PROGRAMMING WITH

STM32 NUCLEO BOARDS

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Dogan Ibrahim

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Pictures of Expansion Board pin outs in Chapter 11 are taken from the Mbed internet sources such as: **https://os.mbed.com/components/X-NUCLEO-IDW01M1/**

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Prof Dr Dogan Ibrahim has BSc degree in electronic engineering, an MSc degree in automatic control engineering, and a PhD degree in digital signal processing. Dogan has worked in many industrial organizations before he returned to academic life. Prof Ibrahim is the author of over 60 technical books and over 200 technical articles on microcontrollers, microprocessors, and related fields. He is a Chartered electrical engineer and a Fellow of the Institution of Engineering Technology.

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PREFACE

ARM is a family of processors based on the RISC architecture that requires fewer transistors than the conventional processors. As a result, ARM processors cost less, have reduced power consumptions, and are therefore desirable for use in portable battery operated devices. Currently, very large percentage of smartphones, laptops, tablet computers, and portable games devices are all designed using the ARM architecture. Most ARM processors have 32-bit instruction sets with floating point support. It is estimated that over 100 billion ARM processors were produced in the year 2017.
ARM Cortex is a family of 32-bit RISC processors consisting of Cortex-M0/M0+/M1/M3 and Cortex-M4. Lately, new models such as Cortex-M323 and Cortex-M33 are available. Although 8-bit microcontrollers have been very popular in the past, Cortex-M series have become a popular replacement for the 8-bit processors.
STM32 Nucleo family of processors are manufactured by STMicroelectronics. These are low-cost ARM microcontroller development boards. This book is about developing projects using the Nucleo-L476RG development board. In the early Chapters of the book the architecture of the Nucleo family is briefly described. Software development tools that can be used with the Nucleo boards such as the Mbed, Keil MDK, IAR EWARM, TrueSTUDIO, and the System Workbench are described briefly in later Chapters.
All the projects in the book have been designed using the Mbed and the System Workbench software development tools (or Toolchains). Mbed is an Online tool that can be used with Internet access. System Workbench can be downloaded free of charge from the Internet.

The book covers many projects using most features of the Nucleo-L476RG development boards where the full software listing for Mbed and System Workbench are given for every project. The projects range from simple flashing LEDs to more complex projects using modules and devices such as GPIO, ADC, DAC, I2C, LCD, analog inputs and others. In addition, several projects are given using the Nucleo Expansion Boards. These Expansion Boards plug on top of the Nucleo development boards and provide features such as industrial input/output, DC motor drive, stepper motor drive, Wi-Fi, and many more.

All the projects in the book have been tested and are working. The following sub-headings are given for each project:
- Project Title
- Description
- Aim
- Block Diagram
- Circuit Diagram
- Mbed Program Listing
- System Workbench Program Listing

I hope you find the projects interesting and the book becomes a useful source of reference for your future STM32 Nucleo based projects.

Prof Dr Dogan Ibrahim
London 2018

Chapter 1 • STM32 NUCLEO DEVELOPMENT BOARDS

1.1 • Overview

This Chapter is about the STM32 Nucleo development boards. Brief specifications of the various Nucleo development boards are described in the Chapter. In addition, the details of the popular Nucleo-L476RG board is described in greater detail.

1.2 • STM32 Nucleo Development Boards

STMicroelectronics is a company with a reputation of supplying quality microcontroller development boards and various hardware and software development tools. The Nucleo family of low-cost development boards are small but powerful boards based on the 32-bit ARM Cortex architecture. These development boards are targeted for a large audience, including students, professional engineers, and hobbyists at all levels. The boards are compatible with the popular Arduino, mbed, ST-LINK, and ST Morpho, making it accessible to users with different backgrounds.

There are over 30 different boards in the Nucleo family, aimed to satisfy the needs of almost all users. The Nucleo boards come in three different sizes: small (Nucleo-32), short (Nucleo-64), and long (Nucleo-144) where the numbers refer to the pin counts of the MCUs. These three groups are further divided into three sub-groups: ultra-low power (green), mainstream (blue), and high performance (magenta).

The ultra-low power boards are based on the STM32 L family and these boards are targeted for low-power applications, such as watches, smart meters etc. Examples of the ultra-low power boards are: Nucleo-L011K4, Nucleo-L031K6 and Nucleo-L432KC. There are three sub-categories in the STM32 L family:

- L0, ARM Cortex-M0+
- L1, ARM Cortex-M3
- L4, ARM Cortex-M4

About half of the STM32 Nucleo boards are in the mainstream category. Examples of the mainstream boards are: Nucleo-F303K8, Nucleo-F042K6, Nucleo-F303RE etc. There are three sub-categories in the mainstream category:

- F0, ARM Cortex-M0+
- F1, ARM Cortex-M3
- F3, ARM Cortex-M4

The high-performance boards have large memories and faster MCUs. Examples of high-performance boards are: Nucleo-F410RB, Nucleo-F401RE, Nucleo-F722ZE etc. There are three sub-categories in the high-performance category:

