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Data capture, transmission and signal processing in AI based closed-loop control system

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Abstract

Data capturing by transducer is very paramount on closed-loop control system. Without data capture transmission is not possible. Once the data has been captured accurately transmission of the data is required without loss of memory. Several measures are required to preserve the data during processing including modulation, demodulation and filtering with all intensions to keep the data secured to perform the required objectives of the closed-loop system functions. With the integration of Artificial Intelligence such as (ANN) in closed-loop control system, the architecture of the system will be slightly altered. This research is concerned with presentation of data capture, transmission and signal processing with the inclusion of Artificial Intelligence in a closed-loop control system. It is hoped that the proposed system will enhance the closed-loop system AI technology and preserve the overall functions requirements of the whole system.

Keyword: Artificial intelligence; Closed-loop; Data; Capture; Transmission; Signal processing

1. Introduction

1.1. Practical Implication

Data capture is part of control system function assignment. The transducer has to capture the data without memory loss and transmit it effectively as required in the closed-loop function definitions. If there is error in data capture and transmission, then the integrity of the control system is jeopardized. The probe, detector or transducer should be active, accurate and precise in the capturing and transmission of data or information to enable the closed-loop system to work well. In signal processing, modulation, demodulation and filtering are all necessary technologies employed to preserve the integrity of the system. For an Artificial Intelligence closed-loop control system, the routing of the signal processing is different as the signal is tapped into AI module for secondary functions. It is this secondary module that makes the system robust and effective in controlling the controller. It is this basis that is the subject to enhance the application of AI in closed-loop control system configuration.

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Data capture involves the harvesting of information from various sources and arranging and storing them for further use. Data capture can be manual or automated. Human data capture involves human interaction in obtaining, storing and keeping the data. It is labour intensive and error prone. It includes obtaining data using paper or digital format from websites, sensors and databases. The automated data methods do not involve direct human interaction, optical character recognition (OCR), barcode scanning and data extraction algorithm. Data capture allows organizations to gather what they can use to get information that is essential in decision making .It helps the organization to have what to fall on in decision-making, It assist in accurate decision making, saves time, improves data quality and allows management to perform better, which is normally reflected as profit or net-worth of an organization.

1.2. Background to the Problem

A closed-loop control system is a device that automatically regulates itself and maintains specified or set point value without human control.

AI based closed-loop control systems is a system that applies artificial intelligence algorithms to continuously monitor and adjust the values or processes by constantly receiving feedbacks from sensors, allowing for precise parametric control. AI closed-loop system analyzes sensors data and makes dynamic adjustments to mechanisms to sustain the desired values or set points. Data capture is very important in the overall process .Without data capture, the control system will not function. Accurate and precise data control is required in AI inspired capture environment. When the data are captured by the transducer, the data should be transmitted without memory loss and adequately through the feedback system to the set point. The same data integrity is required at the AI control post to receive, analyze, process, predict, compare and communicate with control element of the primary closed-loop system. What is the right architecture for the data capture, transmission and signal processing?

2. Signal transmission

This could be done by the movement of a rod, lever, fluid column etc. simple by a change of various electrical quantities. For industrial applications, pneumatic or electrical transmission is preferred, where a central room can observe the complete functioning of a plant from one point. Pneumatic transmissions use flapper valve. In electrical transmitters, resistance and inductance valves are commonly varied to cause a change of current in transmitting circuits. Capacitance variation is also used.

The quantities are transmitted after summation, multiplication, integration and differentiation of the Physical quantities.

More frequently, some modification of the signal is required before it can be accepted by the display.

Many electrical transducers are insufficiently sensitive to give an acceptable change in the indication of the display. There is the need for amplification of the signal. In most cases, pre-amplifiers are incorporated to have stable characteristics. There are also carrier amplifiers suitable with inductive transducers requiring high frequency supplies. The value of the measured quantity is represented by the amplitude of an alternating current or voltage of fixed frequency.

Sometimes filtering is required. In such cases, only a certain range of frequencies that are obtained from a transducer inputs are required. Perhaps these frequencies represent the signal, while other frequencies may be unwanted harmonics and noise resulting from some sort of distortion in the input arrangement. Various circuits configuration are available for filtering: low-pass, high –pass, band –pass and stop-pass circuits.

In many situations, impedance matching is required. The general principles of impedance matching are that the external impedance should match the internal impedance for maximum energy transmission (minimum attenuation).

Input signals to ANN model after modulation, demodulation or filtering have to be passed to ANN to normalize it. Many mathematical functions exist promising for adoption for application.

