

Proposal for the implementation of control strategies through Texas Instruments ecosystems

Propuesta para la implementación de estrategias de control a través de los ecosistemas de Texas Instruments

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Abstract

Introduction: Technological evolution has contributed to the development of multiple microcontrolled platforms, such as Arduino, through which different general-purpose applications can be implemented. However, the need for more specialized systems, such as those required for real-time control, has contributed to the development of microcontrolled systems, including those manufactured by Texas Instruments.

Objective: The objective of this study is to design and implement real-time control strategies using Texas Instruments ecosystems.

Methodology: The work focused on an experimental framework through which digital controllers were designed using the control coprocessor as one of the ecosystems available in the Texas Instruments C2000 microcontrollers. Subsequently, the designed controllers were implemented in test plants to validate their response in real time.

Results: A range of control strategies, both classical and modern, were implemented on the Texas Instruments C2000 microcontrollers. This was done to validate the response of the microcontrollers in the selected test plants.

Conclusions: The controllers designed for the C2000 microcontrollers through the Texas Instruments ecosystems used allow the development of real-time control systems quickly and with high processing capacity given their characteristics. Moreover, these platforms find applications not only in teaching processes but also in industrial environments, given the existence of various software tools like MATLAB and Code Composer Studio for their programming.

Keywords: C2000 microcontroller, Control loop, Digital control, experimental framework, MATLAB/Simulink, Real-time control, Texas Instruments

Resumen

Introducción: La evolución tecnológica ha contribuido al desarrollo de múltiples plataformas de microcontrol, como Arduino, mediante las cuales se pueden implementar diversas aplicaciones de propósito general. Sin embargo, la necesidad de sistemas más especializados, como los requeridos para el control en tiempo real, ha impulsado el desarrollo de sistemas de microcontrol, incluyendo los fabricados por Texas Instruments.

Objetivo: El objetivo de este estudio es diseñar e implementar estrategias de control en tiempo real utilizando los ecosistemas de Texas Instruments.

Metodología: El trabajo se centró en un marco experimental mediante el cual se diseñaron controladores digitales utilizando el coprocesador de control como uno de los ecosistemas disponibles en los microcontroladores C2000 de Texas Instruments. Posteriormente, los controladores diseñados se implementaron en plantas de prueba para validar su respuesta en tiempo real.

Resultados: Se implementó una variedad de estrategias de control, tanto clásicas como modernas, en los microcontroladores C2000 de Texas Instruments. Esto se realizó para validar la respuesta de los microcontroladores en las plantas de prueba seleccionadas.

Conclusiones: Los controladores diseñados para los microcontroladores C2000 mediante los ecosistemas de Texas Instruments permiten el desarrollo rápido de sistemas de control en tiempo real con alta capacidad de procesamiento, dadas sus características. Además, estas plataformas encuentran aplicaciones no solo en procesos educativos, sino también en entornos industriales, gracias a la disponibilidad de diversas herramientas de software como MATLAB y Code Composer Studio para su programación.

Palabras clave: Microcontrolador C2000, bucle de control, control digital, marco experimental, MATLAB/Simulink, control en tiempo real, Texas Instruments



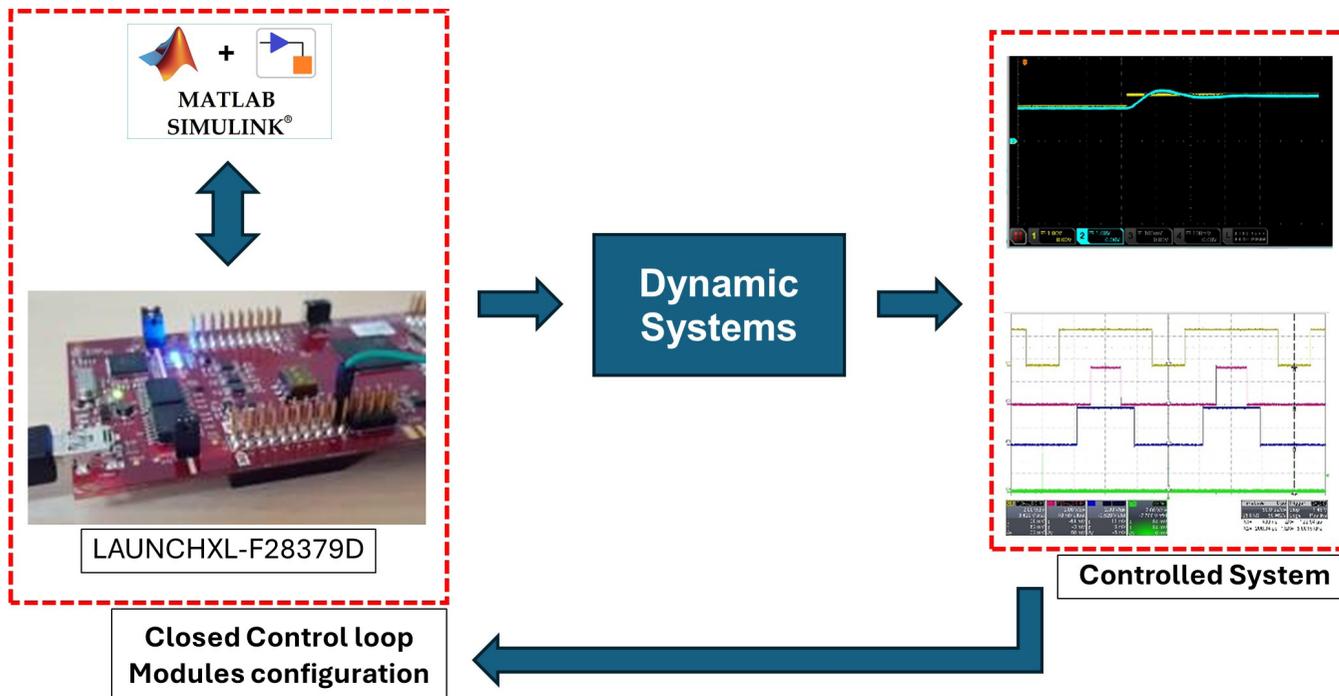
Spanish version



Contribution to literature:

Real-time control of systems and physical variables requires robust, low-cost solutions that can meet the needs of different environments. Although there are currently different platforms and microcontrollers on which this type of development can be carried out, several of these devices do not allow the development of robust applications due to their physical limitations. Therefore, the research focused on the use of the Texas Instruments LAUNCHXL-F28379D microcontroller platform and its different internal modules, where experimental tests and digital controller configurations were also established through the Control Law Accelerator (CLA) and the execution of concurrent tasks through the two CPUs. Likewise, the research provides the necessary elements for the integration of the LAUNCHXL-F28379D platform into environments such as MATLAB/Simulink, where classic and modern control strategies can be deployed and validated. Another contribution focused on the rapid prototyping (RCP) approach, providing evidence of the ability of these platforms to execute closed-loop control in real time, which positions them as a robust and accessible alternative for both teaching and industrial applications in embedded control systems.

Graphical Abstract





Introduction

Control systems are of fundamental importance in the automation and optimization of industrial processes, including manufacturing and robotics. The efficient implementation of these systems is critical to achieving accurate, efficient, and reliable solutions that meet the demands of a progressively demanding market. In this context, technological advances over the last decade have contributed to the development of a wide range of systems or platforms that integrate different hardware resources, thereby enabling the implementation of real-time control systems under the concept of Rapid Control Prototyping (RCP) (1). Existing platforms can be classified mainly by the devices with which they are equipped, including microprocessors, microcontrollers, Digital Signal Processors (DSPs), Analog-to-Digital Converters (ADCs), Pulse Width Modulation (PWM), General Purpose Input/Output (GPIO) ports, Input/Output (I/O) peripherals, and communication protocols. Despite the existence of these components, many lack control architectures that would allow integration between components to improve their real-time response. A compendium of the platforms that have been developed and on which some applications for real-time control have been implemented is provided in (2).