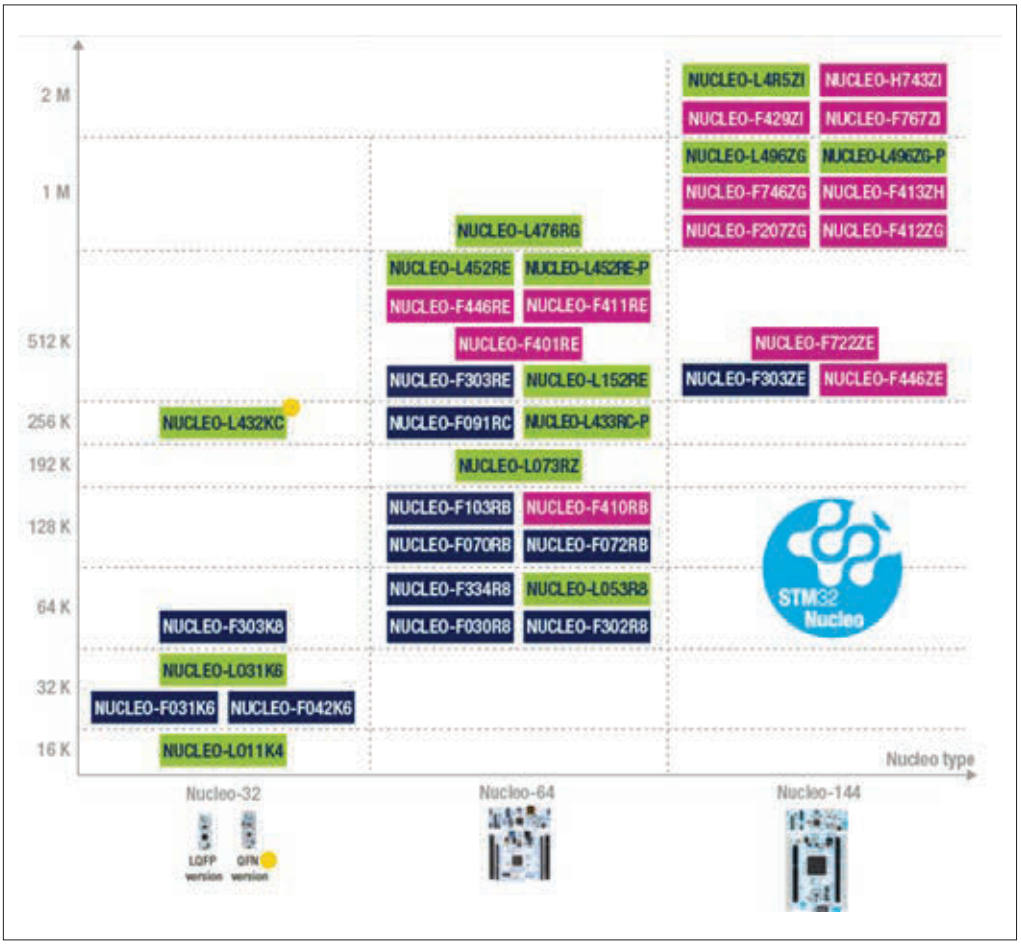
- F2, ARM Cortex-M3
- F4, ARM Cortex-M4
- F7, ARM Cortex-M7

The Nucleo-32 boards are small (50mm x 19mm) and are Arduino Nano compatible. Nucleo-64 and nucleo-144 are Arduino Uno compatible and they also have ST Morpho exten-

sion connectors which carry the MCU pins. There are large number of Arduino Nano/Uno compatible shields available in the market and these shields can easily be used with the Nucleo boards, making it easy to quickly develop projects using the Nucleo boards

Depending upon the model the Nucleo boards have flash program memory sizes from 16KB up to 2MB, and RAM memories from 4KB to 320KB. The clock frequency varies from 32MHZ to 216MHz.

Figure 1.1 shows a comparison of the Nucleo boards.



[Figure 1.1 Nucleo boards. (©STMicroelecronics. Used with permission)]

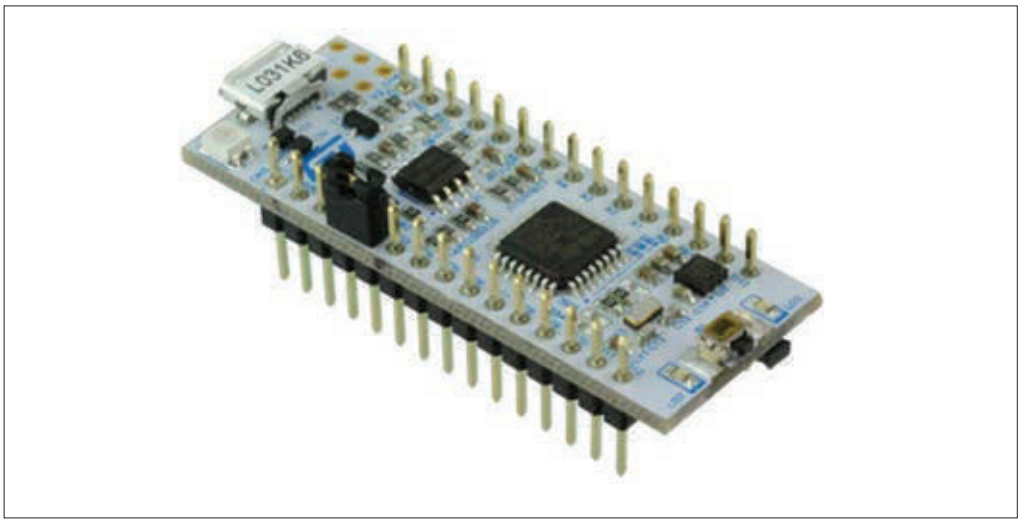
1.2.1 ● Nucleo-32 Development Boards

Figure 1.2 shows an example Nucleo-32 board, the Nucleo-L031K6. This is an ultra-low power low-cost board incorporating the STM32L031K6T6 microcontroller. The board is Ar-

duino Nano compatible so that a large number of Arduino shields can be used with the board. This board has the following features:

- 32MHz Cortex M0+ microcontroller in 32-pin package
- 32KB flash memory
- 8KB RAM
- 1KB EEPROM
- Real-time clock
- Serial interfaces (USART, SPI, and I2C)
- 3 LEDs (USB communication, power, user)
- Push-button Reset
- Flexible power-supply options: ST-LINK USB V_{BUS} or external sources
- Arduino Nano compatible expansion connector
- ST-LINK/V2-1 debugger/programmer with mass storage, virtual COM port, and debug port

Support for Integrated development Environment software (IAR, Keil, ARM mbed, GCC-based IDEs).