The artificial neuron is developed to minimize the characteristics and functions of the biological neuron. It receives much input representing the outputs of the other neuron. It is then passed through an activation function to determine the neuron output set values) [1]. The popular activation operators include: linear, piecewise linear, hard linear, unipolar, sigmoidal, and bipolar sigmoidal, unipolar, multi-models.

3. Signal Processing

Signal processing is the conversion or transformation of data in a way that suits its purpose. It allows engineers to analyze, optimize and correct signals into useable form such as audio streams, images and video or scientific data. It includes the analysis, interpretation and manipulation of signals to improve their quality and utility within control systems. It allows real-world signals such as sounds and images to be transformed into various means such to make them more useful for electronic systems and aid in decision-making.

Signal processing is pivotal in control systems to detect, analyze and control physical quantities. Such systems include industrial processes, autonomous aircraft navigation, to function accurately and effectively. Data from sensors and inputs should be filtered, analyzed and acted upon to ensure precise control [2].

The key signal processing Techniques include: filtering, Fourier analysis, modulation and demodulation, sampling and quantization,

Filters are often employed to eliminate noise to isolate specific portions of a signal for further analysis. Through this technique unwanted components of features are removed from the signal. The different types of filtering techniques are:

- Low-pass filters, this pass low frequencies and attenuates high ones, that is decrease their amplitudes with little or no distortion.
- High-pass filters pass high frequencies and attenuates low ones
- Band-pass filters, only pass frequencies in a specific band
- Band-stop filters, only attenuates frequencies in a specific band

In Fourier analysis complex signals are broken into their constituent sine and cosine parts. This technique is very useful for understanding signal behaviour in the frequency domain, which is fundamental for designing control systems that need to operate within specific frequency ranges or respond to particular signal characteristics.

Modulation is the altering of a carrier signal to encode information. Demodulation is the reverse process, which extracts the original information from the modulated carrier; these practices are used in control systems that require wireless communication channels to transmit and receive data across networks and are central in telecommunication [3].

Sampling and quantization convert continuous analog signals into digital signals that can be processed by digital systems. Sampling here means measuring the signal at discrete intervals, while quantization assigns a finite set of values to these samples. In combination, they enable the analog-to-digital conversion necessary for the digital signal processing that underlies many modern control systems [4].

3.1. Advanced Signal Processing Techniques

Each of these advanced techniques presents opportunities for more sophisticated control and automation. They include:

3.2. Wavelet Transforms

"Wavelets are short wavelike functions that can be scaled and translated. Wavelet transforms take any signal and express it in terms of scaled and translated wavelets [5]." They technique offer an elevated approach to analyzing signals, and are particularly useful for non-stationary signals whose statistical characteristics change over time. Unlike Fourier analysis, wavelet transforms provide both time and frequency localization, which makes it better suited for detecting transient signals and analyzing time-varying systems [6].

3.3. Adaptive Filtering

Adaptive filtering is essential for systems that operate in uncertain or changing environments. These filters adjust their parameters in real time, learning to optimize performance as the signal environment changes. This adaptability is crucial to enable its applications such as echo cancellation in telephony systems or noise reduction in sensor arrays.

3.4. Digital Signal Processing

Digital Signal Processing (DSP) harnesses computer algorithms to analyze, transform and transmit digital signals, bits of information sampled from continuous-time analog signals or produced directly from digital systems. The power of

DSP lies in its flexibility and speed, as it enables complex operations such as image and video compression, speech recognition and advanced radar and sonar systems [7].

3.5. Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning (ML) are revolutionizing signal processing in control systems. Systems that use them can now recognize patterns, learn from data and make decisions—all with minimal human intervention. The integration of AI algorithms enhances the ability of control systems to process and interpret complex signals more efficiently, leading to smarter automation and predictive maintenance.

3.6. Real-Time Processing

The ability to process signals in real time is essential in applications related to safety-critical operations. Advances in hardware and software have made it possible to achieve lower latency ("a short period of delay between when a signal enters a system and when it emerges from it") and higher throughput ("how many units of information a system can be processed in a given amount of time") in signal processing. Real-time processing ensures that systems can react promptly to dynamic condition; crucial requirement for applications such as autonomous driving and active control in aerospace.

3.7. The Internet of Things and Edge Computing

The Internet of things is ushering in a new era of interconnected devices, which generates an unprecedented amount of data to be processed. Edge computing is a decentralized computing model that shifts the processing of this data closer to IoT devices, reducing transmission costs and latency. Signal processing at the edge is becoming more prevalent, facilitating quicker responses and improving the overall efficiency and scalability of IoT systems.