Manufacturers such as Texas Instruments (TI) have transformed the manner in which engineers develop and apply real-time control strategies through such devices, as they feature microcontrolled platforms equipped with advanced hardware for implementing digital controllers. The C2000 microcontroller is an example of a platform that has been equipped with an ecosystem, such as the Control Law Accelerator (CLA). The CLA is a coprocessor that has been designed to execute robust control tasks in parallel with the main processor. This architecture optimizes the use of system resources, thus providing improved performance and responsiveness (3). TI's C2000 microcontrollers have been developed for real-time control in a variety of sectors, including the automotive, electric motors, solar energy, and low-cost compact system design sectors, among others. These microcontrollers have the capacity to enable new possibilities for automation, control, and sustainability in different fields of engineering (4).

The advantages of Texas Instruments' C2000 microcontrollers go beyond their physical characteristics and the fields in which they have been used. These devices can currently be programmed through platforms such as Code Composer Studio (CCS), MATLAB/Simulink, and Energia IDE, among others. The advantage of multi-platform programming is that some of these platforms are open source and do not require any type of license for use. Examples of these are Code Composer Studio and Energia IDE. MATLAB/Simulink, on the other hand, is a tool that requires license for use; however, this is not currently considered a limitation because it is being used in many educational institutions and industries worldwide.

The interesting thing about open source software tools is that their source code can be accessed to make modifications or updates, as was done in (2), where some modifications were made to the Energia IDE source code to include some features of the LAUNCHXL-F28739D card, which is equipped with a C2000 Delfino microcontroller. Other studies have favored the use of tools such as MATLAB/Simulink, which has a Toolbox that provides full support for the implementation of

fundamental functions such as PWM, ADC, and GPIO, as well as more advanced functions such as Control Law Accelerator (CLA) on different Texas Instruments microcontroller platforms (5), (6), (7). The software tools mentioned above are not the only ones used for the development of applications with microcontroller platforms, as there are projects carried out in environments such as LabVIEW (8). In addition to the software and hardware tools available for the design and implementation of real-time control systems, another advantage of this type of device is its low cost, as some of these systems can cost between \$28.59 and \$50 USD (9), (10).

A survey of the relevant literature reveals that Texas Instruments devices, most notably the TMS320F28379D microcontroller and its embedded system, have been employed in the design of PID controllers for Buck converters. The integration of MATLAB/Simulink for modeling and Code Composer Studio (CCS) for hardware implementation has yielded a rapid dynamic response and a high degree of system stability under challenging industrial conditions (11). In the context of hybrid energy systems, the combined use of ATmega microcontrollers on platforms such as Arduino and LAUNCHXL-F28379D is particularly salient, in conjunction with strategies such as maximum power point tracking (MPPT) and pulse width modulation (PWM), which enhance efficiency and extend the life of batteries managed by embedded BMS (12). Furthermore, the integration of C2000 microcontrollers with MATLAB and Simulink Embedded Coder facilitates the automatic generation of optimized code in C/C++, thereby significantly reducing development time and enabling rapid validation through simulation and direct execution on the hardware (13), (14). In (15), a low-cost real-time control platform with embedded isolated electrical sensors was proposed, also supported by C2000 microcontrollers and validated by controlling various converter topologies such as buck, push-pull and H-bridge, all graphically programmed in Simulink, which enhances its academic and industrial use with minimal need for low-level coding. Finally, another study presented experimental validation of an open-loop control system for a three-phase asynchronous motor, where the TMS320F28379D microcontroller executes pulse-width modulation (PWM) control signals to an IGBT inverter. This system also integrates speed and current sensors for real-time communication via MATLAB/Simulink for visualization and analysis, reinforcing its applicability in low-cost, high-reliability industrial automation systems (16).

Methodology

The development of the experimental framework for the research carried out focused on two elements: the first corresponds to the materials, and the second corresponds to the methods used, in which all the configurations and approaches used for the development of the proposed control systems are presented.

Materials: LAUNCHXL-F28379D platform

The LAUNCHXL-F28379D is a microcontrolled platform or embedded system, as these types of devices are commonly referred to. The development of this technology was undertaken by Texas Instruments (TI) with the objective of creating a low-cost platform for evaluation and rapid

prototyping. The device is equipped with a C2000 Delfino microcontroller, bearing the reference number TMS320F28379D. The development of this platform was specifically for applications in motor control, power conversion, and high-performance automotive systems (17). The device operates at a speed of 200 MHz, integrating two 32-bit cores, a CLA coprocessor, 12/16-bit ADC modules, and a 12-bit DAC. The system incorporates ePWM/HRPWM modules that can be synchronized with the ADCs, thus enabling control loops with time resolution in the order of microseconds to be implemented. For sensing and position measurement tasks, peripherals such as eCAP, eQEP, signal inputs, and 5 V encoder connectors are offered. As illustrated in Figure 1, the LAUNCHXL-F28379D platform from TI offers a comprehensive overview of the available options.

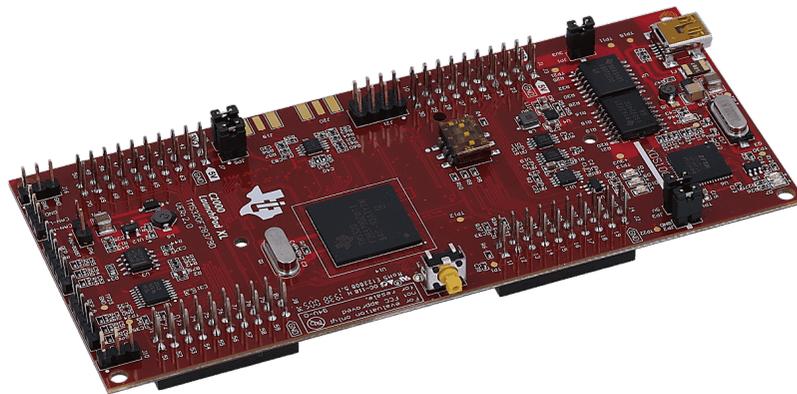


Figure 1. Texas Instruments LAUNCHXL-F28379D platform.

Source: (17).

Test plants

The first plant used consisted of a random transfer function provided by MATLAB. The random systems generated from there are stable and have highly varied dynamics, allowing functions to be created to emulate any physical behavior. The mathematical model for the generated transfer function is presented in equation (1)(1).

$$G(s) = \frac{4}{s^2 + 0.8s + 4} \quad (1)$$

As demonstrated in Figure 2, the system response is shown in continuous time. The dynamics of the system demonstrate a maximum overshoot of 52.7% and a settling time of 9.89 seconds.

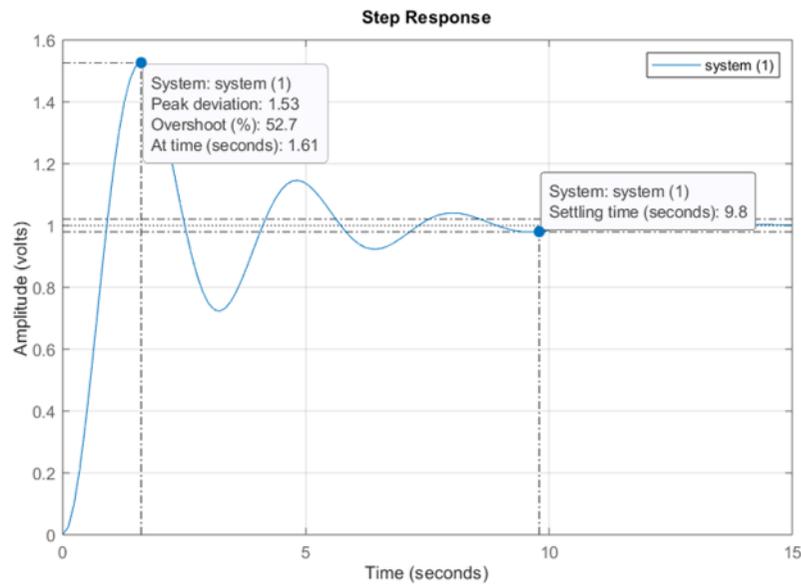


Figure 2. Transient response for the test plant generated by MATLAB.

Source: The authors.

The second plant was focused on a level system consisting of a 16-liter glass tank, two submersible pumps, and a float for level measurement. The pumps used are activated by PWM signals and, like the level sensor, are powered by 6 VDC. The structure of the plant and its dimensions are shown in Figure 3.