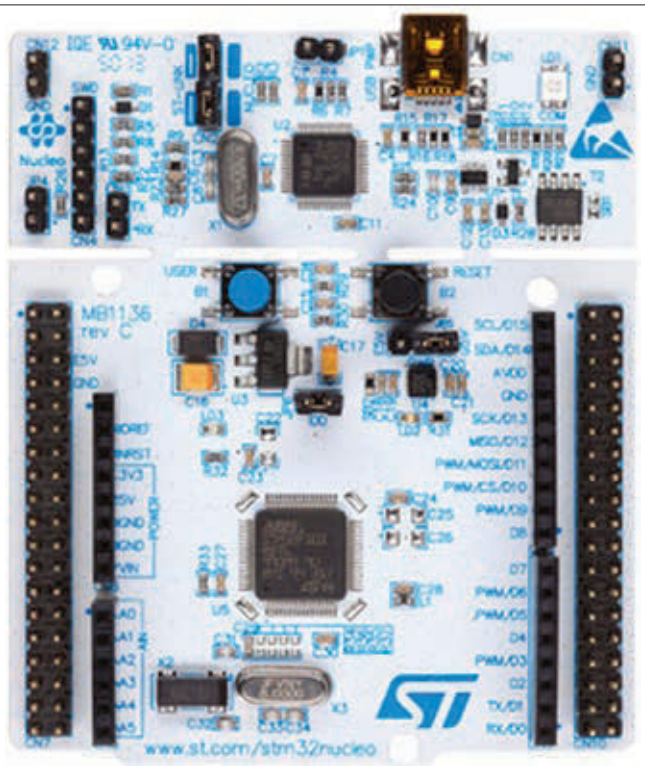
[Figure 1.2 Nucleo-32 development board (Nucleo-L031K6)]

1.2.2 • NUCLEO-64 DEVELOPMENT BOARDS

Figure 1.3 shows an example Nucleo-64 board, the Nucleo-F091RC. This is a mainstream board incorporating a 64-pin MCU. The board is Arduino Uno compatible and as such a large number of Arduino shields can be used with the board. This board has the following features:

- 1 user LED
- 1 user push-button switch
- 32.768kHz crystal oscillator
- ST morpho connector

- Arduino Uno expansion socket
- Flexible power-supply options: ST-LINK USB V_{BUS} or external sources
- ST-LINK/V2-1 debugger/programmer with mass storage, virtual COM port, and debug port
- Comprehensive free software libraries
- Support of a wide choice of Integrated Development Environments (IAR, Keil, ARM mbed, GCC-based IDEs)



[Figure 1.3 Nucleo-64 development board (Nucleo-F091RC)]

1.2.3 ● Nucleo-144 Development Boards

Figure 1.4 shows an example Nucleo-144 board, the Nucleo-F722ZE. This is a high-performance board incorporating a 144-pin MCU. The board is Arduino Uno compatible. The features of this board are:

- Ethernet compliant with RJ45 connector
- ST morpho connector
- ST-LINK/V2-1 debugger/programmer with mass storage, virtual COM port, and debug port

- ST Zio connector
- 3 user LEDS
- 2 push-button switches
- 32.768kHz crystal oscillator
- Flexible power-supply options: ST-LINK USB V_{BUS} or external sources
- Comprehensive free software libraries
- Support of a wide choice of Integrated Development Environments (IAR, Keil, ARM mbed, GCC-based IDEs)

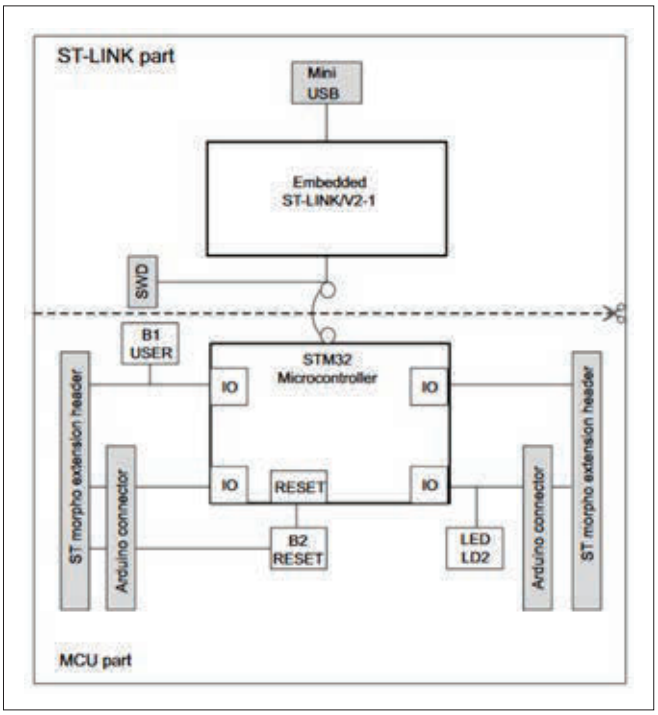
[Figure 1.4 Nucleo-144 development board (Nucleo-F7222ZE)]

1.3 • The Nucleo-L476RG Development Board

The Nucleo-L476RG board is one of the most popular Nucleo development boards. This is a 64-pin ultra-low power board (see Figure 1.1). This board will be used as the example development board in all the projects in this book. Therefore, full details of this board are given in this section so that the readers are familiar with this board. Further details about the Nucleo-64 boards can be obtained from the STMicroelectronics User Manual **UM1724, STM32 Nucleo-64 boards, 2017**.

