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Artificial Intelligence based closed-loop control system design

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Abstract

Control systems especially closed-loop control system is mostly used in manufacturing and many other industrial processes. Closed-loop system is designed and used to align actual values of a given industrial process to a given command or reference value in real time with a high degree of accuracy. The current global trend in application of Artificial Intelligence is not markedly used to model, design, fine tune and optimize closed loop control systems. This article is in tandem for this purpose to highlight potential system design and configuration that can project the application of AI-Artificial Neural Network (ANN) in closed-loop control system. It shows how the conventional closed loop control system can be configured and with AI, with the intention to optimize the control functions.

Keywords: AI; Closed-Loop; Control; Feedback; System; Monitoring; Signal

1. Introduction

Artificial Intelligence (AI) is a computer science area concerned with the design of intelligent computer systems, exhibiting the characteristics that we associate with intelligence in human behavior [1]. AI is to comprehend model and implement theories of intelligence in this functions to design intelligent systems.

Artificial intelligence, on the whole, involves developing a PCs using propositional computing which enables the system to make decisive steps, translate articulations, recognize voices and analyse visuals logical thinking, cognitive applications, ability in processing, vision, and device movement and manipulation .But the true test of artificial intelligence is how well computer-aided programming codes and instructions imitate the workings of the human brain, guaranteeing that decisions are made and carried out in a way that makes sense. AI functions through the learning process where named-information are properly analysed to learn and extract the features in the information, so as to make projections into the future [2].

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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:

(i)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 [4]. Figure 1 shows the components of expert system.

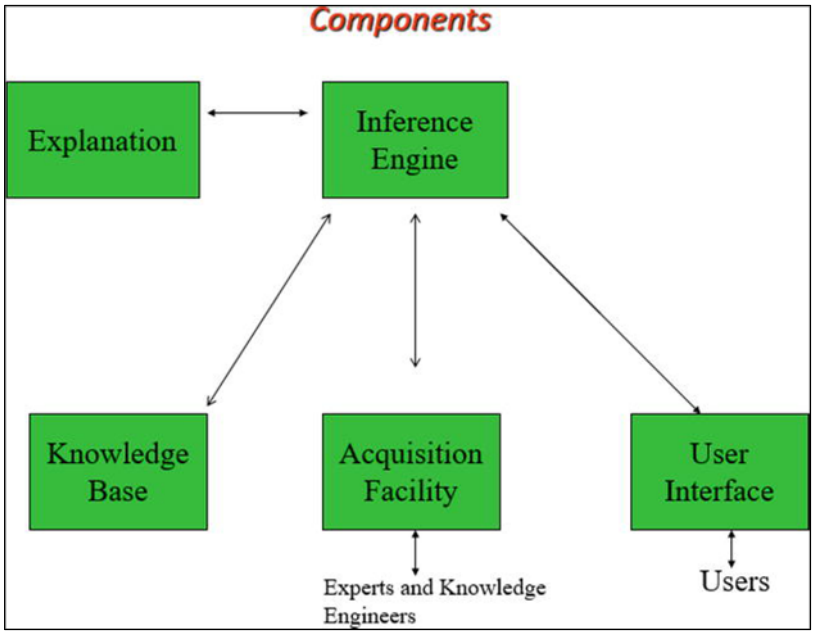

Figure 1 Components of an Expert system [4]

- Robotics: This is an area that allows repetitive work that should be done by human to be over taken be robots [4], [6], [7].

- Fuzzy Logic:[8] 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[8]. Fuzzy-logic allows for a range of intermediate degrees of truth in addition to the purely binary examples of 0 and 1[9].

Figure 2 is the representation of Boolean and Fuzzy logic.