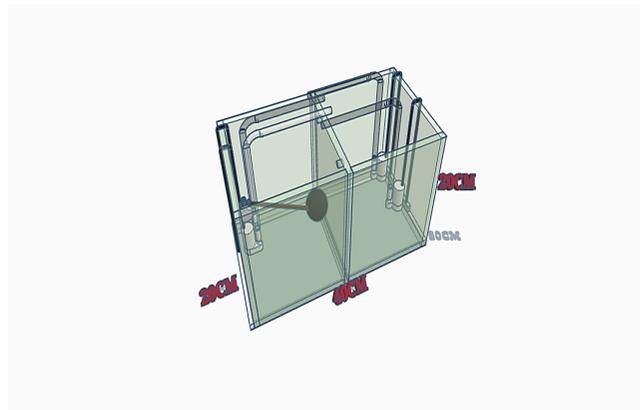


Figure 3. Level plant designed for validation of the experimental framework.

Source: The authors

The mathematical model that has been developed to describe the behavior of the level plant is presented in equation (2)(2). The model under consideration was obtained through data collection and an off-line identification process in MATLAB.

$$G(s) = \frac{0.0009854s + 6.558 \times 10^{-5}}{s^3 + 0.18s^2 + 0.005435s + 6.38 \times 10^{-5}} \quad (2)$$

The transient response for the level plant is shown in Figure 4. It can be seen that the dynamics of the system correspond to those of this type of system and have an approximate settling time of 176 seconds.

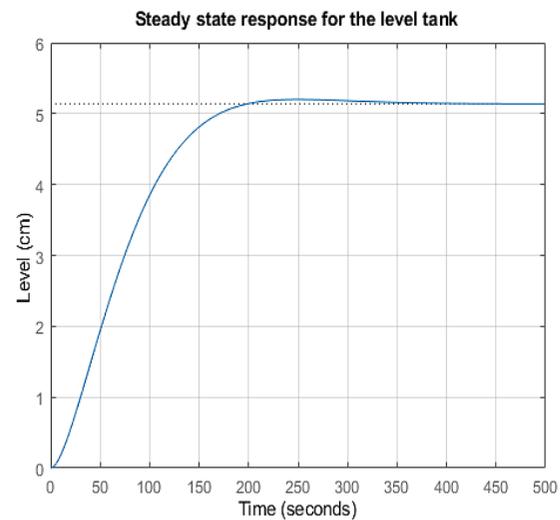


Figure 4. Transient response for the level plant shown in figure 3.

Source: The authors

MATLAB PID Tuner

PID Tuner is an interactive application included in MATLAB's Control System Toolbox that enables automatic tuning of PI, PID, and PID controllers for linear systems or linearized models. PID Tuner automatically calculates the K_p , K_i and K_d parameters for different PID controller configurations. Using this application does not require in-depth knowledge of classical control theory, as it is a graphical method, and its interface allows the user to visually adjust the control system response under parameters of faster response and greater stability, observing its dynamics and response in real time. In addition, PID Tuner offers the possibility of exporting the controller to the MATLAB workspace or to other modules such as Simulink, where automatic code generation is also available, providing the user with flexibility in how they interact with and operate the developed controllers. Figure 5 shows the graphical environment of MATLAB's PID Tuner.

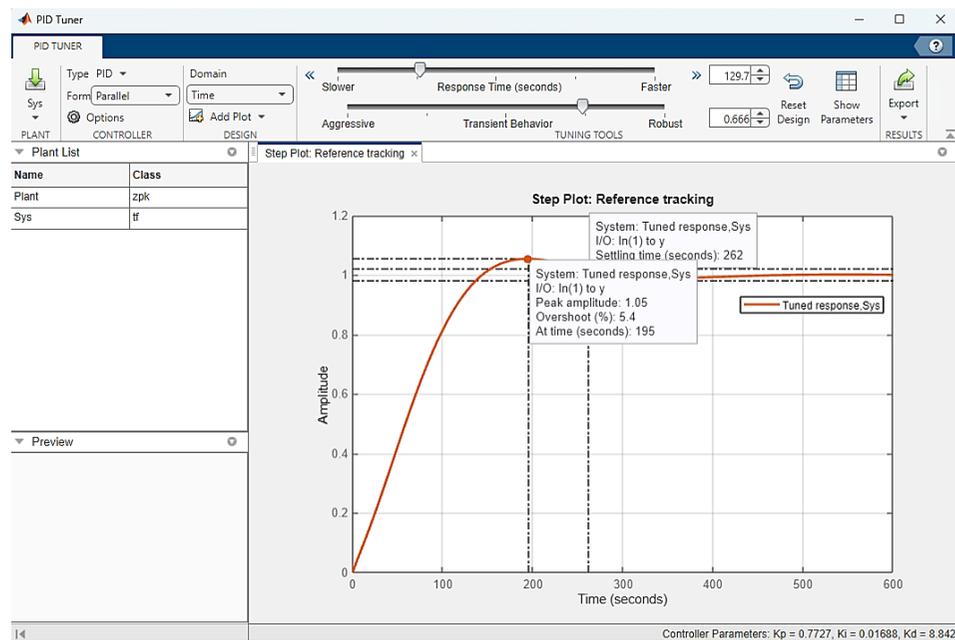


Figure 5. Graphical user interface for the MATLAB PID Tuner.

Source: The authors

Méthods: CLA MATLAB/Simulink Configuration

One of the contributions of the research carried out focused on the configuration and use of ecosystems integrated into the Texas Instruments LAUNCHXL-F28379D card for the implementation of real-time control strategies. In this particular instance, the ecosystem employed was the Control Law Accelerator (CLA), which was configured and programmed using MATLAB/Simulink, employing the use of block diagrams. CLA constitutes a specialized processing ecosystem that has been integrated into several microcontrollers of the C2000 family for the implementation of real-time control systems. Its primary function is to reduce the CPU's operational load, thereby decreasing the time between data acquisition and system response. The integrated structure of the C2000 microcontroller of LAUNCHXL-F28379D is summarized in figure 6.

While the CLA performs specific low-latency control tasks, the CPU is responsible for managing other functions, including communication and general supervision of the different system signals. It is evident that other features of the CLA are geared towards parallel processing and Interrupt Service Routines (ISR). The structure of the CLA divides instruction execution into several stages that run simultaneously with CPU instructions. The configuration of the CLA in MATLAB/Simulink involves the use of two distinct components: the CLA Subsystem, which serves as the entry point for operation data and the vectors or matrices that facilitate the operation, and the CLA Subsystem itself. The second block corresponds to the task trigger and is designated as the CLA Task Trigger. As illustrated in figure 7, the block diagrams mentioned previously offer a visual representation of the configuration and operational characteristics of the CLA.

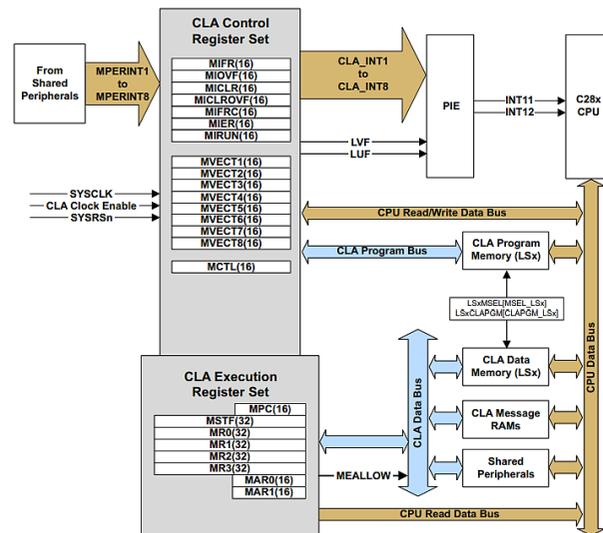


Figure 6. Block diagram of the internal architecture of the CLA ecosystem.

