Microcontroller-Based Learning Platform Redesign

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1 Project Overview

Title: Development of a Microcontroller-Based Learning Platform (MLP) for Tertiary Education
Client: Victoria University of Wellington (VUW), Electrical and Electronic Engineering Courses
Duration: Ongoing (Design Phase Completed as of Document Date)
Role: Lead Designer and Engineer (Hardware Focus)
Objective: To modernize an outdated 8051-based educational platform by selecting a contemporary microcontroller, designing peripheral modules (e.g., DAC), and creating protective enclosures. This enhances student learning in embedded systems, digital logic, and electronics through hands-on experiments.

This project addresses the need for a robust, versatile, and safe learning kit to replace aging hardware prone to maintenance issues. It emphasizes modularity, industry alignment, and cost-effectiveness while meeting educational requirements for university-level courses.

2 Key Project Goals and Design Objectives

As outlined in the Project Design Requirements (PDR), the primary goals include:

1. **Microcontroller Selection:** Replace the 8051 with a modern alternative offering superior performance, I/O capabilities, and development tools.
2. **Peripheral Module Design:** Develop at least one module (e.g., Digital-to-Analog Converter - DAC) to demonstrate interfacing and educational utility.
3. **Protective Enclosures:** Design enclosures for all modules to ensure safety, durability, and ease of use/maintenance.

Additional objectives:

- Ensure compatibility with various peripherals (e.g., motor drivers, LCD keypads).
- Prioritize student safety through electrical protection and mechanical robustness.
- Minimize long-term maintenance burden and fit within university budget constraints.

3 Current System Analysis: The 8051 Microcontroller

The existing MLP uses the Intel MCS-51 (8051) family, introduced in the 1980s. While foundational for teaching embedded concepts, it is outdated:

- **Architecture:** 8-bit Harvard (CISC).
- **Clock Speed:** ∼12 MHz.
- **Memory:** 128-256 bytes RAM / 4-8 KB ROM.
- **Limitations:** Limited performance, poor modern tool support, increasing repair needs due to student use.

This project presents an opportunity to upgrade to a system aligned with industry standards like ARM-based architectures.

4 Microcontroller Design Approach

4.1 Selection and Justification

After evaluating options (custom PCB vs. development boards), the **STM32F411RE Nucleo-64 Development Board** was chosen for its balance of features:

- **Architecture:** 32-bit ARM Cortex-M4 (RISC).
- **Clock Speed:** Up to 100 MHz.
- **Memory:** 512 KB Flash, 128 KB SRAM.
- **Peripherals:** Multiple SPI/I2C/UART interfaces, ADC/DAC support, PWM timers.
- **Advantages:**
  - Plug-and-play for education (pre-built, integrated debugger).
  - Extensive community/documentation from STMicroelectronics.
  - Low cost (∼$24.10 NZD) and reduced maintenance.

4.2 Comparison Table: Custom PCB vs. Development Board

Feature	Custom Microcontroller PCB Design	Microcontroller Development Boards
Design Control	Full control over hardware and layout	Fixed but versatile and feature-rich
Development Time	Long (hardware design, PCB fabrication)	Immediate use (pre-built)
Ease of Use	Complex (requires expertise)	Plug-and-play with built-in tools
Support Tools	Must develop/source (IDEs, debuggers)	Integrated IDEs (e.g., STM32CubeIDE)
Suitability for Teaching	Less suited (setup complexity)	Highly suited for prototyping and learning
Costs	High initial/ongoing (fabrication, infrastructure)	Lower (bulk availability, minimal maintenance)
Scalability/Flexibility	High for specific applications	High for general education
Documentation/Community	Must develop internal	Extensive manufacturer support

Table 1: Comparison of Custom PCB vs. Development Board

This selection aligns with PDR requirements for performance, affordability, and educational value.

5 DAC Module Design Approach

The DAC module demonstrates analog signal generation, supporting applications like motor control and signal analysis.

5.1 Design Objectives and Compliance

- **Resolution:** Up to 32-bit (emulated via multi-channel synthesis).
- **Interface:** SPI-compatible with STM32, Arduino, Raspberry Pi, etc.
- **Safety:** Fuses, diodes, and protection circuitry.