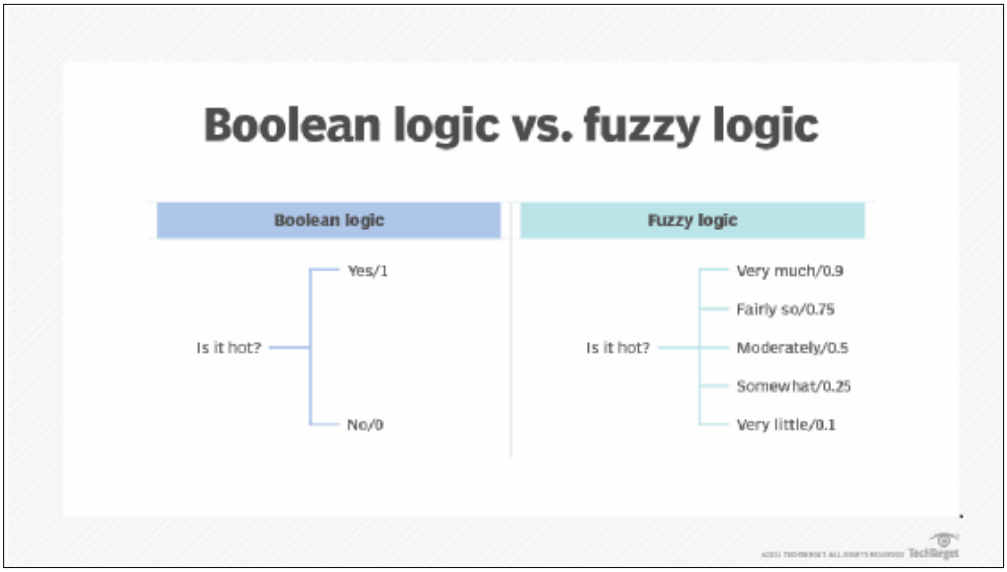

Figure 2 The difference between Boolean logic and Fuzzy logic [9]

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[9]. However, in unsupervised Learning: This is learning process, the target output is not presented to the network. It is as if there is no teacher present the pattern. The system only learns on its own by discovering and adapting to structural features in the input pattern [10].

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 feedforward, multilayer feedforward or recurrent networks

Figure 3 shows a typical ANN architecture.

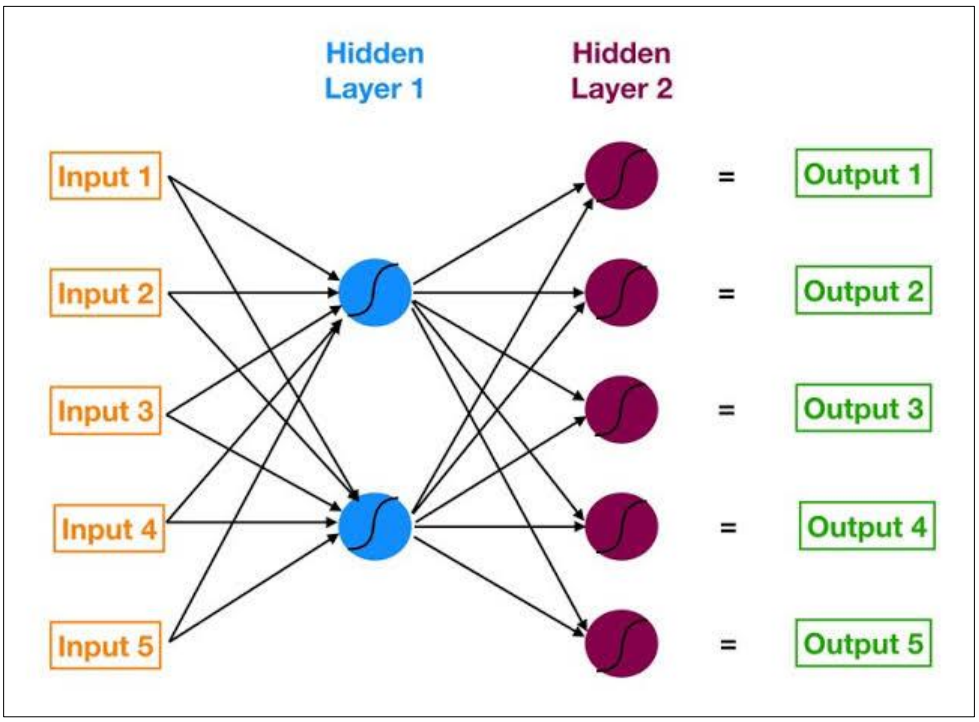

Figure 3 A Multilayer Feedforward Network [10]

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.

A closed loop control system is a mechanical or electronic device that automatically regulates a system to maintain a desired state or set point without human intervention or interaction.

An AI based closed-loop control systems refers to a system that uses artificial intelligence algorithms to continuously monitor and adjust the values in a space or process by constantly receiving feedback from sensor, allowing for precise

parametric regulation based on real time conditions, adopting to changing factors without manual intervention. AI analyzes sensor data and makes dynamic adjustments to mechanisms to maintain the desired values or set points.

The system constantly measures the current value using sensors and compares it to the desired set point, sending feedbacks to AI algorithm to make necessary adjustment. AI can learn from past data and environmental factors to predict potential values fluctuations and proactively adjust to the desired value. AI can handle complex non-linear relationship between variables allowing for more accurate control in situations with multiple influencing factors.