Source: Texas Instruments

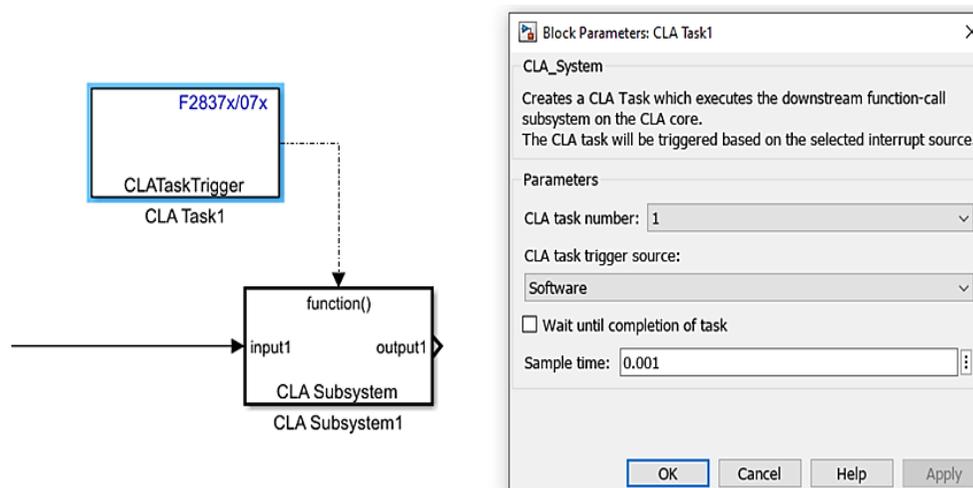


Figure 7. CLA configuration in MATLAB/Simulink.

Source: The authors

Classic and modern controllers

When discussing process control, it is important to keep in mind that the theoretical concepts highlight three main categories: classic control, modern control, and advanced control. Each of these encompasses a variety of controllers that vary in terms of their implementation and complexity. Control theory also uses two basic forms of representation: continuous time and discrete time. The former is used when analyzing and studying systems at the simulation level, while the latter is used when implementing physical systems and hardware tools such as a DSP, FPGA, microcontroller, etc. (18), (19). As the use of physical systems was established in the experimental framework of the research carried out, the controllers were developed in discrete time.

Classic controller

The PID (Proportional, Integral and Derivative) controller depicted in figure 8 was selected as the classical technique. This controller is used in a variety of industrial sectors because of its versatility, which allows it to be used in both standard and parallel forms. Furthermore, the combination of its different stages enables the creation of additional variations, such as PI, PD, PID2 and PIDF (20). Another salient feature of PID controllers is their ability to adjust while the system is in operation (21). Currently, a multitude of tuning techniques are documented for each of the controller's components (22–24).

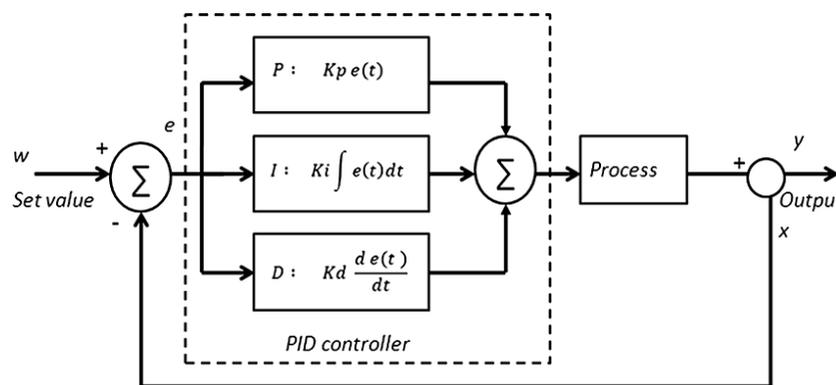


Figure 8. Block diagram for the PID controller used.

Source: (25)

Modern controller

The RST (Reference Signal Tracking) controller depicted in figure 9 was used as a modern technique. The RST controller provides the system with dynamic behavior because its structure is based on pole relocation, which helps to improve the system's performance in the face of external disturbances and other parameters. In contrast to the PID controller, the RST necessitates a comprehension of the dynamics of the plant or process in open loop.

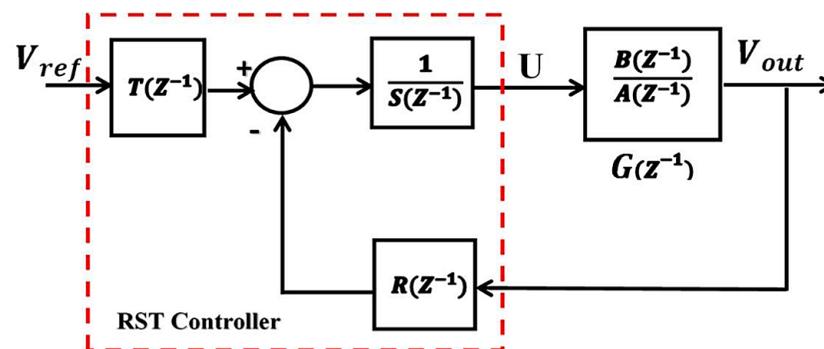


Figure 9. Block diagram of the used RST controller.

Fuente: The authors

Finally, to synthesize the methodological procedures through the integration of the various components and materials, figure 10 presents a comprehensive methodological workflow diagram designed to fulfill the research objectives.

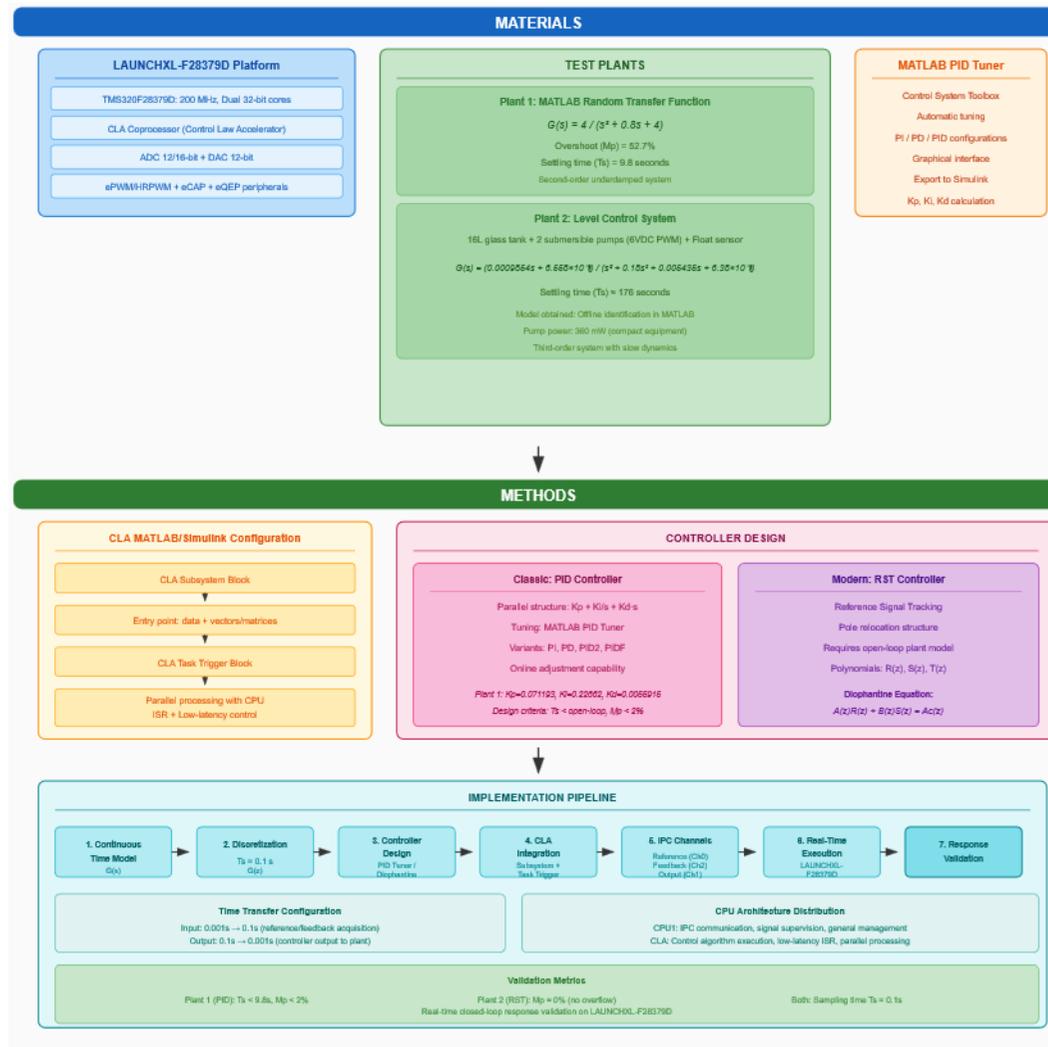


Figure 10. Methodological workflow diagram.