Requirement	Compliance Strategy
Weight/Dimensions	¡500g, ¡30cm (Hammond 1591XXDSFLBK enclosure, $\sim$300g)
Compatibility	SPI support for multiple platforms
Electrical Safety	Fuses, diodes, input protection
Output Resolution	32-bit via DAC8565 quad-channel (16-bit per channel)
Real-Time Monitoring	SPI logging and analog measurement
Connectors	Banana jacks/IDCs rated ¿10,000 cycles
Operating Range	Matches STM32 (-10°C to +85°C, humidity-tolerant)
Repairability	Modular PCB with replaceable components
Programming Tools	Compatible with STM32CubeIDE, Arduino IDE
Cost	BOM/enclosure ¡ $300 NZD

Table 2: DAC Compliance Table

5.2 Functionality Overview

- **Key Components:**
  - DAC8565 (Texas Instruments): 16-bit quad-channel DAC for high-resolution output.
  - REF5025ID: Stable 5V voltage reference for linearity.
  - LM741 Op-Amps (x2): Buffer outputs for load stability.
- **Signal Flow:**
  1. Digital input via SPI from microcontroller.
  2. Conversion to analog voltage.
  3. Buffering for stability.
  4. Output via banana jack.

Design Process: Schematic in EasyEDA (ERC/DRC validated). Iterations fixed wiring/capacitor issues. PCB layout includes test points and protection.
Next Steps: Breadboard prototyping, PCB fabrication, functional testing.

6 Protective Enclosure Design Approach

Enclosures ensure safety, modularity, and durability.

6.1 Objectives

- Size/Weight: ¡30cm, ¡500g per module.
- Robustness: Withstand 700mm drops; electrical isolation.
- Ease: Disassembly, maintenance, intuitive interfaces.

6.2 Selection and Justification

- **Chosen Enclosure:** Hammond 1591XXDSFLBK (ABS plastic, IP54-rated, ESD-resistant).
- **Advantages:** COTS (cost-effective), CNC-machinable, flanged for mounting.
- Separate enclosures for microcontroller and DAC to enhance isolation/troubleshooting.

6.3 Design Considerations

- **DAC Enclosure Layout:**
  - Banana jacks: +15V, GND (x2), Analog OUT.
  - IDC connector for digital input.
  - Status LEDs (+Ve/-Ve).
  - CNC Cutouts: 4x Ø6.4mm holes (jacks), 1x 21x8.5mm slot (IDC), 2x Ø3mm holes (LEDs).
- **STM32 Enclosure Layout:**
  - GPIO headers (Ports 0-4, ADC).
  - USB-C, 5V DC jack, PROGRAM/RESET buttons.

Mounting Options: Standoffs, foam tape, or screws for robustness/maintainability.
Next Steps: Prototyping, CNC modifications, final assembly.

7 Cost Analysis

Worst-case estimate (NZD; excludes bulk discounts/CNC costs ∼\$10-20/enclosure).

Module	Component	Quantity	Unit Price	Total
Microcontroller	STM32F411RE Board	1	\$24.10	\$24.10
DAC Module	DAC8565	1	\$15.00	\$15.00
	LM741 Amplifier	2	\$2.50	\$5.00
	REF5025ID	1	\$5.00	\$5.00
	Capacitors/Resistors	Various	\$3.00	\$3.00
	Fuse/Diode/LED	Various	\$2.00	\$2.00
	PCB Fabrication	1	\$20.00	\$20.00
Protective Enclosures	Hammond 1591XXDSFLBK	2	\$12.30	\$24.60
	Screws/Mounts	Various	\$4.00	\$4.00
Total				**\$103**

Table 3: Project Cost Analysis

8 Design Limitations and Future Work

- **Current Shortcomings:** Incomplete interface diagrams, wiring schematics, and connector groupings.
- **Ongoing Plans:** Finalize PCB/wiring, prototype enclosures, verify against PDR specs (e.g., drop tests, power measurements).

9 References

Selected from project documentation:

1 Rojas et al., "A comprehensive review of microcontroller architectures," Journal of Embedded Systems, 2020.

3 STMicroelectronics, "STM32 Nucleo-64 boards," 2025. Available: `https://www.st.com/en/evaluation-tools/nucleo-64.html`.

11 "8051 Microcontroller Hardware," UMBC.edu, 2025.

- Full list available in design document.

10 System Architecture Overview (From Supplemental Document)

The redesigned platform features modular architecture:

- Core: STM32F411RE microcontroller.
- Peripherals: DAC module (expandable to others).
- Enclosures: Protective cases for safety and modularity.
- Focus: Enhanced training for embedded systems, with improved hardware integration and educational tools.