1.3.1 ● Two Part Board

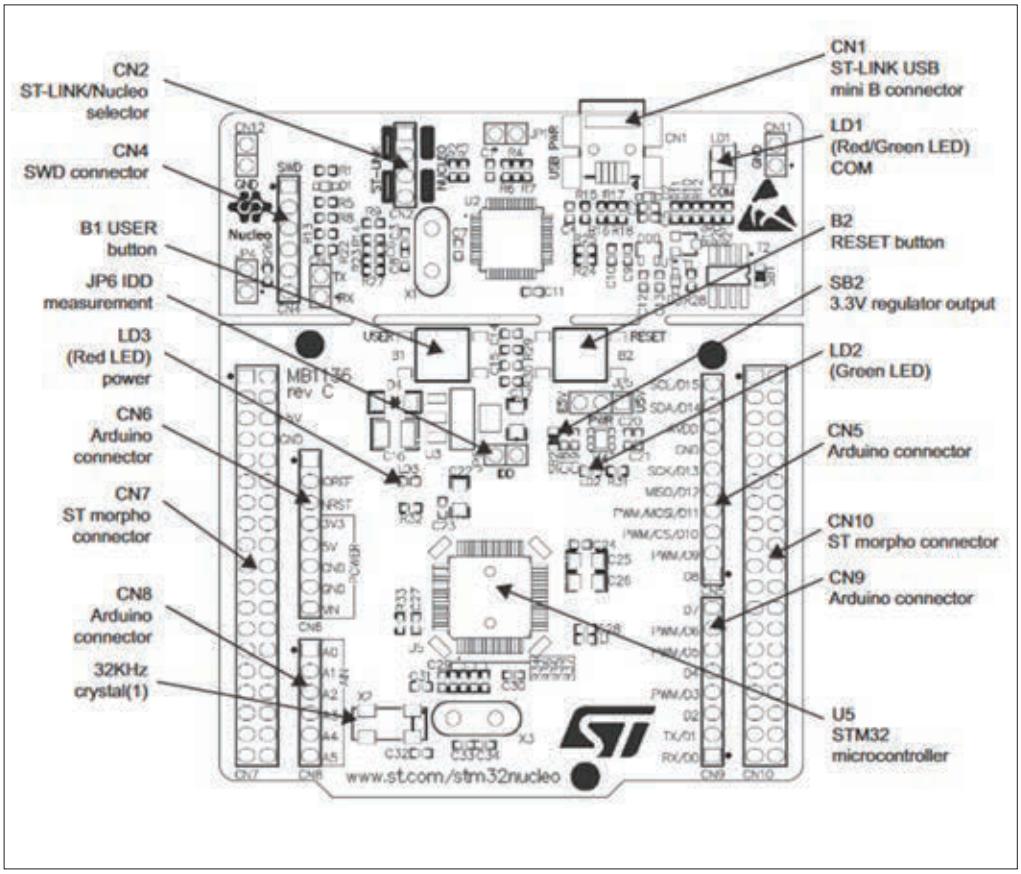
The board measures 70mm x 82.5mm. As shown in Figure 1.5 the board consists of two parts: the smaller ST-LINK part with the mini USB port, and the MCU part. The ST-LINK part of the PCB can be cut if desired to reduce the overall board size. If this is done the MCU part can only be powered by VIN, E5V and 3.3V through the VIN on CN7 ST morpho connector, or 3.3V on CN6 Arduino connector. It is possible to program the MCU after the ST-LINK part is cut by connecting wires between CN4 on the ST-LINK board and SWD signals on connector CN7 (pin 15 SWCLK. and pin 13 SWDIO).



[Figure 1.5 Nucleo-L476RG board parts. (©STMicroelecronics. Used with permission)]

