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Development and Evaluation of Control System in Mechatronics – A Systematic Survey

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Abstract

The advancement of mechatronic enabling technologies and the mechatronic design approach has resulted in sophisticated mechatronic systems. Automated mechatronic systems are becoming more complicated and more intelligent. Mechanical systems that enable the next generation of manufacturing systems will have whole new features and capabilities as a result of these modifications. Even basic monitoring has grown into self-optimizing performance in these gadgets. With the addition of bio-mechatronics and micro-mechatronics, the application fields of mechatronics have expanded. Bio or microcontroller-based applications are the focus of this publication, which aids researchers in building and testing control systems. Design considerations for mechatronic systems are addressed in this work. In order to implement more complicated control algorithms in an industrial setting, new controller design tools are required. The early evaluation of designs and the support of critical design choices may be made possible via the use of modelling and simulation technologies.

Keywords: Conceptual design, mechatronic design, evaluation, reinforcement learning

1. Introduction

The field of mechatronics is becoming more popular. There are many different contexts in which this phrase is used. Even applications that, by a stricter definition, cannot be considered mechatronic systems, employ it. Control system design, plant model, engine control, active suspension, and chain mechanism are all important rules in mechatronics. The Arduino employs embedded systems and microcontrollers to program the design of robots in various applications, such as automated parking systems and temperature monitoring systems. Sensors, controllers, and actuators are important components of categorized control

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systems because they aid in system design. The controller is the mechatronic system's "brain", processing user instructions and detected inputs to create command signals transmitted to the actuator of the system. Electrical energy may be converted to mechanical energy using actuators. Various devices, such as command buttons, GUIs, and touch displays, are used to gather user commands [1-5].

This helps the robot move when NI's lab view software and hardware are configured with inputs and outputs in mind. Nevertheless, not all systems-based designs are mechatronic in nature. By focusing on a single application area, a mechatronics designer may produce sophisticated products. The mechatronic design also suggests a collaborative effort [6, 7]. In order to come up with a synergistic combination, experts in mechanical and electrical engineering, control, and computer engineering should work together.

1.1 Concept Evaluation and Generation

A collaborative robot or an inverted pendulum are examples of nonlinear systems that have been genetically programmed. It employs a magnetic manipulator to examine the approximation capabilities of these approaches further. Each of the four coils is controlled by a current controller, and a steel ball is allowed to roam around the coils. This system grooves of 10 mm in diameter are created around the ball to guarantee that it travels only in the specified direction, with a restriction on the edges [8]. The decision is based on the cost of Reinforcement Learning (RL) computations and the fact that a system with four inputs merely spatially replicates the same nonlinear behaviour; therefore, it has been opted to restrict the system to only two coils in this scenario.

1.2 Development of Mechatronics

Concurrent, interdisciplinary, and integrated design techniques are required for mechatronic product and system development. There are many methodologies and models used in mechatronics and design assessment, that are covered in this chapter. A method for generating and evaluating ideas is shown. There will be an examination of the criteria and mathematical basis of the technique. A systematic technique is used to explain the mechatronic criteria based on mechatronic skills and their scoring.

1. A nonlinear fuzzy integral is used to aggregate new standards.

2. For each application, the mechatronic design index is shown.

In order to achieve a particular target state, it is ensuring that the agent obtains the maximum feasible cumulative reward; the policy is modified repeatedly such that it maximizes the scalar value accumulated across the system's state space. Each state change has a predetermined reward connected with it, which is determined by a value function.

1.3 Parameter Estimation in Control System

The use of Genetic Algorithms (GAs) for dynamical system modelling and parameter estimation is well-established. Genetic programming, on the other hand, is a relatively new modelling technique utilized in RL, but it has the potential to succeed in high-dimensional systems where previous techniques have failed. Analytical equations based on pre-set function combinations are used to generate a nonlinear process. Genetic optimization techniques are known to be computationally intensive, as is the case with these approaches. The local regression is an established modelling technique that provides quick inexpensive approximation. There are a variety of nonlinear modelling techniques available [9-11]. The grid-based local linear model structure and the data-based local linear regression are well defined.