Fuente: The authors

Results

Controllers implementation

The PID controller applied to the plant generated by MATLAB was designed and implemented taking into account that the system would have a settling time (T_s) shorter than that of the open-loop response, and an overshoot (M_p) of less than 2% was proposed. The controller was tuned using MATLAB's PID Tuner, using the plant transfer function described in equation (1). The designed controller is shown in Figure 7, which has a parallel structure. The advantage of the

PID Tuner is that it allows the controller structure to be changed as it is tuned. After adjusting the parameters, the values $K_p = 0.071193$, $K_I = 0.22662$ y $K_D = 0.0055915$ were obtained. The responses for the simulation of the open-loop system and the closed-loop controller are shown in figure 11.

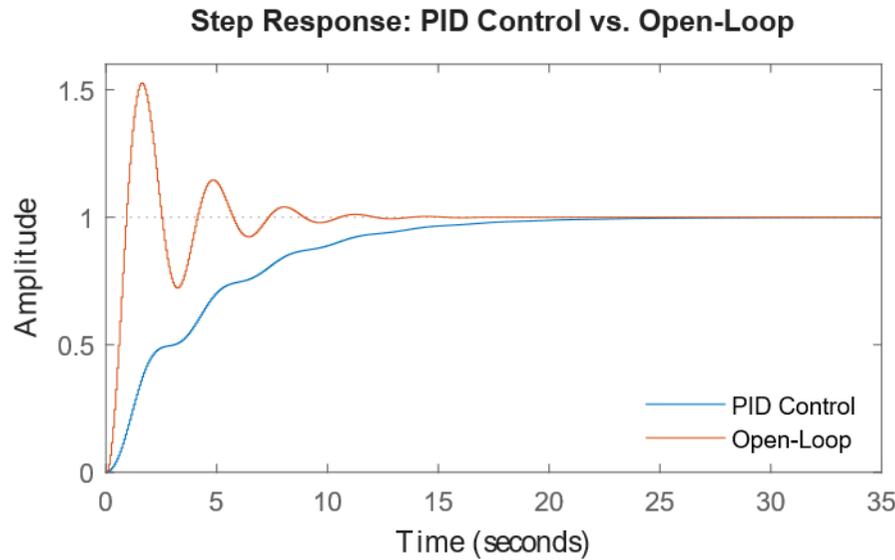


Figure 11. Open-loop simulation of the plant described in equation (1)(1) and its PID controller.

Source: The authors

Following the acquisition of the constants K_p, K_I y K_D for the PID controller, the digital control strategy for the test plant, as delineated in equation (1)(1), was implemented. The result of this implementation is shown in figure 12, which also shows the configuration of the PID controller in the CLA ecosystem of the LAUNCHXL-F28379D platform.

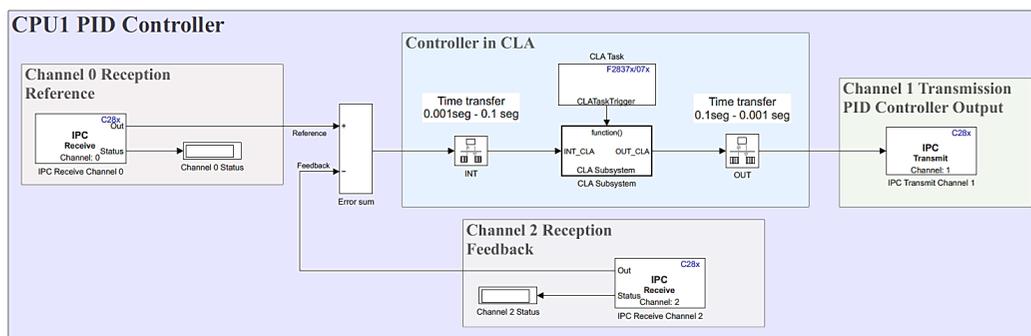


Figure 12. Proposed structure for the PID controller in the test plant (1)(1).

Source: The authors

In order to validate the operation of the proposed control structure for the test plant, the system presented in equation (1) (1) was discretized. For the purposes of this process, a sampling time $T_s = 0.1T_s = 0.1$ seconds was used. The discrete representation of the system is presented in

equation (3)(3), and the response to the implementation of the control strategy on the LAUNCHXL-F28379D platform is shown in figure 13.

$$G(z) = \frac{0.17604z^2 + 60.16172}{z^2 - 1.44z + 0.77777} \quad (3)$$

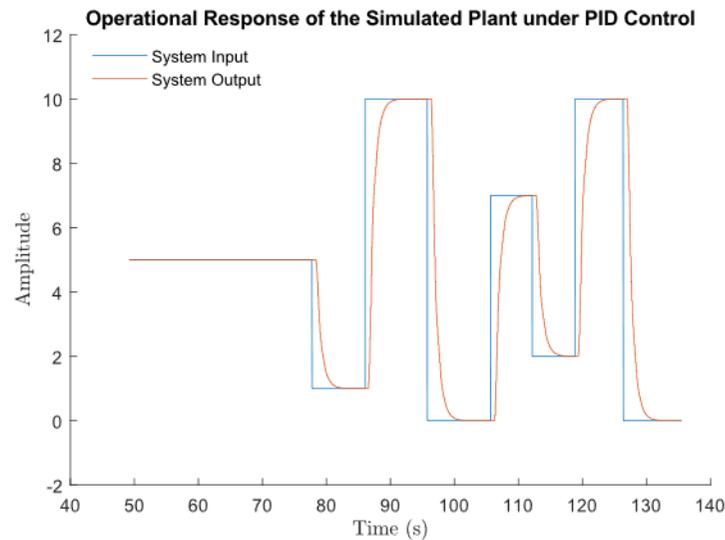


Figure 13. PID controller response for test plant (1) on the LAUNCHXL-F28379D platform using the CLA ecosystem.

Source: The authors.

The design of the RST controller applied to the level plant was based on its discrete mathematical model, which was obtained from equation (2)(2). Once more, using a sampling time of $T_s = 0.1$ seconds, the mathematical representation presented in equation (4)(4) was obtained. Subsequently, the configuration of the RST controller, as depicted in figure 9, was adopted. This involved identifying the values of the polynomials $R(z)R(z)$, $S(z)S(z)$ y $T(z)T(z)$, which were essential for the configuration of the system to achieve the desired closed-loop behavior. The polynomials under consideration were obtained by solving the Diophantine equation presented in equation (5)(5).

$$G(z) = \frac{2.45 \times 10^{-6}z^3 + 2.466 \times 10^{-6}z^2 - 2.417 \times 10^{-6}z - 2.433 \times 10^{-6}}{z^3 - 2.982z^2 + 2.964z - 0.9822} \quad (4)$$

$$A(z)R(z) = B(z)S(z) = A_c(z) \quad (5)$$

By solving the system of equations for the RST controller of the level plant, the polynomials for the control loop were obtained, as shown in figure 14. For this design, it was taken into account that the behavior of the closed-loop control system should not present oscillations greater than the reference value, as this would represent an overflow of the maximum level allowed by the characteristics of the system.

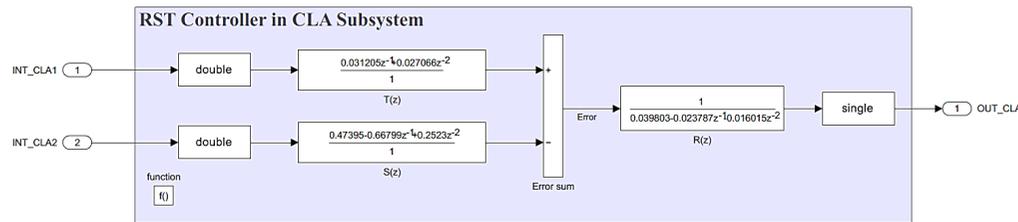


Figure 14. Polynomials obtained for the RST controller of the plant described by equation (4)(4).

Source: The authors.