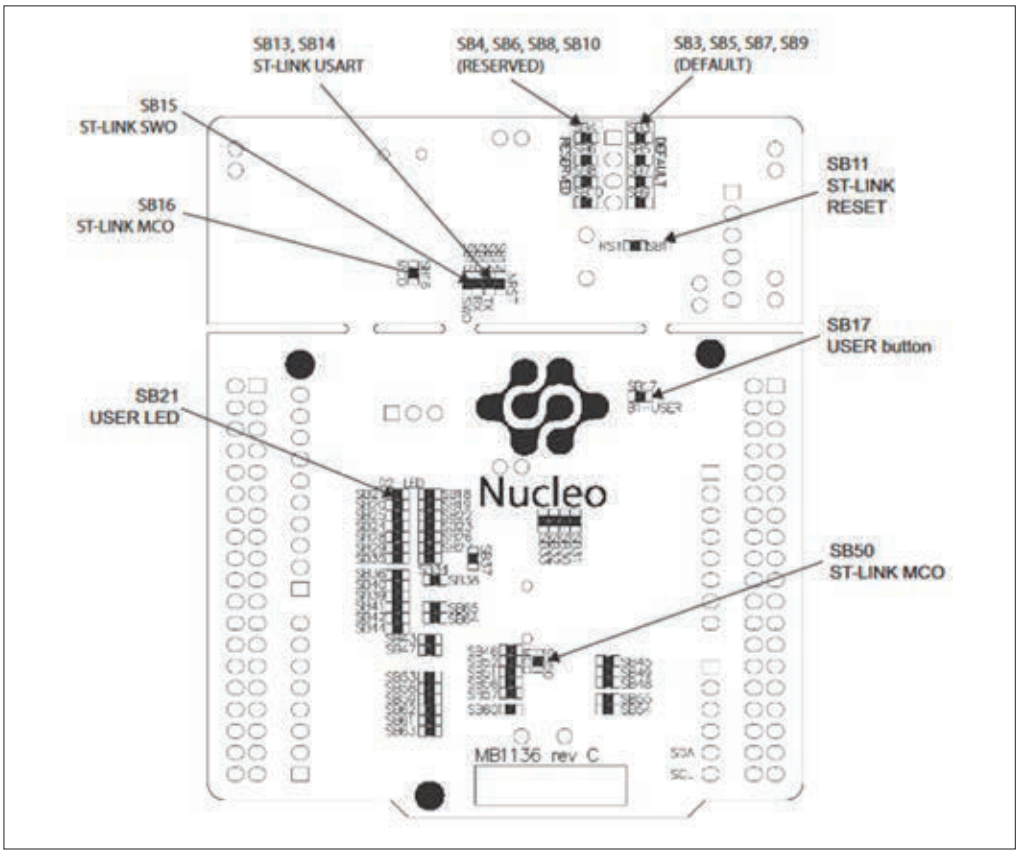
The components on the top side of the board are shown in Figure 1.6. Some of the important components that you may need to know their locations on the board are:

- CN1: mini USB socket
- CN2: ST-LINK/Nucleo selector
- B1: User push-button
- B2: Reset button
- LD1: red/green communications LED
- LD2: green user LED
- LD3: red power LED
- Arduino connectors
- ST morpho connectors



[Figure 1.6 Components on the top side of the board. (©STMicroelecronics. Used with permission)]

The bottom side of board is shown in Figure 1.7.



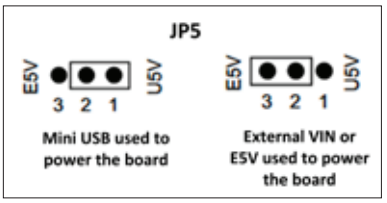
[Figure 1.7 Bottom side of the board. (©STMicroelecronics. Used with permission)]

1.3.2 ● The Power Supply

Power to the board is normally supplied through the mini USB connector CN1 using a USB cable, connected to a PC. It is also possible to use an external power source VIN (7V-12V), E5V (5V) or +3.3V.

Powering through the mini USB connector

When powered through the CN1 mini USB port (U5V) a jumper must be connected between pin 1 and pin 2 of jumper JP5 on the MCU board as shown in Figure 1.8. Notice that this is the default state of this jumper.



[Figure 1.8 Powering the board through the mini USB port]

Jumper JP1 on the ST-LINK board can be configured depending on the maximum current consumption of the MCU board. This jumper should be OFF (default state) for an allowed current of 300mA, and it should be ON for an allowable current of 100mA. If the total current consumption of the board exceeds 300mA then it is important that an external power supply must be used through VIN or E5V.

Powering through external inputs

External power can be applied through VIN or E5V inputs. When power is to be supplied by an external power supply, the following jumpers must be configured:

- Jumper JP5 pin 2 and pin 3 connected
- Jumper JP1 OFF (removed)

VIN can be supplied through pin 8 of connector CN6 or pin 24 of connector CN7. The voltage range must be between 7V to 12V. The maximum current capacity should be 800mA when the input voltage is 7V, 450mA when the voltage is between 7V and 9V, and 250mA when the voltage is greater than 9V and less than 12V.

E5V can be supplied through pin 6 of connector CN7. The voltage range is 4.75V to 5.25V, with maximum current capacity of 500mA.
When power is supplied through VIN or E5V, it is still possible to use the USB connector for communication, programming or debugging. In this situation, the board must first be powered using VIN or E5V and then the USB cable should be connected to the PC.

The following procedure should be followed if external power will be used and at the same time the USB connector will be used for communication/programming/debugging:

- Connect pin 2 and pin 3 of jumper JP5
- Remove jumper JP1
- Connect external power VIN or E5V
- Make sure that LD3 is turned ON
- Connect the USB connector to your PC

External power input +3.3V

It is also possible to power the board using external +3.3V power supply. The range of this supply must be between +3V to +3.6V. When powered through the +3.3V, the ST-LINK board is not powered and therefore the programming and debugging features are not available. This is usually the case when the ST-LINK part of the PCB has been cut. The +3.3V external power supply must be applied to pin 4 of connector CN6.

Notice that when powered by USB, VIN or E5V, +5V power is available at pin 5 of CN6 or pin 18 of CN7. These pins for example can be used to provide power to an extension board (e.g. to an Arduino).

1.3.3 ● The LEDs

LD1 provides information about the ST-LINK communication. The default colour of this LED is red and it turns green when communication is in progress between the PC and the ST-LINK.

