


# Chapter 2


## Hybrid Control Systems: Integrating AI With Traditional Methods

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### ABSTRACT

*In recent years, hybrid control systems have been used in many practical applications because they are an adequate method capable of addressing this kind of complexity and vagueness, which is characteristic of today's business and scientific environment. It provides the evaluation of the fundamental concepts and solutions for the incorporation of AI in conventional control schemes. The chapter also examines other fields including robotics, aeroplane, industrial processes and power systems as other areas that have benefited from hybrid control methods. To solve the difficulties posed by nonlinear, time varying, and stochastic systems, the interaction of machine learning approaches such as artificial neural networks, fuzzy logic, and adaptive control with PID, optimal and robust control approaches is explored. Possible research topics bring concerns the analysis of hybrid control architectures for large-scale, contingent, safety-relevant systems, the extension of sensing and communication functionalities, and design of proper planning and decision-making strategies.*

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## 1. INTRODUCTION

The analysis of hybrid control systems enables the identification of a promising and nearly invulnerable technique in modern control engineering of complex dynamic processes while combining the confirmed characteristics of artificial intelligence with the abilities that have been proved for traditional control approaches. It is important to know that these systems are capable to govern both continuous and discrete dynamics and therefore are very suitable to resolve the increasing complexity and the uncertainty, which is demonstrated in many modern applications (Piga & Bemporad, 2020). Classical control strategies often fail to operate satisfactorily when it is faced by non-linear systems, unexpected disturbances, or varying working conditions. In cases where such knowledge bases cannot be developed then there is benefit in using artificial intelligence techniques such as machine learning, fuzzy logic and expert systems. Due to the incorporation of the intelligent algorithms, the hybrid control systems can also apply data learning, adapt to the dynamic environment, and make accurate real-time decisions overcoming the limitations that are present in the conventional control (Bessa, 2022).

### 1.1 The Historical Evolution and Driving Forces Behind Hybrid Control Systems

This progression of control systems starts from the precept of the classical control theory that was based on mathematical model and analysis of mainly linear systems to develop the more current state of the art modern control schemes that utilize enhanced computational paradigms to solve nonlinear system related issues. Initially, control systems depended a great deal on mathematical approaches and seemed to have difficulties in dealing with the variability and disturbances. The new digital computers came into the picture which helped to exercise much better control algorithms and the new adaptive and robust controls. The general advancement of automation technology in the recent decades have also broadened the scope of control engineering. Therefore, the next step on this evolutionary path is the hybrid control systems that incorporates the learning and decision-making characteristics of AI into a control design that is more flexible and intelligent (Zhu & Zhong, 2023).

### 1.2 Current Relevance and Impact of Hybrid Systems in Modern Technology

It is also clear that the importance of hybrid control systems is as relevant as ever in today's technologies, which are getting more complex and constantly requiring more flexibility. Here are examples which show their necessity in different branches and Figure. 1 relates as to influence that hybrid systems have in the current technology. Robotics: Hybrid control systems are especially suitable to be implemented in robots working in unknown and complex spaces. These systems make it possible for the robots to quickly shift from one operation to another, avoid barriers that may have been unknown before and update their data base. For example, an autonomous mobile robot that is likely to function in an unpredictable environment such as a residential building may mainly use classical control for the basic operation of the robot's movement while using artificial intelligence for navigation and avoidance of the obstacles in environments (Levine & Shah, 2022). Aerospace: Various control system solutions are used in the aerospace industry to control the aircraft and spacecraft where there is need for Integrated Hybrid Aerospace Control Systems referred in Figure 1. These systems can operate under many different conditions such as during the acceleration phase during take-off and landing, or during level flight when changes

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