1.4 Benchmark Modelling

Because there are so many different techniques to accomplish the same goal, there are no easy instructions on which strategy to utilize. Moreover, the offered algorithms haven't been thoroughly tested in the real-world environment. Finally, because of their widespread usage in a wide range of sectors, understanding control system applications is necessary. In this study, several control methods for regulating accurate magnetic manipulator systems have been investigated and evaluated.

1.5 Perseverance of purpose

Researchers have recently made substantial success integrating reinforcement approach through special feature extractions. The training agents to play many games using raw pixel data and developing sophisticated manipulative abilities utilizing key sensory inputs are two famous instances. Due to the absence of a widely accepted standard, the continuous monitoring process can be paid through deep learning approach learning. This study presents fresh results from rigorous evaluations on a variety of reinforcement learning techniques used to train deep neural network rules. It is also possible to create, implement, and evaluate novel algorithms and jobs since benchmarks and reference implementations are readily accessible.

2. Related Works

As far back as in 1982, a methodological framework for describing operational parameters of an autonomous guided vehicle system was proposed by Maxwell and Muckstadt. This area of study has continued to flourish ever since. In [12], a kinematic and dynamic study of a tricycle-like mobile robot was presented. Kinematic analysis was performed on a robot equipped with wheels that may move about on a surface. The Euler–Lagrange technique was used to determine the non-holonomic mobile robot's dynamics. It is the goal of this research to evaluate the new position controller for this wheeled mobile robot in terms of global asymptotic stability.

3. Development of Mechatornic Design

Mechatronics is more of a philosophy than a new academic field. It still needs the interdisciplinary expertise of mechatronic design team members with backgrounds in a variety of industries. Mechatronics is a way of thinking about design. In the introduction, it was said that a system’s approach to design is necessary to get the best potential results. However, it's not practical or required to keep re-inventing the wheel since time to market is a major consideration. To respond more quickly to market needs, mechanical designs of manufacturing equipment are possible. It is significantly simpler to adapt a flexible manufacturing line that uses software to reconfigure than a traditional line that uses mechanical equipment to manually change [13-16]. Time to market is a significant consideration not just in product development, but also in the design of manufacturing methods. With the correct tools and knowledge sources, novice designers may benefit from the wealth of information available.

3.1 Control System Design

In the design of mechatronic systems, simulation may play an important role. With computer simulations, various ideas may be compared and assessed without the need to produce physical prototypes, saving money and time. Control engineering simulation tools rely heavily on block diagrams of the mathematical model they simulate. There are direct connections between these models and the different system components' transfer functions.

It's possible to add non-linearities to them if required. As a result, transfer functions and block diagrams may not be the best models for a mechatronic system. Assumption in a block diagram is that separate blocks do not impact each other or that any interaction between unions has been accounted for in the parameters. This suggests that other parts of the system will have difficulty replacing them [17].

As a further complication, a number of physical component parameters are scattered across the block diagram. Investigating the impacts of parameter changes becomes a tiresome task in the absence of a supporting system that automatically links the various mechanical system parameters to the block diagram parameters. Mechanical diagrams and electrical network diagrams do not suffer from this flaw. Energy-based modelling tools like the bond-graph process may connect iconic pictures with mathematical calculations. It is possible to have a better understanding of the design process via the use of such models [18]. Figure 1 shows the basic block diagram of mechatronics control system.