LD2 is a green colour user controlled LED. This LED is connected to pin 11 of connector CN10 (STM32 I/O pin PA_5) on the Nucleo-L476RG board. The Arduino D13 port pin is also connected to LD2. Applying logic 1 turns ON the LED.

LD3 is the red power LED that indicates when +5V power is available on the MCU board.

1.3.4 ● Push-Button switches

There are two push-button switches on the MCU board called B1 and B2.

B1 is the user button and is connected to STM32 I/O pin PC_13 (pin 23 on connector CN7 on the Nucleo-L476RG board).

B2 is the Reset button used to reset the MCU.

1.3.5 ● Jumper JP6

This jumper is labelled IDD and can be used to measure the current consumption of the MCU by removing the jumper and then connecting an ammeter to the jumper pins. This jumper is ON by default.

1.3.6 ● The ST-LINK/V2-1

The ST-LINKV2-1 programming and debugging tool is integrated in the Nucleo boards and it makes the boards Mbed Enabled. ST-LINK/V2-1 supports only SWD for STM32 devices. The ST-LINK/V2-1 does not support SWIM interface and the minimum supported application voltage is limited to 3V. The ST-LINK/V2-1 supports virtual COM port interface on USB, USB software re-numeration, mass storage interface on USB, and USB power management request for more than 100mA power on USB.

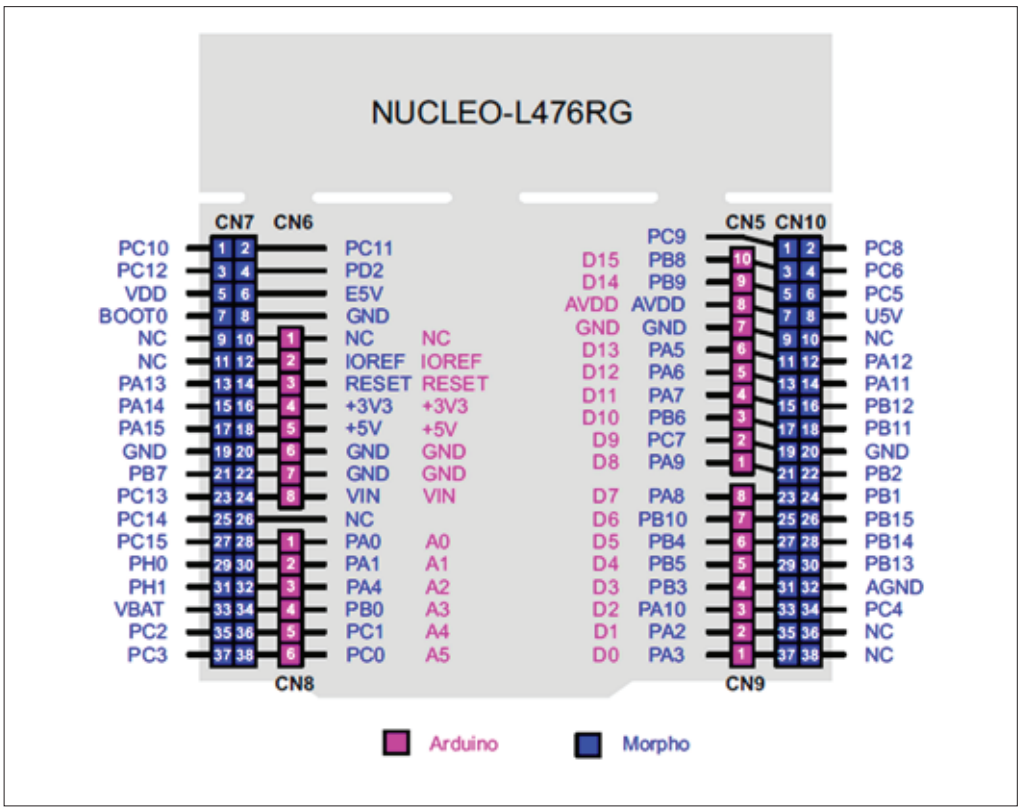
There are two different ways to use the embedded ST-LINK/V2-1 depending on the CN2 jumper settings. When both CN2 jumpers are ON (the default state) then the ST-LINK/V2-1 functions are enabled for on-board programming. When both CN2 jumpers are OFF then the ST-LINK/V2-1 functions are enabled for external CN4 connector (SWD supported).

Before connecting the Nucleo-64 board to a Windows PC, a driver for ST-LINK/V2-1 must be installed. This can be downloaded from the following site. You will have to register at the site so that you can download the driver. At the time of writing this book the driver was called **en.stsw-link009.zip**:

http://www.st.com/en/development-tools/stsw-link009.html#getsoftware-scroll

1.3.7 • Input-Output Connectors

Figure 1.9 shows the input-output connectors for the Nucleo-L476RG board. Notice that different models may have different pin configurations and you should check the appropriate User Manual for the correct configuration of the model you are using. CN5, CN6, CN8 and CN9 are Arduino Uno compatible connectors. CN7 and CN10 are the ST morpho connectors that carry most of the MCU signals.



[Figure 1.9 Nucleo-L476RG I/O connectors. (©STMicroelecronics. Used with permission)]

The Arduino Uno connector pin configuration on the Nucleo-476RG board is shown in Table 1.1.