Once the values of the polynomials $R(z)$, $S(z)$ y $T(z)$ for the RST control structure were known, the controller shown in Figure 8 was simulated in MATLAB/Simulink. In this controller, a minimum overshoot (M_p) (close to zero) had to be guaranteed given the dynamics of the plant to be controlled. The result of the simulation of the RST controller for the level plant is shown in figure 15.

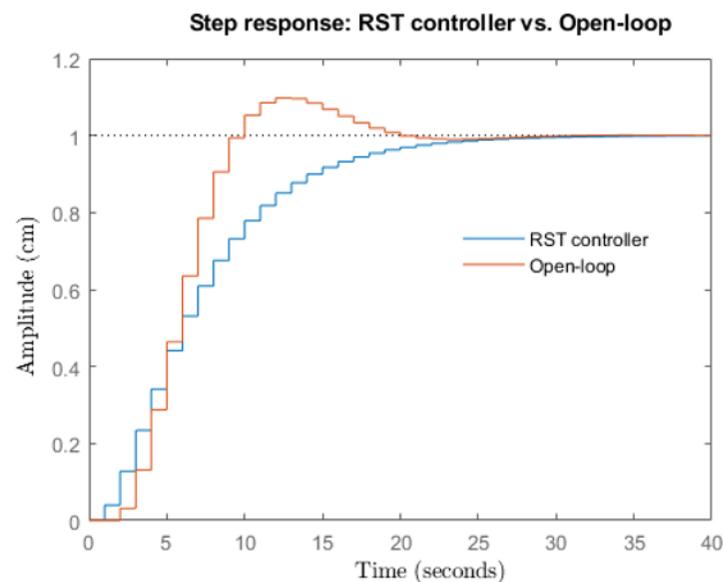


Figure 15. Open-loop simulation of the plant described in equation (4)(4) and its RST controller.

Source: The authors

Following simulation of the RST control strategy for the level plant, the control loop depicted in figure 8 was implemented in MATLAB/Simulink using the CLA ecosystem of the LAUNCHXL-F28379D platform, employing a methodology analogous to that employed for the PID controller. The result of this implementation structure is demonstrated in figure 16.

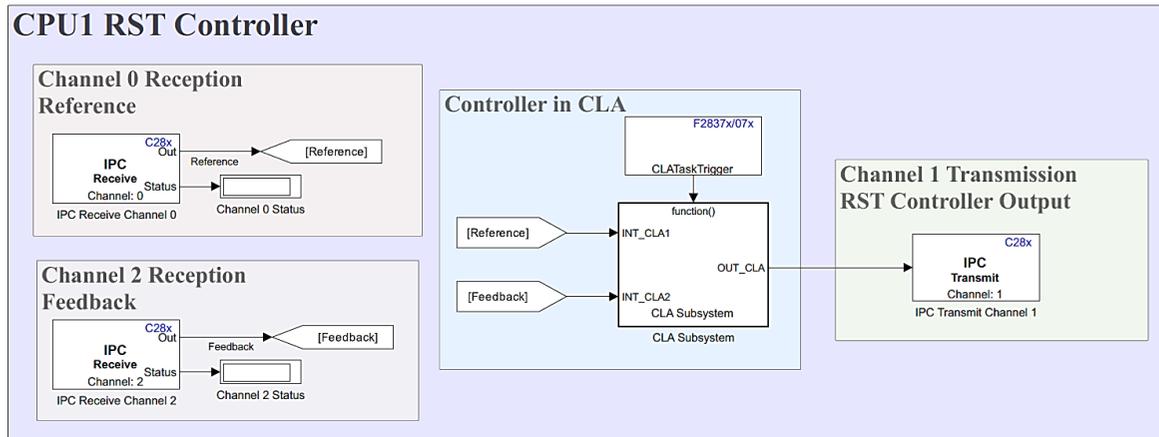


Figure 16. Proposed structure for the RST controller at the plant level, using equations (4)(4) y (5) as parameters.

Source: The authors

The response obtained for the implementation described in figure 16 is shown in figure 17. The digital control system and the plant described in equation (4)(4) were discretized to a sampling time $T_s = 0.1T_s = 0.1$ seconds. The same sampling time as the digital implementation was used for the PID controller, ensuring that the parameters and configuration of the CLA ecosystem on the LAUNCHXL-F28379D platform would have the same operating conditions.

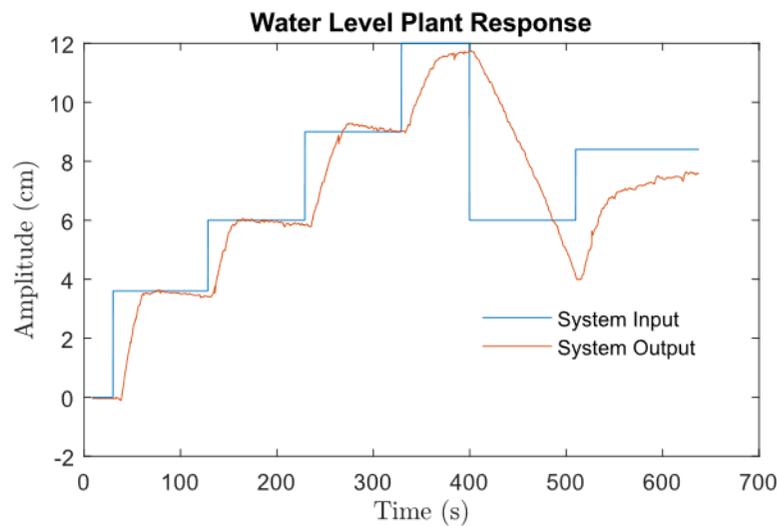


Figure 17. Response of the RST controller for the level plant on the LAUNCHXL-F28379D platform using the CLA ecosystem.

Source: The authors

Discussion

After presenting the results for the implementation of the proposed digital controllers, some important implications of the experiments carried out were analyzed:

The digital controllers proposed for each of the plants used a sampling time of $T_s = 0.1T_s = 0.1$ seconds. The transient response for the random plant shows that this time complies with the Nyquist-Shannon sampling theorem, allowing the dynamics of the system to be captured appropriately. In the level plant, possible oversampling occurred because the system has slow dynamics that vary little depending on the chosen sampling time. This can represent an unnecessary increase in the computational load of the CLA, accumulation of numerical error in the integral action of the PID controller due to excessive iterations, and high energy consumption. Testing with differential sampling times for the random and level plants could improve the response of the latter, since, having slow dynamics, a longer sampling time would better suit its characteristics. Finally, the CLA could be adjusted to microsecond time resolutions, which would help optimize the capacity of C2000 microcontrollers for motor control applications.

Another important element in the study focuses on hardware limitations. For example, C2000 microcontrollers have shared memory between CPU1, CPU2, and the CLA, which restricts the size of buffers and the order of controllers to be implemented. In terms of processing power, C2000 microcontrollers have speeds of 200 MHz and fixed-point architecture optimized for control, allowing the CLA to execute actions in parallel through busses shared with the CPU. The systems and devices used are low power, which means additional stages of power circuits must be added to control more robust devices. Other types of external communication protocols could also be used to send and manage information remotely.

Comparing the results obtained with previous studies reported in the literature, some differences were found in the applications carried out. In [\(11\)](#), a real-time controller was developed for buck converters. The study was based on a model-based approach to reduce complex programming processes and experimental validation with hardware/software architecture. In [\(15\)](#), a low-cost control platform was developed for power systems with current and voltage sensors for validation in a 20 kVA three-phase buck converter. The work carried out in [\(16\)](#) corresponds to an experimental hardware and software implementation dedicated to variable speed training of an asynchronous motor without load powered by a three-phase two-level inverter using open-loop control with real-time communication between the encoder and MATLAB/Simulink. In [\(26\)](#), a proposal for the implementation of digital controllers using Texas Instruments microcontrollers was developed using rapid control prototyping (RCP) and free software for the development of practices using PWM, ADC, DAC and other peripherals from C2000 microcontrollers. In this work, authors used Energia IDE as a reference framework for the controller implementations. Finally, although the studies reported in the literature present applications for power electronics and real-time remote systems, they do not use specific features of C2000 microcontrollers such as IPC, CLA, dual-core processes, among others.



