

Demonstration Boards for Security Education with Microcontrollers

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ABSTRACT: For security education demonstration boards are useful and reflect the multifunctional effects. We have used these boards for the microprocessor-based educational systems in this paper. This practice is intended for educational purposes and is managed by various development boards with different microcontrollers and minimum sizes. The purpose is to generate a full global educational system for security education. We have developed some experiments using specific development boards.

Keywords: Microprocessor Development System, Multifunctional Demonstration Board, Nucleo L476RGT6 Board, Software Development Tools

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1. Introduction

The curriculum of the Bachelor's degree of Electronics at the Technical University of Gabrovo includes two disciplines related to microcontrollers and embedded systems design and application - Microprocessor Circuits and Embedded Systems. Several microcontroller families based on different cores are being used: 8-bit general purpose microcontrollers with PIC and AVR processor cores and 32-bit microcontrollers with ARM processor cores. This implies the use of different types of hardware development tools, which in turn increases the costs and hampers students.

In general the hardware development tools for educational purposes could be divided into two major groups in relation to their complexity [1]:

- More complex development tools, containing a wide range of peripheral blocks - input devices, displays, interfaces, sensor blocks, etc.;

- Development boards almost without peripheral blocks, adapted to add various additional modules, shields, click-boards, etc.

In short, the advantages and disadvantages of the both approaches have been examined in [1]. Applying the second variant is motivated in the case of using several types of microcontrollers in training. It is supported by the presented in [1] multifunctional demonstration module, which includes commonly used blocks in the microprocessor systems. There is also a breadboard on it, allowing easy addition of various input! output devices, sensor and actuator blocks, etc.

In the present paper, this approach is further extended by designing a microprocessor development system, including the multifunctional module and additional devices inappropriate to be implemented on the same PCB due to an increase in overall dimensions.

Since the element of comparative versatility of the system is to be preserved, it is intended to be controlled by development boards with various microcontrollers with minimal form factor, minimum periphery and low cost.

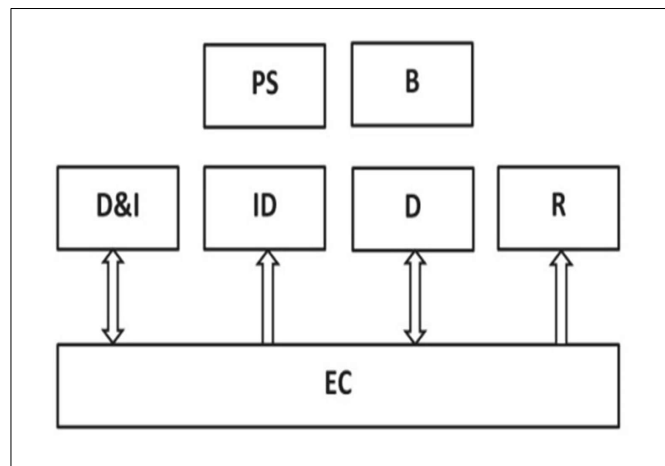
The flexibility in implementing various microcontrollers and additional peripherals makes it possible to use the presented development system also in other disciplines of engineering education - digital circuits design, communication technologies, etc. [2], [3].

The presented results have been achieved using Nucleo L476RGT with a STM32L476RGT6 microcontroller and the integrated development environment Keil uVision5. Experiments with two other development boards - Arduino Uno and PIC32-PINGUINO OTG have been made, which integrated development environments are quite simpler.

In section 2 the components of the multifunction module are briefly described. In section 3 the suggested system is presented, and in section 4 some sample algorithms and programs used in the testing of the system are given.

2. The Multifunctional Demonstration Board

The block diagram of the multifunctional demo-board is presented in Figure 1 [1].