3.8. 5G and Wireless Communications

The role of 5G in signal processing is significant, as its reshaping wireless communications by offering higher speeds, lower latency and increased capacity. This next-generation wireless technology enables more reliable and efficient control systems, particularly those that rely on remote sensing and actuation. As 5G networks continue to expand, they will further enhance the capabilities and applications of signal processing in control systems [8].

[9][10][11].

AI functions through the learning process, where named-information is properly analyzed to learn and extract the features in the information, so as to make projections into the future.

There are other main categories into which artificial intelligence can be subdivided, including: expert system, robotics, fuzzy-logic, neural networks: supervised learning, unsupervised learning, reinforced learning and Hebbian learning, machine learning, etc. These include:

- Expert System: is a computer program created to simulate human judgment. This computer program applies artificial intelligence techniques to resolve issues in a particular field that often calls for human knowledge [12].
- Robotics: This is an area that allows repetitive work that should be done by human to be over taken by robots [13], [12], [14], [15] [16], [17].
- Fuzzy Logic:[18], It is used to deal with the problems that are partly true, in this case the truth takes a probabilistic outlook, between the maximum values for it being true and false[18]. Fuzzy-logic allows for a range of intermediate degrees of truth in addition to the purely binary examples of 0 and 1[10].
- Neural networks: The human brain is synonymous with it. It is made up of a network of neurons that learns and performs tasks independently through the use of deep learning. It can be: supervised, unsupervised, reinforced, and Hebbian learning.

In supervised learning case every input that is used to train the network is associated with an output pattern, which is the desired output. A teacher is assumed to be present during the learning process, when a comparison is made between the network's output and the correct expected output, to determine the error present[19]. However, in unsupervised Learning: This is a learning process. The target output is not presented to the network. It is as if there is no teacher presents the pattern. The system only learns on its own by discovering and adapting to structural features in the input pattern [11].

In reinforced Learning: In this learning method, the teacher, though present, does not present the expected answer but only indicates if the computed output is correct or incorrect. The information helps the network in its learning process. A reward is given for the correct answer and a penalty for a wrong answer. In Hebbian learning- learning is inspired by biology, based on correlative weight adjustment.

The neural network can be single layer feed forward, multilayer feed forward or recurrent networks. [20] presented artificial intelligence based control-loop control system design.

Figure 1 shows a typical ANN architecture.

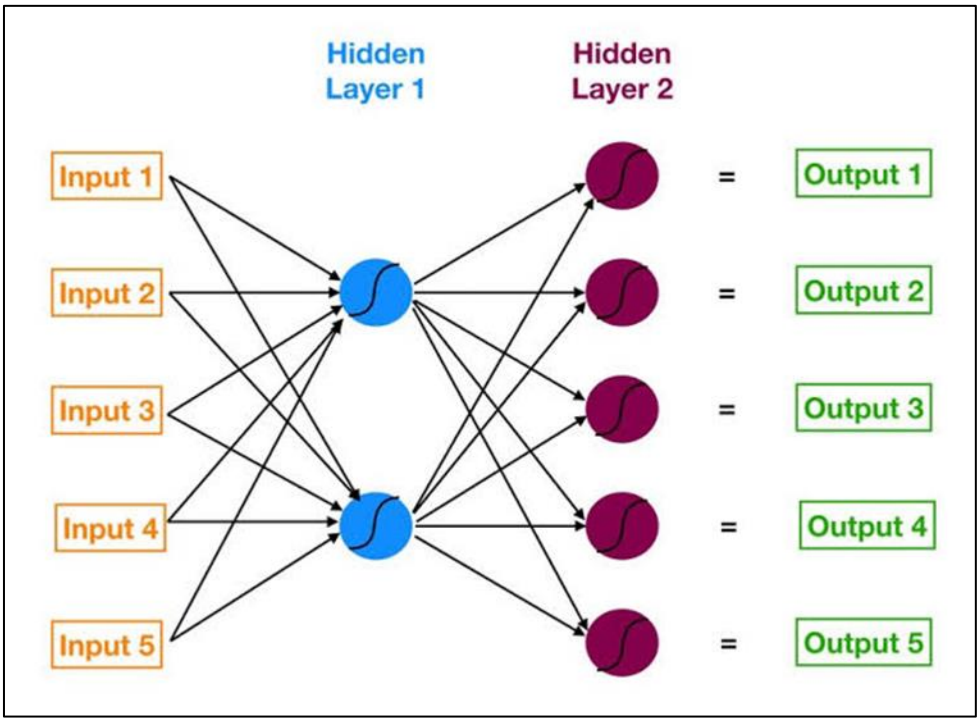

Figure 1 A Multilayer Feed forward Network [11]

- Machine Learning: This area of artificial intelligence allows a computer or machine to process analyze, and interpret data in order to use that data to solve problems in the real world.