Connector	Pin	Pin name	STM32 pin	Function
	1	NC	-	-
	2	IOREF	-	3.3V Ref
	3	RESET	NRST	RESET
	4	+3.3V	-	3.3V input/output
	5	+5V	-	5V output
	6	GND	-	Ground
	7	GND	-	Ground
	8	VIN	-	Power input
	1	A0	PA0	ADC12_IN5
	2	A1	PA1	ADC12_IN6
	3	A2	PA4	ADC12_IN9
	4	A3	PB0	ADC12_IN15
	5	A4	PC1	ADC123_IN2
	6	A5	PC0	ADC123_IN1

RIGHT CONNECTORS

	10	D15	PB8	I2C1_SCL
	9	D14	PB9	I2C1_SDA
	8	AREF	-	AVDD
	7	GND	-	GND
	6	D13	PA5	SPI1_SCK
	5	D12	PA6	SPI1_MISO
	4	D11	PA7	TIM17_CH1 or SPI1_MOSI
	3	D10	PB6	TIM4_CH1 or SPI1_CS
	2	D9	PC7	TIM3_CH2
	1	D8	PA9	-
	8	D7	PA8	-
	7	D6	PB10	TIM2_CH3
	6	D5	PB4	TIM3_CH1
	5	D4	PB5	-
	4	D3	PB3	TIM2_CH2
	3	D2	PA10	-
	2	D1	PA2	USART2_TX
	1	D0	PA3	USART2_RX

Table 1.1 Arduino UNO connector pin configuration

1.3.8 • The Demo Software

The Nucleo boards are shipped with a pre-loaded demo software. To run the demo software on the Nucleo-L476RG board, follow the sequence below:

- Check that jumper JP1 is OFF, JP5 is ON, JP6 is ON, and CN2 are ON
- Connect the Nucleo-L476RG board connector CN1 to a PC with a mini USB cable (Type A to mini-B cable). The red LED LD3 (PWR) and LD1 (COM) should light up. LD1 (COM) and green LED LD2 should blink.
- Press button B1 (left button).
- Click button B1 and you should see the blinking rate of the green LED LD2 to change accordingly.

If the demonstration software is run successfully then the board should be ready for use in projects.

1.4 • Summary

In this Chapter we have learned about the types of STM Nucleo development boards. In addition, the specifications and configuration of the popular Nucleo-L476RG board has been described in greater detail and the steps to run the demonstration software on the Nucleo-L476RG are given.

In the next Chapter we shall be looking at the various hardware development tools that can be used with the Nucleo boards in various projects.

Chapter 2 ● STM32 NUCLEO EXPANSION BOARDS

2.1 ● Overview

This Chapter is about the STM32 Nucleo expansion boards. With the help of the expansion boards we can easily and quickly develop complex microcontroller based projects. Brief specifications of the various popular expansion boards are given in this Chapter.

2.2 ● STM32 Nucleo Expansion Boards

The expansion boards are equipped with Arduino Uno or ST morpho compatible connectors. These boards are tested hardware and they are plugged on top of the Nucleo boards. Expansion boards help us to build projects quickly and with little effort since these boards are supported by the STM32 based software modules. The combination of STM32 Nucleo boards and expansion boards is a unified scalable approach with unlimited possibilities for application development, prototyping or product evaluation.

Further information on the Nucleo expansion boards can be obtained from the following ST web site:
http://www.st.com/en/evaluation-tools/stm32-nucleo-expansion-boards.html?querycriteria=productId=SC1971

2.2.1 • Bluetooth Low Energy Expansion Board (X-NUCLEO-IDB04A1)

The X-NUCLEO-IDB04A1 is a Bluetooth low energy board (Figure 2.1) that gives the Bluetooth communications capability to the Nucleo boards. This board is compatible with the Arduino Uno connectors. The X-NUCLEO-IDB04A1 is interfaced with the STM32 MCU via the SPI bus.

The basic specifications of the Bluetooth board are:

- BlueNRG low power and low energy
- Bluetooth low energy 4.0 master and slave compliant
- Low current consumption (7.3mA RX and 8.2mA TX)
- 8dBm maximum transmission power
- -88 dBm receiver sensitivity

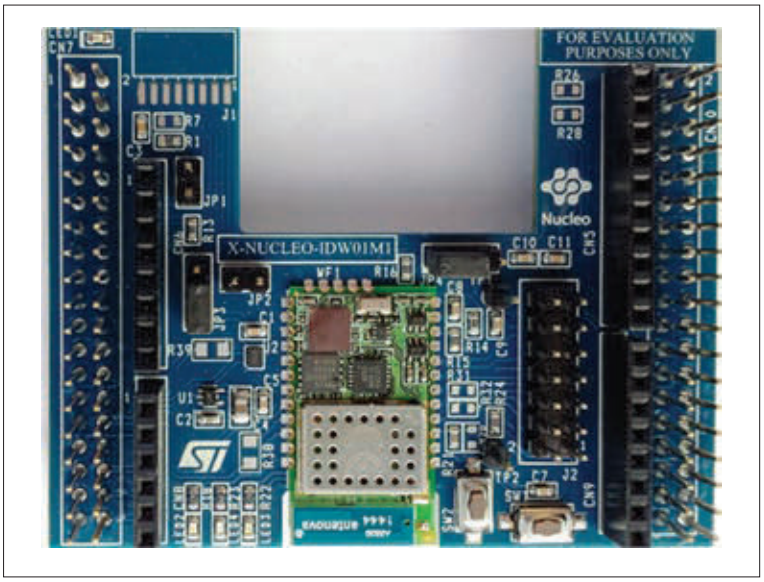
[Figure 2.1 Bluetooth low energy expansion board]

2.2.2 ● Wi-Fi Expansion Board (X-NUCLEO-IDW01M1)

This is a Wi-Fi board (see Figure 2.2) which gives the Wi-Fi capability to the Nucleo boards. The module incorporates an antenna and a power amplifier and is compatible with the IEEE b/g/n specifications. The module can be configured as a socket server or a socket client and the firmware features an IP stack with up to 8 TCP/UDP sockets, dynamic web page support with SSI, and get and post API for transferring files to/from servers. X-NUCLEO-IDW01M1 module supports secure sockets with TLS.SSL encryption. It is interfaced to the Nucleo boards via the UART serial port and the Wi-Fi functions can easily be accessed using the standard AT commands. The module is compatible with both the Arduino Uno connector and the ST morpho connector.