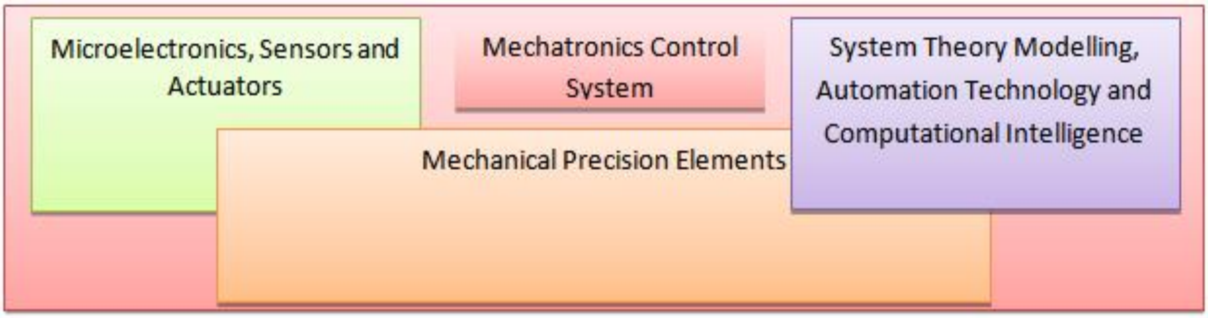

Figure 1. Basic block diagram of mechatronics control system

3.2 Autonomous Vehicle

Unmanned transport vehicles, such as automated guided vehicles, are replacing human-driven industrial trucks and conveyors [19]. There is evidence to support their effectiveness as a workplace feature in reducing logistical mistakes and operational expenses. In some manner, all of these ideas relate to the functioning of self-guiding vehicles. It's possible to swiftly modify the program of automated guided vehicles to respond to unforeseen changes in the manufacturing plan's logistical flows, for example, without a centralized server, they are also capable of operating decentralized. As a matter of fact, in the literature, numerous essential enabling technologies have been identified: automation, augmented and virtual reality (AR and VR), and big data analytics are just a few of the emerging technologies that are changing the way we work and live. In the domain of autonomous robotics, autonomous guided vehicles are one of the technologies. In addition, the input/output subsystem of these autonomous guided vehicles makes it simple to link them to other equipment and devices in the plant. A vast quantity of data generated by these autonomous guided vehicles are sent over by IoT protocols, saved and analyzed by the cloud computing systems, and utilized by big data technologies for control parameters and production optimization [20-22].

3.3 Mechatronic appraisal of design

A full assessment necessitates the establishment of design standards and requirements. Well-defined criteria and specifications may help the designer produce functional ideas that can then be tested. In order to do the evaluation, four stages must be followed. Prior to evaluating alternatives, the criteria for determining which ones are worth considering must be established. Finally, it is necessary to decide on the relative relevance of each of the aforementioned criteria and how they interact. A discrete Choquet integral is used to calculate the final scoring values after the design choices have been examined for each metric. Option A is selected because of its high score, which is based on the unique criteria and other aspects of the design environment (design team experience, knowledge, etc.). The designer may now either choose the option that will be further developed in the detailed design phase or go back and re-evaluate some of the earlier processes and design choices [23].

3.4 Reinforcement Learning Evaluation

This technique may be used to optimize deep neural network policies in most primary and locomotors tasks, despite its simplicity. Reinforcement may provide competitive performance even in professions with a high Degree of Freedom of movement (DOF), such as Ant. Reinforcement, on the other hand, might suffer from early convergence to local optimal.

3.4.1 Decision process

Algorithms that use the notion of incentives and penalties to train the system to adopt suitable behaviors are known as machine learning algorithms. The Markov Decision Process, or MDP, is believed to exist in our universe. This approach served as the foundation for the notion of reinforcement learning. In spite of the fact that it doesn't explicitly model the MDP, the model-free technique is a real algorithm in this system. A policy is a probability distribution generated by the system when a specified action is taken in a specific condition.

The system is permitted to change the rewards and penalties it awards and gets them as a result. Negative incentives are sometimes known as punishments. Most policies are calculated using the total of immediate rewards and discounted sums of all prizes earned after the initial action was taken. Problem is that the machine is educated to be an expert at route planning by using this technique. Because of the policy-based education system, this might be a problem.

3.4.2 Dynamic programming

Reinforcement Learning (RL) and Dynamic Programming (DP) may be used to solve issues in a wide range of domains, including autonomous control and artificial intelligence. DP and RL, on the other hand, can only discover accurate solutions in the discrete case for many of these problems. Approximation is thus important for actual DP and RL.

3.4.3 Optimizing steps

Algorithms that deal with this kind of situation benefit greatly from optimum control. In the context of artificial intelligence, RL offers a mechanism for creating a fictitious function to use for the previous information through feedback. Artificial intelligence's ultimate objective is to create such a being. In DP and RL, two sets of identical terms and notations are used: The vocabulary and notations used in this section are heavily influenced by control theory. Figure 2 shows the dynamic programming and reinforcement learning elements in the block diagram.