4. Conventional Signal Processing Path

The simple closed-loop system for a conventional system comprise: the input, set point, control element (controller); actuator, plant/process, output and feedback.

In such a system, the value of the parameter of interest is set and the control element is intended to keep the plant or process at this designated value. Signal is sent to the plant the actuator to put the value of the process at the stipulated value. The output from the plant is measured by a sensor and send via a feedback loop to the set point, where comparison is made and any difference between the input and output is calculated as an error and is feedback to the control element to inform the actuator to implement these differences. The process continues till the output matches the input and all processes continue repeatedly. A simplified block diagram for a closed-loop control system is shown in Figure 2.

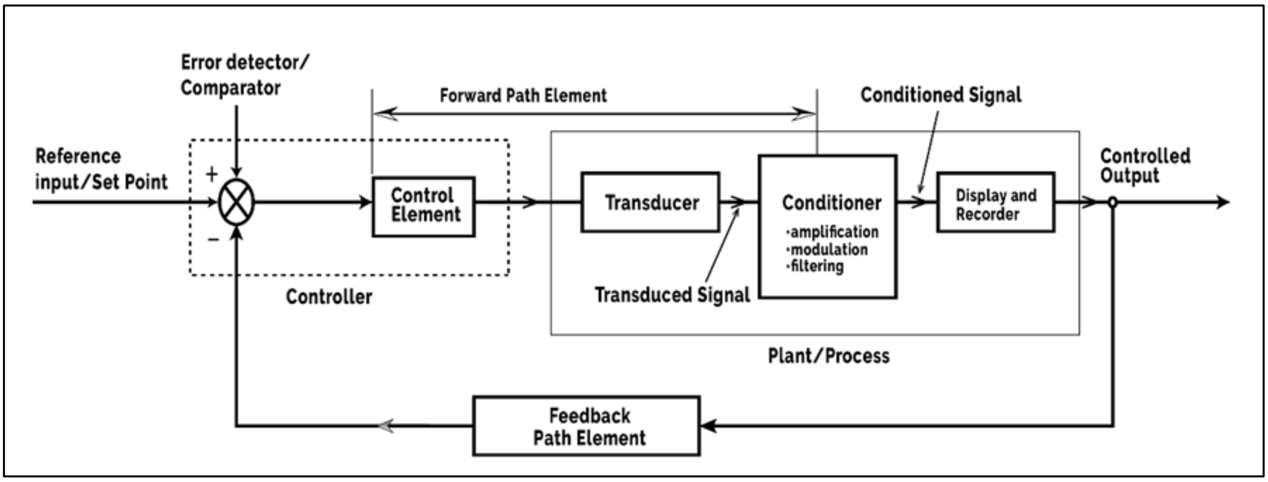

Figure 2 Conventional Signal Processing Path

5. Signal Processing with AI

Signals from the plant or processes are usually conditioned. The conditioning is to enable the output to be measureable and to remove unwanted noise within acceptable limits with accuracy and precision. In many instruments the conditioner is part of the display. It is therefore important to tap the signal from the plant or process after it has been conditioned before it is fed in AI Algorithm. For example if the set or reference command or input for a torque on a shaft is put at 20N-m, and the actual output from the display is 19.50 N-m. The input value from the display to the AI algorithm should be 19.50N-m; while the maximum value of the AI algorithm should be 20N-m, just like the set or reference input. If, the set point is altered to another value, say 30N-m, then the AI Algorithm should also be adjusted to 30N-m. The AI algorithm in this case is more or less a checker or secondary monitoring point that sends secondary signal to the control element for necessary adjustment. If the output from the process matches that of the input, then the AI algorithm will be zero value or no signal information to the control element for any adjustment. The AI algorithm should be done in a way that the maximum value can be adjusted to match with the set point value of the process or plant (supervised learning). The algorithm is more useful, when the error signal from the control element to the plant is unreliable. In that case the AI is expected to take over the running of the plant or process until when the control element is repaired or replaced. If the error signal from the control element is reliable, errors obtained from the AI algorithm is expected to perfectly match with that of the control element.

The entire arrangement is adequate and recommended for plants or processes like furnaces, nuclear plants where plant control is very important or where plant /process monitoring is complex and where multivariable processes and vibrations or undesired elements are inherent in the processes.