It has potential applications in smart homes, optimizing temperatures based on occupancy, weather conditions, user preferences; industrial processes-maintaining precise temperatures like in furnaces or chemical reactors; greenhouses-adjusting temperatures and humidity levels for optimal plant growth; Healthcare facilities-precise temperature control in critical care environments.

It gathers real-time data about the current temperature in the environment, the A algorithm processes the sensor data, considering factors like external weather, time of day and user input, based on this analysis, the AI calculates the necessary adjustment to reach the desired value, by sending signals to actuators to implement the calculated adjustment. For this particular scenario, the benefits include: improved energy efficiency-by precisely regulating temperature based on real-time conditions, energy consumption can be minimized; enhanced comfort in maintaining consistent and comfortable temperatures for occupants and predictive capabilities-AI can anticipate changes in temperature and proactively adjust to maintain optimal condition.

Practical Implications

In industrial plant and process, there are needs for the physical quantities of interest to be put under control. Some of these plants and processes run for months and years without stoppage. The set command or reference point needs to be maintained so as not to affect the plant or process. Such physical parameters required for control include: temperature, pressure, volume, speed, pH, strain, force, power, torque, current or voltage, humidity, etc.

A closed-system finds applications in heating, ventilation and air conditioning HVAC Systems to maintain desired indoor temperature in residential, commercial, and industrial settings. This ensures comfortable living and working conditions, as well as energy -efficient operation. It is also important in temperature-sensitive experiments and processes, such as those requiring chemical reactions or even biological samples like incubators, ovens, or water baths to maintain precise and stable temperatures. For many industrial processes, such as chemical reactions, food processing, or pharmaceutical manufacturing, require closed-system temperature control mechanisms to maintain specific temperature for quality assurance, safety, and overall process efficiency. For electronic cooling, closed system temperature control mechanisms can be employed in cooling systems for electronic devices. Such as computers or server racks, to maintain optimal operating temperatures and prevent overheating or thermal damage. This ensures the reliable and efficient performance of the electronic systems. For a refrigerating, systems, closed –system temperature control mechanisms are essential in refrigeration systems used for food storage, such as refrigerators and freezers, as well as commercial cold storage system facilities.

The requirements for control may be because of safety, cost, health or environmental issues or process requirement. This calls for research to improve on the existing technologies on control system Engineering. That opportunity has been created by Artificial intelligence that is currently revolutionizing the scientific world

2. Background to the Problem

There are industrial processes, such as biochemical processes within reactors, where temperature regulations within the system is still a major problem leading to over as well as under shooting, settling times and pronounced oscillations [11]. There are also non-linear systems as well as multivariable processes where control of the processes is difficult.

According to [11], AI, especially ANN is yet to make significant inroad into the field of control systems. This may be caused by the transformation of complex differential equations or Laplace transform equations to a useable form for AI application, unpredictability of disturbances and the need for description of the physical model. It is observed by [11] a clear lack of literature in this area, signaling lack of exploration and advancement of research in AI based control system.

The major concern of this research is on how to infuse AI in a conventional closed- loop control system and use it in areas where current applications are difficult like non-linear systems; high fluctuating scenarios and undoubtedly in linear systems if advantages are found.

2.1. Conventional Systems

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 this differences. The process continues till the output matches the input and all process continues repeatedly. A simplified block diagram for a closed-loop control system is shown in Figure 4.