PS	Power Supply
B	Breadboard
D&I	Display and Indication
ID	Input Devices
D	Drivers
R	Relays
EC	Expansion Connectors

Figure 1. Block diagram of the demo-board PS Power Supply B Breadboard

It includes several commonly used I/O devices - five tactile push buttons, a rotary encoder, 10 LEDs, a 4-digit 7-segment display, and a 2x16 LCD display.

There is an 8-bit serial shift register SN74HC595N, which could be used to minimize the I/O pins of the microcontroller, when implementing multiplexed LED display, a matrix LEDs, etc.

A relay block with two RAS-05-15 relays is provided, with a galvanic isolation of the load via optocouplers.

A motor driver block is also provided to control stepper and low power DC motors, relays, solenoids, etc. It consists of L293B IC - a quadruple high-current half-H driver, a stepper motor controller L297 and a high voltage, high current dual full-bridge driver L298.

The dual voltage power supply (+5V and +12V) is intended for the logic and the driver block.

The mini breadboard allows increasing the functions of the demo board by using a large number of additional modules.

All the I/O pins of the blocks are wired to expansion pin header strips in order to connect the desirable function with the pins of the microcontroller development board. This simplifies the wiring by avoiding a great number of configuring microswitches and jumpers, as it is in other development boards.

3. Nucleo Board and the Microprocessor Development System

Why ARM microcontroller?

As previously mentioned, the purpose of the development system is to use it for educational purposes in two disciplines. At Microprocessor Circuits 8-bit microcontrollers with a simpler CPU architecture are studied, as the students face the complex matter for the first time. Embedded Systems is being studied in the next semester, achieving two goals: expanding the knowledge and skills for designing and implementing embedded systems, and at the same time - the ability to study microcontrollers with more sophisticated CPU architecture such as ARM-based, which are widely spread too.

ARM Cortex is a wide set of popular 32/64-bit architectures and cores, divided into three main subfamilies:

- **Cortex-A** (Application) are processors for devices performing complex computing tasks and found in most of mobile devices, like phones and tablets.
- **Cortex-M** (eMbedded) is a range of energy efficient and easy to use processors designed for the low-cost embedded market.
- **Cortex-R** (Real-Time) processors offer high-performance computing solutions for embedded systems where reliability, fault tolerance, maintainability and deterministic real-time response are essential.

Thus, Cortex -M based microcontroller is a very suitable choice to be studied.

Many manufactures offer a wide range of ARM microcontrollers: STMicroelectronics, Microchip, Maxim, Freescale, Holtek, Infineon, NXP, Silicon Labs, etc.

STMicroelectronics has a large portfolio of 32-bit Arm Cortex MCUs, namely STM32.

STM32 advantages [4]:

- Cortex-M based MCUs - a powerful alternative of 8-bit embedded microcontrollers, like PIC, MSP430, etc.
- Available completely free ARM based tool-chain;
- Pin compatibility - most of STM32 MCUs are designed to be pin compatible;
- 5V tolerant - they can interface other devices that do not provide 3.3V I/O, without using level shifters;

- Comparatively not expensive devices if the designer would like to migrate from 8/16-bit MCUs to a more powerful platform, while keeping a comparable target price;
- Integrated bootloader, allowing reprogramming the internal flash memory using some communication peripherals (USART, I²C, etc.).

Some drawbacks:

- Too many challenges to inexperienced users during the study process. If they are completely new to embedded development, they will suffer from the difficulties with the ST documentation;
- A lack of good documentation especially for its HAL;
- Lack of STMicroelectronics official development environment;
- Lack of MCUs for the IoT.

The Nucleo L476RGT6 development board

There are many development STM32-based boards on the market, including Arduino-compatible. For instance, the microcontroller on the STM32F103C8T6 board can even be programmed using Arduino IDE. But as the original STMicroelectronics boards like Discovery and Nucleo are extremely cheap, a Nucleo board has been used.