Industrial Implications

The experimental framework demonstrates the viability of C2000 ecosystems for the development of industrial control systems, where the model-based design approach enables estimated reductions in development times of 60-80% for algorithm design, 50-70% for unit testing using PIL (Processor-in-the-Loop) validation, and 40-60% for peripheral integration compared to traditional manual coding methods in C/C++. The LAUNCHXL-F28379D platform includes a number of additional devices that can be used in specific industrial applications, such as the ability to simultaneously control traction inverters, DC-DC converters, and onboard chargers in electric vehicles at half the traditional system cost, achieving 96% efficiency in synchronous motor control and 99% accuracy in detecting bearing failures, electric arcs, and imbalances in ventilation systems. Another advantage of C2000 microcontrollers is their ability to temporarily adapt to low sampling times (in the order of microseconds) to respond to fast-moving system applications. In terms of communication protocols, C2000 microcontrollers are equipped with industrial protocols such as CAN, facilitating rapid integration into industrial networks and systems.

Research limitations

The research conducted has limitations that must be considered for the correct interpretation of the results and their potential transfer to industrial environments. These limitations are classified into three categories: methodological, hardware, and experimental scope.

Methodological limitations

The sampling time was applied uniformly to the test plants used without performing a parametric sensitivity analysis to evaluate the impact of different T_s values on controller performance. The mathematical model of the level plant was obtained through an offline identification process in MATLAB, without documenting the specific identification method used, the model validation criteria, or the percentage of fit obtained. This omission limits the repeatability of the study and the evaluation of the uncertainty associated with the identified model. Additionally, no robust stability analysis or evaluation of gain and phase margins was performed for the designed controllers, which is relevant to ensure performance in the face of parametric variations in the process. The PID controller was tuned exclusively using the MATLAB PID Tuner tool, without comparison with other tuning methods documented in the literature, such as Ziegler-Nichols, Cohen-Coon, or optimization-based methods. For the RST controller, the selection criteria for the closed-loop system poles were not specified, nor was the desired characteristic polynomial documented, limiting understanding of the design process.

Hardware restrictions

The LAUNCHXL-F28379D platform has dual-core architecture (CPU1 + CPU2) with parallel processing capacity and redundancy; however, the implementations presented use only CPU1 in





conjunction with the CLA, leaving CPU2 unexploited. This configuration does not take advantage of the capabilities available in this type of system.

The level system used as a test plant employs submersible pumps with a maximum power of 360 mW, which restricts validation to very low-power systems. Direct transfer of the results to industrial systems operating in the kilowatt to megawatt range would require additional power stages and protection circuits not contemplated in the experimental framework. Level sensing was performed using a float with a resistive output connected directly to the microcontroller's ADC, without incorporating isolation between the sensing stage and the controller. This configuration is inadequate for industrial environments where protection against electromagnetic noise and ground potential differences is required. The CLA memory usage for the implemented algorithms was not documented, which is necessary information for evaluating scalability to higher-order controllers such as extended state observers or adaptive controllers. CLA memory has size constraints that may limit the complexity of the implementable algorithms. Communication was restricted to internal IPC channels between CPU1 and CLA, without integration of industrial communication protocols such as CAN and EtherCAT, which are standard in industrial automation applications and are available on the platform used.

Experimental scope limitations

Experimental validation was limited to two test plants with slow dynamics: a second-order system randomly generated in MATLAB ($T_s = 9.8T_s = 9.8$ seconds) and a third-order level system ($T_s = 176 \text{ seconds}$, $T_s = 176 \text{ seconds}$). Plants with fast dynamics representative of typical industrial applications of C2000 microcontrollers, such as electric motor control, switched power converters, or current loops in three-phase inverters, were not included. The comparison with previous studies was descriptive in nature and did not include comparative experimental tests under equivalent conditions. The same controllers were not implemented on alternative platforms (Arduino, dSPACE, FPGA) that would have allowed the specific advantages of the C2000 ecosystem to be quantified in terms of latency, computational resource consumption, or ease of implementation. The experiments were conducted under controlled laboratory conditions, without evaluating the performance of the controllers in the face of external disturbances, load variations, noise in measurement signals, or adverse environmental conditions (temperature, humidity, electromagnetic interference) that characterize real industrial environments.

Finally, no prolonged operation tests were performed to evaluate the long-term stability of the implemented controllers, sensor drift, or potential numerical accumulation problems in the integrators during continuous operation.

Roadmap future research

Finally, Figure 18 presents a roadmap of possible lines of research that could be developed in the future based on the technologies used in this study.

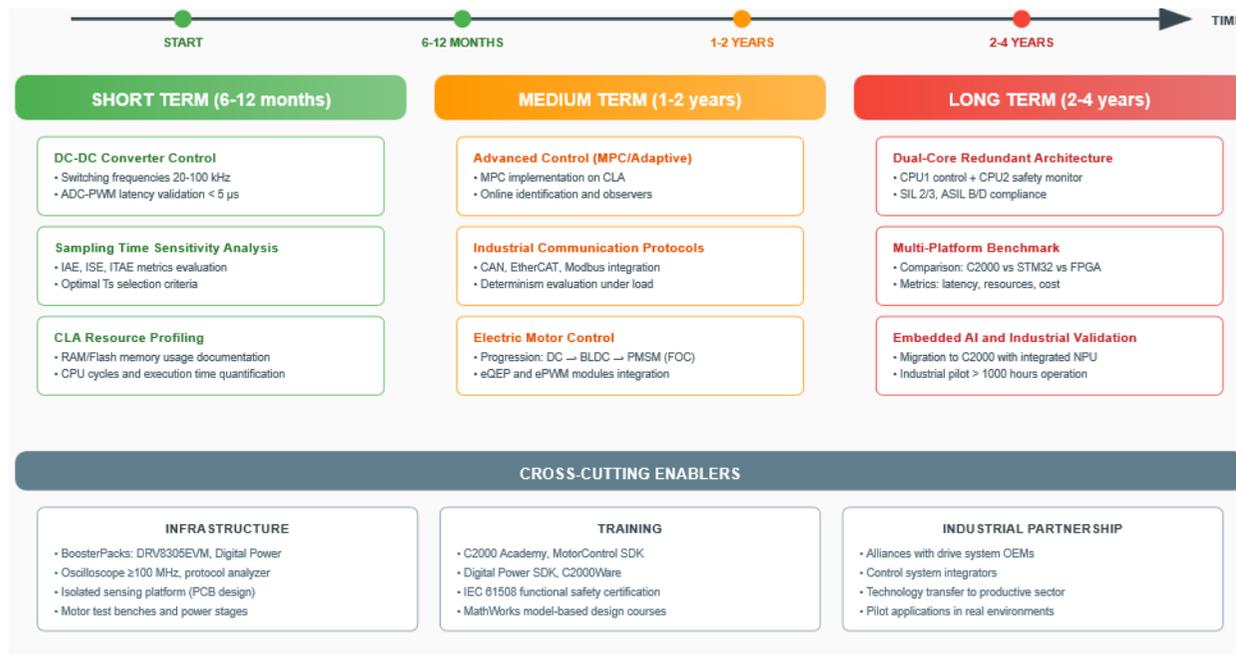


Figure 18. Roadmap about future research directions.

Source: The authors.

Conclusions

The research carried out has demonstrated the viability and effectiveness of Texas Instruments ecosystems, particularly the LAUNCHXL-F28379D platform, to implement real-time control strategies. The integration of modules such as the CLA (Control Law Accelerator) enabled the development of algorithms with low-latency control circuits and parallel processing, which was critical to ensuring an adequate system response in experimental applications.

The level plant, developed as an experimental prototype, showed that its transient response was slow. One of the factors causing this behavior is the use of a hydraulic system with two motor pumps for use in compact equipment with a maximum power of 360 mW, since although these motor pumps limit the speed of the system response, they are useful in validating the effectiveness of controllers under real conditions for small-scale static systems.

The tests performed showed that CLA coprocessors are relatively flexible. Although they were designed to adapt to systems such as Texas Instruments' own motors and power converters, they are versatile enough to be used in other types of physical processes such as level control or generic systems. This feature increases the applicability of the C2000 microcontroller in both academic and industrial environments.

However, the application of Simulink and the model-based design (MBD) method was essential for optimizing the design, simulation, and execution of PID and RST controllers. Automatic code generation using the embedded coder and the C2000 Microcontroller Blockset enabled a



smooth transition from the simulation environment to hardware execution, minimizing errors, and significantly reducing development times.