The basic features of the Wi-Fi board are:

- Low power IEEE 802.11 b/g/n compatible
- Integrated amplifier and antenna
- TCP/IP and TLS/SSL stacks
- Dynamic web page support, get & post web content
- WEP/WPA/WPA2 encryption
- 16 configurable GPIOs
- Standard AT command support through UART interface
- Software support
- Compatible with Nucleo boards through Arduino Uno and ST morpho connectors



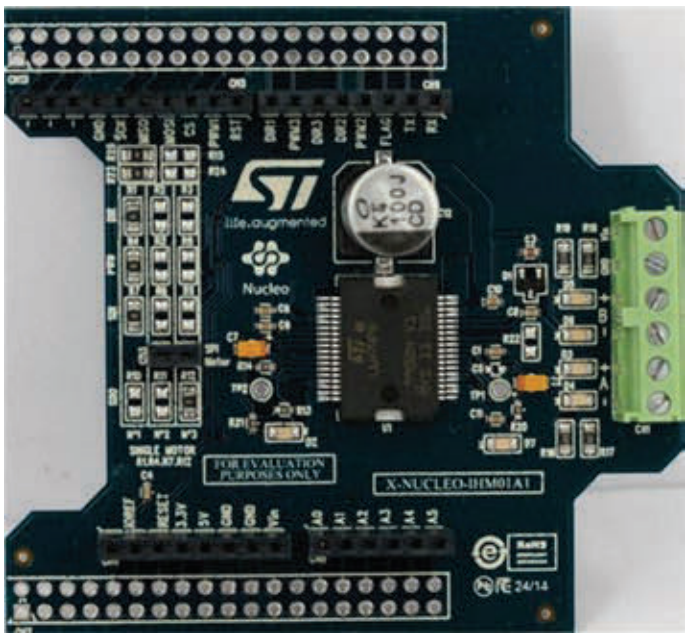
[Figure 2.2 Wi-Fi expansion board]

2.2.3 • Stepper Motor Expansion Board (X-NUCLEO-IHM01A1)

This is a stepper motor driver board (see Figure 2.3) based on the L6474 where it can drive up to three stepper motors. The module is compatible with the Arduino Uno connector on the Nucleo boards.

The basic specifications of this board are:

- Phase current up to 3A with advanced current control
- Voltage range from 8V to 45V with protected power stage
- Up to 1/16 microstepping resolution
- Power and fault LEDs



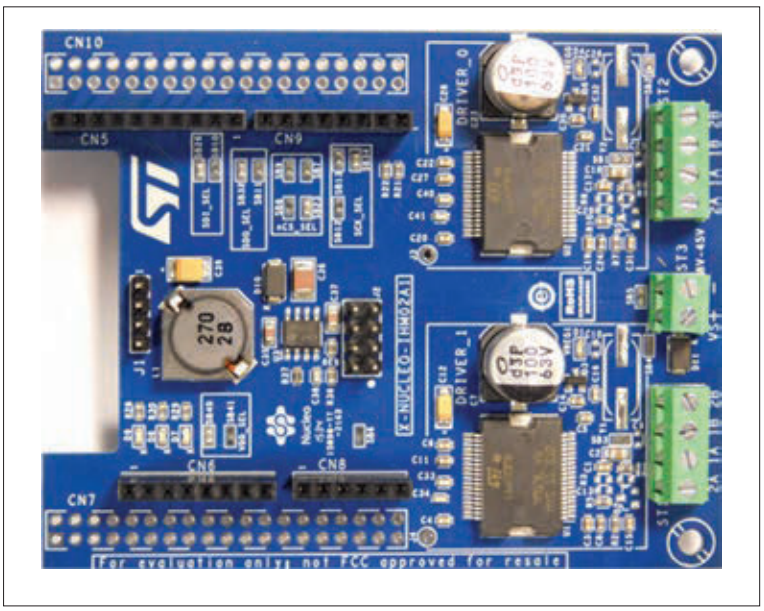
[Figure 2.3 Stepper motor expansion board]

2.2.4 ● Two Axis Stepper Motor Board (X-NUCLEO-IHM02A1)

This is a two axis stepper motor driver expansion board (Figure 2.4) based on two L6470s. The module provides microstepping and up to two stepper motors can be connected to the module. More than one module can be plugged into a Nucleo board for multi stepper motor control. Each L6470 is controlled via daisy chain over the SPI bus.

The basic features of this board are:

- Operating voltage 8V to 45V
- Peak output current up to 7A (3A RMS) for each motor driver
- 3.3V or 5V digital control voltage
- USART communication with a PC
- SPI interface between the L6470s
- Arduino Uno connector compatible
- Layout compatible with the ST morpho connectors
- Five LEDs to indicate the status of the L6470s, digital control voltage, and fault conditions



[Figure 2.4 Two axis stepper motor board]