STM32 Nucleo boards are supplied with two sets of extension connectors, allowing easily applying hardware add-ons: Arduino compatible and ST morpho connectors. They also integrate an ST-Link debugger/programmer. They work with a wide range of development environments including IAR EWARM, Keil MDK-ARM, mbed and GCC/LLVM-based IDEs.

Figure 2 shows Nucleo L476RGT board with STM32L476RGT6 microcontroller.

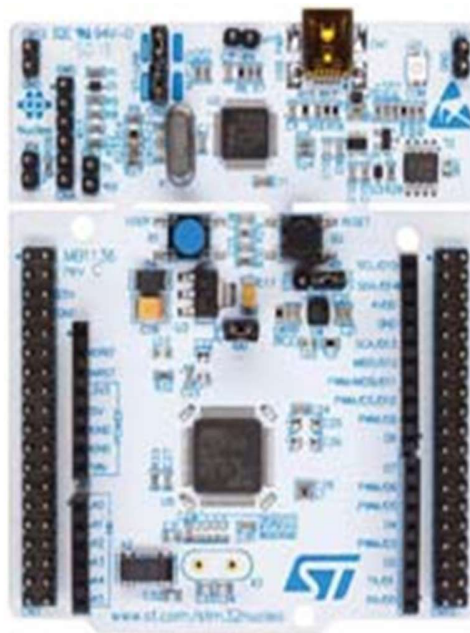


Figure 2. Nucleo L476RGT6 development board

Except the above mentioned two sets of board expansion connectors, there are also 1 user LED, 1 user and 1 reset push-buttons, 32.768 kHz low speed external (LSE) crystal oscillator on the Nucleo L476RGT, flexible power-supply options: ST-LINK USB VBUS or external sources and on-board ST-LINK/V2-1 debugger/programmer. Also free software libraries and examples are available with the STM32Cube MCU Package [5].

The Development System

The suggested development system is shown in Fig. 3. Except the control microcontroller board (in our case Nucleo L476RGT6) and in addition to the multifunctional demo-board, several often used peripherals have been added: a matrix keypad 4x3, a low power 5V DC motor, a stepper motor PM35L-048-HPD4 [6], a servo motor SG90 and a LED matrix 8x8.

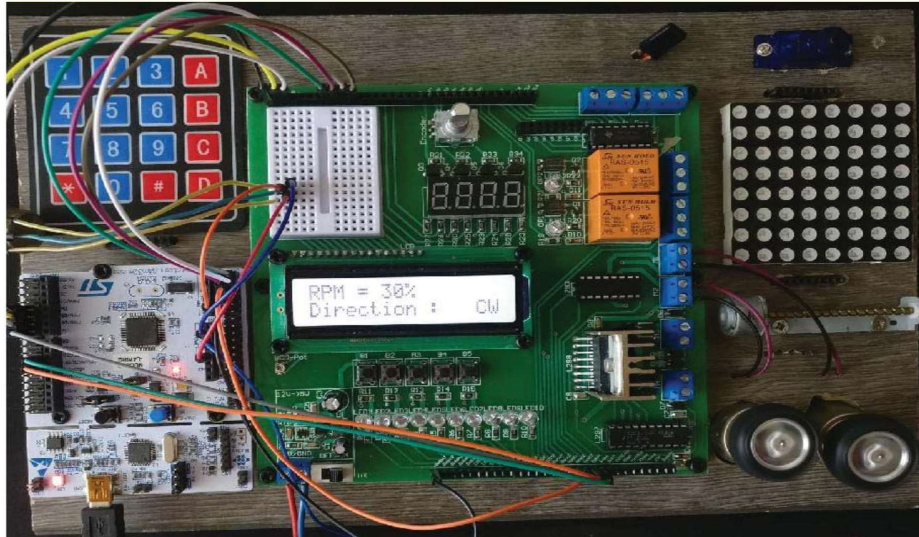


Figure 3. The suggested development system with Nucleo L476RGT6

Nucleo is firmly mounted on the microprocessor system base, but it could be easily exchanged with other development boards which are compatible with the mounting holes: Arduino Uno, Olimex's PIC32-Pinguino-OTG with PIC32MX440F256H microcontroller [7], Netduino 3 with 168Mhz Cortex-M4 (STM32F4) of Wilderness Labs [8], etc. (Figure 4). The system would operate with many other low size development boards, but they could be just put on or out of the base board.