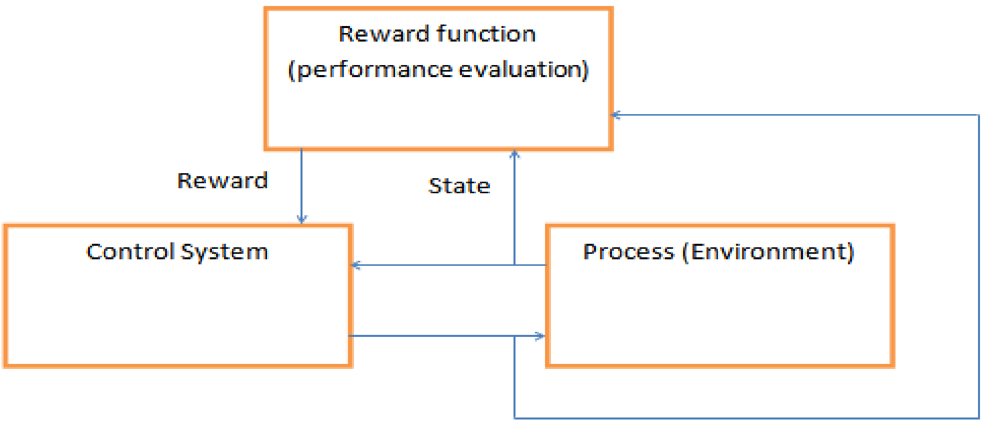

Figure 2. DP and RL elements for interaction

A Markov decision process may be used to model the DP/RL issue (MDP). In an MDP, the controller (agent) monitors the process (environment) state and performs an action in accordance with a control system unit at each discrete time step. This action causes the function to transition into a new state. The controller receives a scalar reward for a smooth transition. After that, the controller takes a measurement of the new state, and the process is repeated. Nonlinear and stochastic state transitions are common. There's a visual representation of this kind of interaction. The policies that maximize the overall feedback action across an exchange have been seeked.

4. Future Research

The conventional communication protocols such as TCP/IP have been used to link "things" to the Internet in the Internet of Things (IoT). Things provide services by using their unique identification, data collection and transmission, and actuation capabilities, whether or not they need human involvement.

4.1 Information and communication technologies

To achieve this level of automation, especially without the need for human interaction, new tools and research will be required. Closing the loop in any setting is a difficulty regardless of technology, but IoT definitions tend to focus on that aspect of the problem. It is necessary to have a solid foundation in dynamics and control theory. In a dynamic system, feedback may have a positive or negative impact on the system's behaviour. Autonomous feedback control may allow unstable systems to achieve levels of performance that are impossible for stable systems to achieve, despite the system's apparent stability. Close coordination between control specialists and ICT experts will be necessary for the closed-loop integration of physical systems with the Internet.

4.2 Future IoT enhancements

New theoretical and algorithmic breakthroughs by the control community can only partly overcome the limits of today's IoT infrastructure. The IoT stack and existing component technologies fundamentally restrict the capability for enhanced control, as is often envisioned. There are certain issues with the Internet of Things (IoT), but researchers are working to overcome these issues and make closed-loop control feasible.

4.2.1 Complexity

Complication has become a major issue in many industries in this modern society. Detailed system-wide analysis, estimate, and high-performance control design are required to overcome this challenge without raising the cost of the systems.

4.2.2 Capability of control system

Previously, control system technology was just a service for a certain technical solution; currently, it's an actual brick for optimizing investment indices like capital and operational expenditure. In the near future, the control position will undergo yet another transformation as it becomes an essential and cross-sectoral component in an increasingly complex industrial landscape.

4.2.3 Transition effect

It is essential that current resources, raw materials, and energy be better used in order to transition to a low-carbon and sustainable economy. The use of sophisticated modelling, simulation, and control systems will be essential in making this shift.

4.2.4 Decision process

Managing complex infrastructures, such as the engineered devices and systems that support our civilization, as well as our societal, economic, and political institutions, relies on the discipline of control because, it is the only one to provide a rigorous foundation for making optimal decisions in dynamic systems when faced with uncertainty.

5. Conclusion

Mechatronics is a systems-based design concept for electromechanical systems. For a company to be successful, it must be able to provide all the required support tools. This paper has discussed about modelling and simulation tools that are tailored to certain use cases. For the purpose of evaluating design options, well-known methodologies for conceptual analysis and assessment throughout the mechatronic design process have been described.

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