current sensor, a signal is obtained $u(t,p), t \in T_a$, where t – time, T_a – signal analysis time, $p = (p_1 \dots p_n)$ – vector of parameters of the controlled object. The list of these parameters and the range of their possible changes are determined by specific inspection tasks. This signal is sent to the ADC. The Discrete Hilbert Transform Module extracts the envelope and phase of the signal, which depend on both time and the vector. The elements of the vector have different effects on the envelope and phase of the signal. In order to increase the measurement information, different modes of operation of the eddy current sensor can be used, as well as various secondary deterministic and statistical parameters of the signal obtained from its amplitude and phase [22]. Feature Selection takes out some of the most informative features necessary to obtain a vector of estimates $\left(\hat{p}_1 \ldots \hat{p}_n\right), m \le n$ of the parameters of the monitored objects. The vector $\left(\hat{p}_1 \ldots \hat{p}_n\right), m \le n$ obtained at the output of the Neural Network, which has previously passed the stage of training on a series of test samples.

The RedPitaya platform can perform a crucial role in the feature extraction process in ECT. Thanks to its flexible programming capabilities and a wide range of signal processing tools, RedPitaya can be configured to perform complex feature extraction tasks. This process can include the use of digital signal processing, statistical signal characterisation, spectral analysis, signal filtering, machine learning algorithms and other methods to identify useful features in ECT data.

Thus, the use of the RedPitaya platform opens up wide opportunities for the implementation of innovative functions in automatic eddy current inspection, namely:

- high-speed signal acquisition and analysis, processing of large amounts of data and recognition of complex patterns;
- application of artificial intelligence; the use of machine learning algorithms makes it possible to create automatic recognition, classification and forecasting systems based on eddy current inspection data;
- integration with cloud platforms, which opens up new opportunities for storing, processing and analysing data in the cloud environment; this will make it possible to create distributed systems and provide access to data and analysis results from different locations; expanding the capabilities and functionality of existing ECT tools by incorporating the RedPitaya platform into them.

3. Conclusion

Automated eddy current non-destructive testing systems have an important role in industry, including aviation, nuclear industry, automotive and many other industries. Increasing the reliability of testing, its implementation in real time, and automating the process of making diagnostic decisions require the use of more sophisticated testing technologies and algorithms for processing experimental data.

The RedPitaya platform has wide functionality, reliability, and accessibility, which makes it a convenient tool for implementing projects to create automated ECT systems.

An automated ECT system based on RedPitaya can perform not only specific control tasks, but also be a convenient tool for researching new methods and algorithms for processing information in ECT, performing their comparative analysis, and quickly and efficiently debugging their software implementations.

A certain limitation for use in ECT is the absence of input commutators, which makes it impossible to use matrix sensors.

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