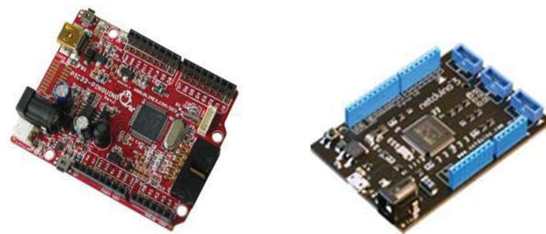


Figure 4. Arduino Uno compatible development boards - PIC32- Pinguino-OTG and Netduino 3

4. Software Development Tools and System Verification

The operation of the development system has been verified by simple programs for the input and output devices, motors and additional sensor blocks.

The STM32 toolchain is supported by three groups of software development tools:

- Tools to configure and generate code - STM32CubeMX;
- A comprehensive set of partner compile and debug IDEs: IAR EWARM (IAR Embedded Workbench), Keil MDK-ARM, GCC-based IDEs, ARM mbed online, etc.

- Monitor, program and Utilities tools: STM Studio, ST-Link utility, ST-MCU-Finder, etc.

STM32CubeMX

STM32CubeMX is a graphical tool for STM32 microcontrollers. It allows microcontroller and board selection from a list of STM boards, type of package, hardware peripherals, etc. and also an easy switching to another microcontroller. It generates after that the code necessary to configure the ST HAL (Hardware Abstraction Layer).

STM32CubeMX generates initialization C code and includes a utility tool for settings, like pin multiplexing, clock tree setting, peripheral configurations, etc.; generates IDE-ready projects for various integrated development environment toolchains; calculates the power consumption, etc.

Figure 5 shows Nucleo L476RGT board selection. In Fig. 6 Pinout & Configuration window is shown. A sample program controls DC direction and the rmps and outputs data on the LCD. The necessary pins for the PWM, direction and LCD have been configured.

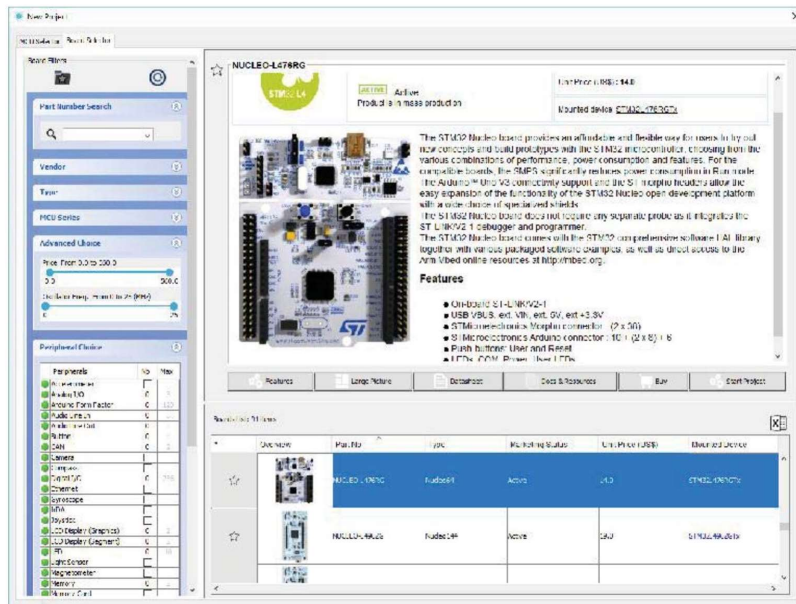


Figure 5. Development board selection window



Figure 6. STM32CubeMX Pinout & Configuration window

Figure 7 shows timer and clock configuration for our example.