Finally, the CPU architecture of the C2000 microcontroller and the efficient configuration of peripherals such as ePWM, ADC, and DAC stand out, consolidating Texas Instruments ecosystems as a robust, scalable, and accessible solution for the development of real-time control systems. This platform is suitable not only for educational purposes but also represents a powerful tool for innovation in industrial environments.

CrediT authorship contribution statement

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References

1. Hoyos-Gutiérrez J, Cardona-Aristizabal J, Muñoz-Gutiérrez P, Ramirez-Jimenez D. A Systematic Literature Review on Rapid Control Prototyping Applications. IEEE R Iberoamericana Tecnologías Aprendizaje. 2023;18:76-85.

<https://doi.org/10.1109/RITA.2023.3250559>

2. Ramirez-Jimenez DF, Parrado AL, Medina JV. Overview of a framework for Implementation of digital controllers in Energia IDE using Texas Instruments microcontrollers. 2021 IEEE 5th Colombian Conference on Automatic Control (CCAC) [Internet]. Ibagué, Colombia: IEEE; 2021 [cited 2024 July 4]. p. 13-18.

<https://doi.org/10.1109/CCAC51819.2021.9633305>

3. Microcontrollers (MCUs) & processors | TI.com [Internet]. Available from: <https://www.ti.com/microcontrollers-mcus-processors/overview.html>



4. Instruments T. C2000 real-time microcontrollers | TI.com [Internet]. Available from: <https://www.ti.com/microcontrollers-mcus-processors/c2000-real-time-control-mcus/overview.html>
5. Rahman MA, Abushaiba AA, Elrajoubi AM. Integration of C2000 Microcontrollers with MATLAB Simulink Embedded Coder: A Real-Time Control Application. 2024 7th International Conference on Electrical Engineering and Green Energy (CEEGE) [Internet]. Los Angeles, CA, USA: IEEE 2024
<https://doi.org/10.1109/CEEGE62093.2024.10744177>
6. Angrilli D, Centi F, Credo A, Tursini M. Neural Network Control of AC/DC Converters Robust to AC Grid Faults. 2024 IEEE 22nd Mediterranean Electrotechnical Conference (MELECON) [Internet]. Porto, Portugal: IEEE 2024
<https://doi.org/10.1109/MELECON56669.2024.10608575>
7. Ramírez-Jiménez DF. Proposal of a Flying-Cutting Plant for the Development of Control Systems in Academic Environments. Ciencia e Ingeniería Neogranadina. 2025;35:87-112.
<https://doi.org/10.18359/rcin.7500>
8. Xu Q, Zhuang J, Xu Z. Parameter Identification Design of Intelligent Contactor Based on DSP-Control Law Accelerator. 2024 9th Asia Conference on Power and Electrical Engineering (ACPEE) [Internet]. Shanghai, China: IEEE 2024
<https://doi.org/10.1109/ACPEE60788.2024.10532501>
9. Yu K, Yang Z, Li Y, Yi H, Wang F, Zhuo F. Three-Phase Three-Level Shunt APF Control System Based on Multi-Task Parallel MCU. 2020 IEEE Applied Power Electronics Conference and Exposition (APEC) [Internet]. New Orleans, LA, USA: IEEE 2020
<https://doi.org/10.1109/APEC39645.2020.9124099>
10. Alonge F, D'ippolito F, Garraffa G, Giaconia GC, Latona R, Sferlazza A. Sliding Mode Control of Quadratic Boost Converters Based on Min-Type Control Strategy. IEEE Access. 2023;11:39176-39184.
<https://doi.org/10.1109/ACCESS.2023.3267984>
11. Gorel G, Bektes Y, Korkmaz F, Ozkaya H. PID Controller Design in Buck Converters: Real-Time Implementation and Performance Evaluation with TMS320F28379D. Journal of Engineering and Applied Sciences. 2025;3:1-14.
<https://doi.org/10.70988/ajeas.1583799>
12. Malele RH, Mendu B, Monchusi BB. Microcontroller-Driven Battery Management in Hybrid Energy Systems: A Systematic Review of Applications, Control Strategies, and Emerging Trends. IEEE Access. 2025;13:29341-29360.
<https://doi.org/10.1109/ACCESS.2025.3539929>



13. Rahman MA, Abushaiba AA, Elrajoubi AM. Integration of C2000 Microcontrollers with MATLAB Simulink Embedded Coder: A Real-Time Control Application. 2024 7th International Conference on Electrical Engineering and Green Energy (CEEGE) [Internet]. Los Angeles, CA, USA: IEEE 2024

<https://doi.org/10.1109/CEEGE62093.2024.10744177>

14. Ramírez-Jiménez DF, Torres Valencia CA. Experimental Design and Simulation of a Fly-Cutting Plant for Academic Environment Practices. *Machines*. 2024;13:15

<https://doi.org/10.3390/machines13010015>

15. Merchan-Villalba LR, Lozano-Garcia JM, Gonzalez-Longatt F, Ramirez-Arredondo JM, Pizano-Martinez A, Avina-Cervantes JG. Low-Cost Real-Time Control Platform with Embedded Isolated Electrical Sensors for Power Electronics. *Electronics*. 2023;12:3320.

<https://doi.org/10.3390/electronics12153320>

16. Halimi H, Elgarouaz M, Lazrak L, Daoudi S. Experimental validation of an open loop drive control of an asynchronous motor with the TMS320F28379D DSP card and speed sensor. *Results in Engineering*. 2025;26:105116.

<https://doi.org/10.1016/j.rineng.2025.105116>

17. LAUNCHXL-F28379D Development kit | TI.com [Internet]. [cited 2025 June 30]. Available from:

<https://www.ti.com/tool/LAUNCHXL-F28379D>

18. Ogata K. *Ingeniería de control moderna*. 5a. ed. Madrid: Pearson Educación; 2010

19. Smith CA, Corripio AB. *Principles and practice of automatic process control*. 2nd ed. New York: J. Wiley; 1997

20. Dorf RC, Bishop RH. *Modern control systems*. Thirteenth edition. Hoboken: Pearson; 2016

21. Ramírez-Jiménez DF, Bedoya-Benítez PA, Muñoz-Gutiérrez PA. Visualization and Control System for a Wastewater Laboratory Plant with Biological Treatment. *Ciencia e Ingeniería Neogranadina*. 2024;34:105-122.

<https://doi.org/10.18359/rcin.7270>

22. A. H. Bharmal, M. Khan, A. Dilawar, A. Ali, S. U. Baig, I. A. Makda, A. Usman, H. Qamar. Hardware-in-Loop-enabled Controller Design for Isolated Boost Converter using Ziegler-Nichols Method for Electric Vehicle Applications. *IECON 2023- 49th Annual Conference of the IEEE Industrial Electronics Society*. 2023. p. 1-6

<https://doi.org/10.1109/IECON51785.2023.10311854>

23. Supriyanto H, Suryatini F, Martawireja ARH, Rudiansyah H. IMPLEMENTASI KONTROLER PID DENGAN METODE TUNING ZIEGLER-NICHOLS DAN COHEN-COON PADA SISTEM SCADA KENDALI LEVEL AIR. *JTT*. 2022;8:149.

<https://doi.org/10.31884/jtt.v8i2.410>





24. Bobál V, Macháček J, Prokop R. Tuning of Digital PID Controllers Based on Ziegler - Nichols Method. IFAC Proceedings Volumes. 1997;30:145-150. doi: 10.1016/S1474-6670(17)41430-3

[https://doi.org/10.1016/S1474-6670\(17\)41430-3](https://doi.org/10.1016/S1474-6670(17)41430-3)

25. Halim AH, Ismail I. Tree physiology optimization on SISO and MIMO PID control tuning. Neural Comput & Applic. 2019;31:7571-7581.

<https://doi.org/10.1007/s00521-018-3588-9>

26. Jiménez DFR, Arbeláez CMG, Gutiérrez PAM. Propuesta para la implementación de controladores digitales usando microcontroladores de Texas Instruments. EIEI ACOFI [Internet]. 2025 [cited 2026 Feb 11];

<https://doi.org/10.26507/paper.4247>