- Looking forward, research in signal processing for control systems will likely focus on further
- Integrating AI and machine learning, improving real-time processing capabilities and expanding it potentials of IoT with more sophisticated edge computing solutions exist.

Increased collaboration between academia and industry will be vital to drive these advancements, along with continued investment in research and development.

6. Proposed AI-Based Closed-Loop Signal Processing Path

In the proposed AI Based closed-loop system model, AI is introduced into the system as shown with designated functions. At the output from the plant or process, data is taken and recorded. It is used to create a model and train on AI desired objective- the input value. This is equally compared with the desired value and signal sent to the control element if there is a deviation from the desired value. In case of a deviation, the information is used to drive the actuator proportional to the error signal. The AI is to assist the controller in performing its functions and additionally stores the recorded data. Figure 3 shows a proposed AI-based closed-loop signal processing path.

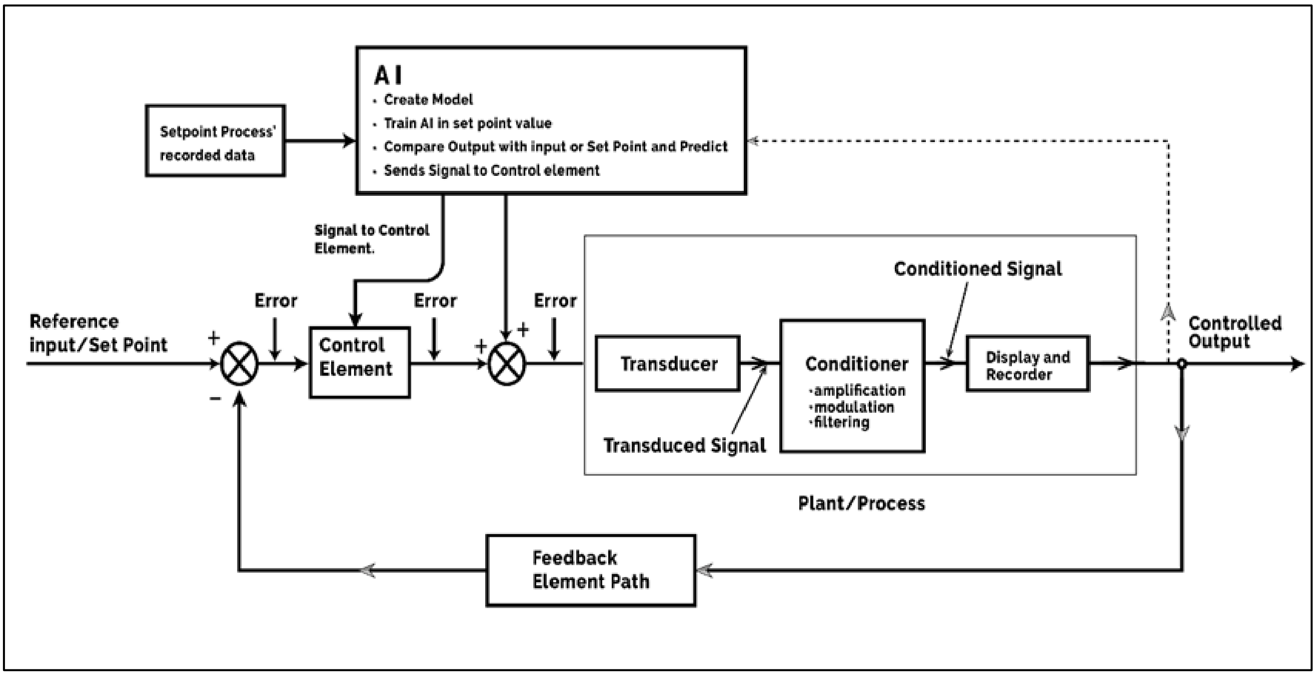

Figure 3 Proposed AI-Based Closed-Loop Signal Processing Path

7. Conclusion

The evolution of signal processing technologies carries immense potential for improving the performance and capabilities of control systems. This progress, however, is not without its challenges and areas for further investigation. There is the need to ensure scalability to maintain performance, which requires a great considerable of skill. As control becomes complex scaling, signal processing algorithms are needed to manage large datasets; and throughput become challenging. Security and privacy are other paramount concerns. Cyber -attack is increasing. Confidentiality of data being processed need robust security checks, measures and vigilance. Innovations in encryption and secure protocols are critical to address these concerns. However, safety measures are needed for online processes and interferences by intruders for online process. The application of this technology as suggested will enhance the closed-loop control system and improve on the controlled functions command.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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