The Integrated Development Environment μ Vision

The ARM Keil products are the world leading software development tools for Cortex-M processor based devices [9]. So the Keil μ Vision5 IDE is used in the present work.

The μ Vision IDE combines project management, run-time environment, build facilities, source code editing, and program debugging utilities [10]. The debugger supports options, like breakpoints, watch windows, and execution control and full visibility to device peripherals. Figure 8 shows the Project Manager and Run-Time Environment window.

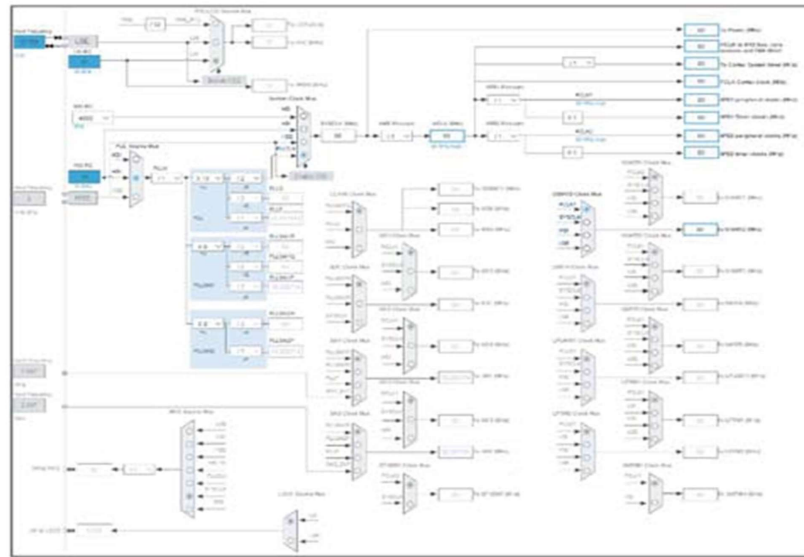


Figure 7. STM32CubeMX Clock Configuration window

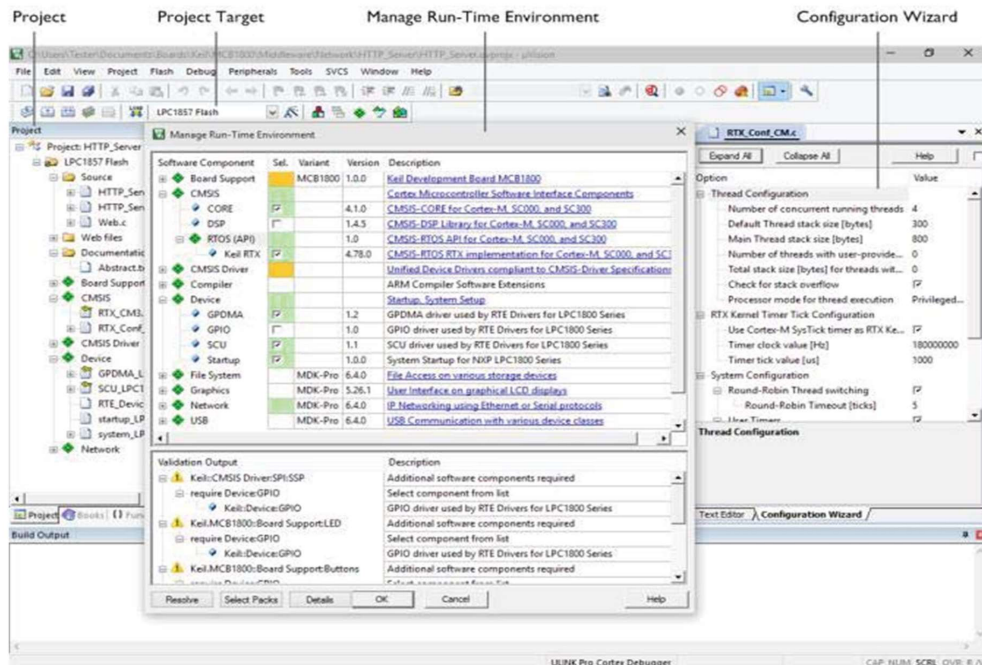


Figure 8. μ Vision 5 Project Manager and Run-Time Environment window

Figures 9 and 3 show respectively a part of the main function in a sample program for DC motor control and its operation. The whole project, including all the files, which could be seen in the picture, has been generated by the STM32CubeMX.