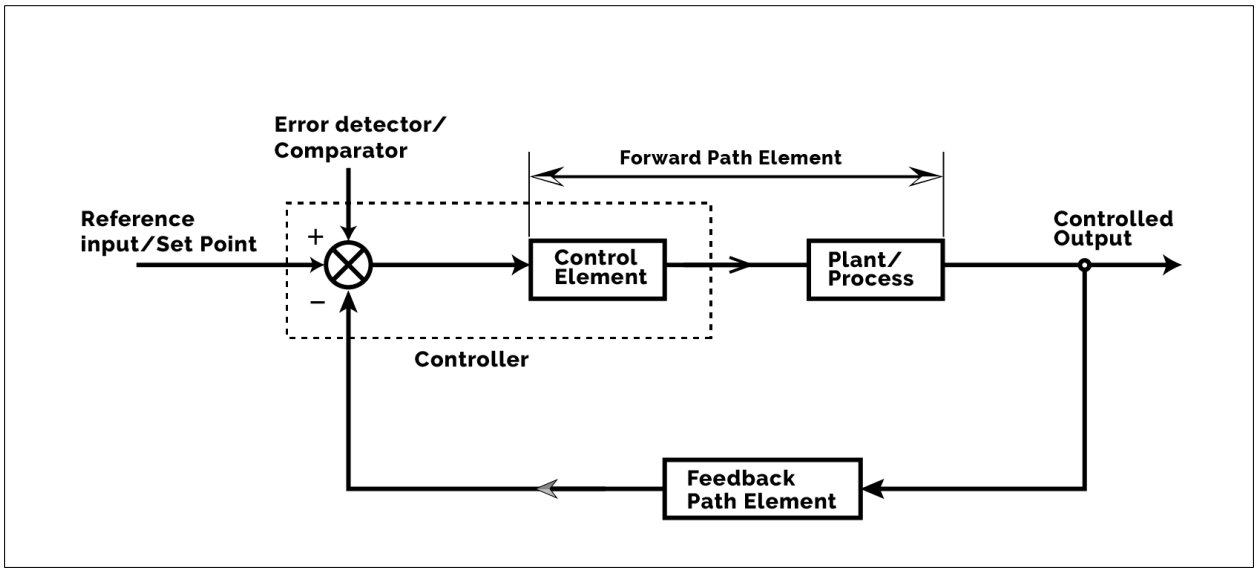

Figure 4 Conventional Closed-Loop Block Diagram of Automatic Control System

2.2. Proposed AI-Based Closed-Loop System

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 are taken and recorded. It is used to create a model and train on AI desired objective- the input value. It 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 assist the controller in performing its functions and additionally stores the recorded data. The proposed block diagram of the system is shown in Figure 5.

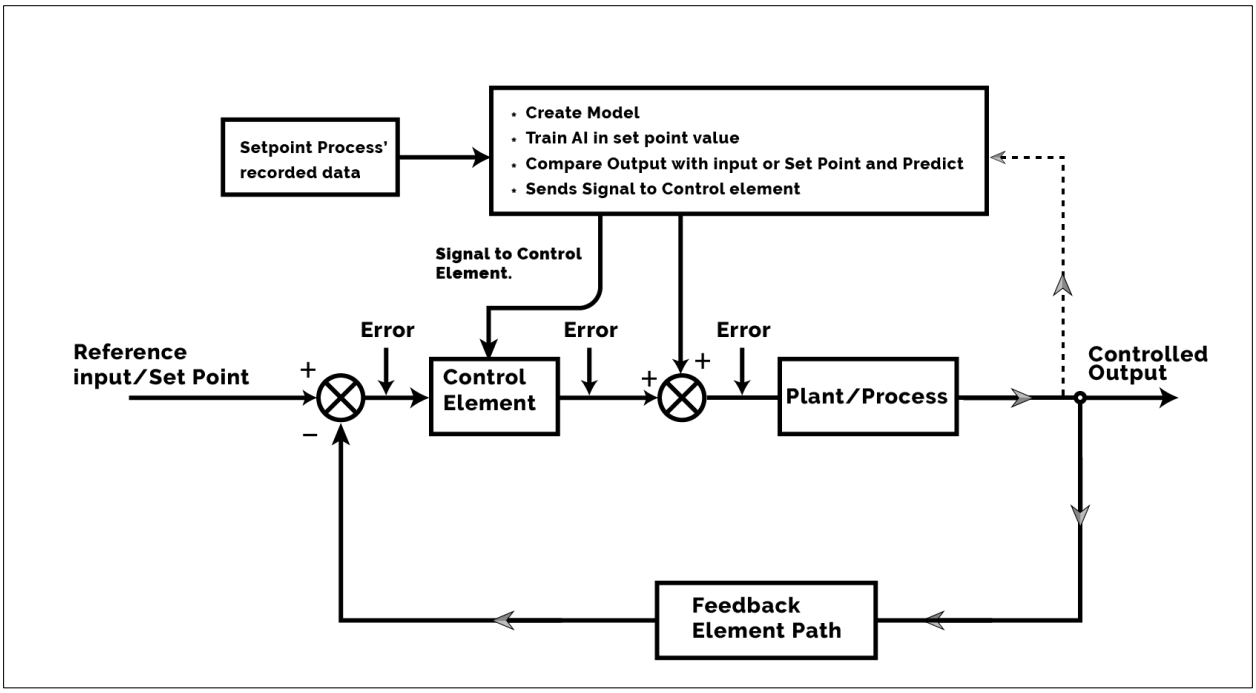

Figure 5 Proposed Closed-Loop Block Diagram for AI Control System Design

3. Conclusion

AI is needed in control engineering to create empirical process models such as ANN. AI based modelling from plant process data is capable to reduce modelling time. Adequate data acquisition is required to generate the needed information for actuation. It offers new window for systems design. AI will increase the potential of recorded data and veritable for analysis and system's evaluation. However, safety measures are needed for online processes and interferences by intruders are possible.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed

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