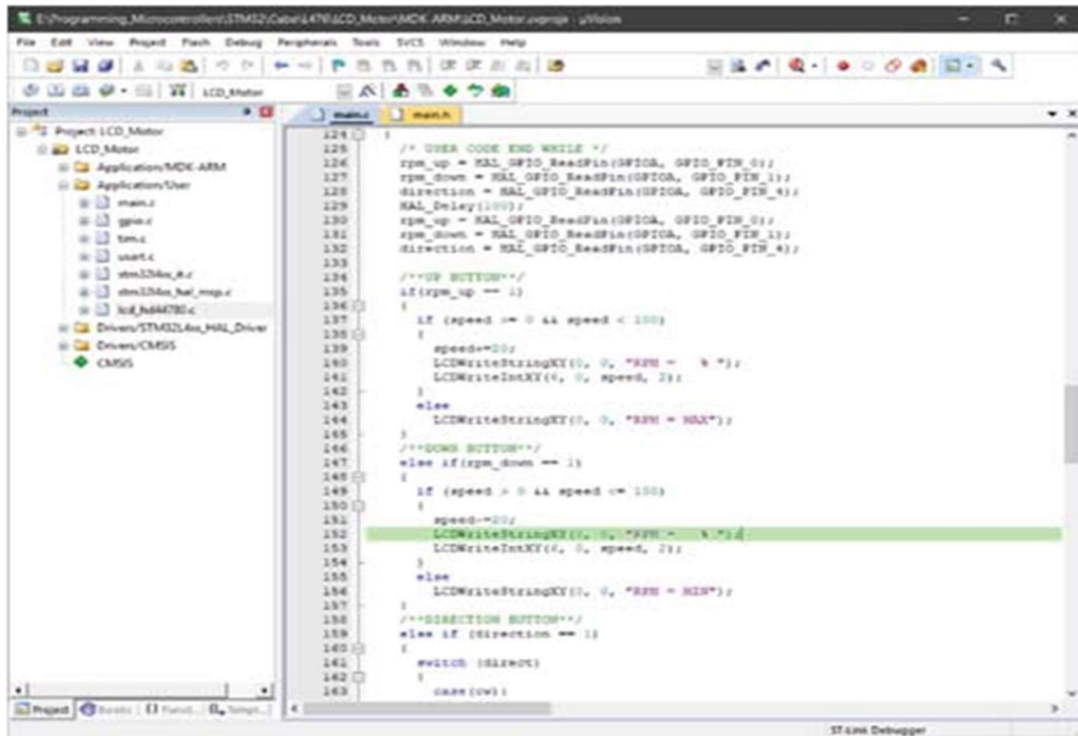


Figure 9. Part of the sample program in the µVision 5 Editor window

5. Conclusion

A microprocessor development system based on a multifunctional demonstration board is presented in the paper. It is to be used in Microprocessor circuits and Embedded systems courses at the Bachelor degree of Electronics, where various 8-, 16- and 32-bit microcontrollers are used, but could be useful in other disciplines too. Thus, the goal is the system to be comparatively “universal” and to be controlled by various microcontroller development boards. It has been tested with several development boards and the some results using Nucleo L476RGT with 32-bit ARM-based STM32L476RGT6 microcontroller are presented.

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